POWER SYSTEMS DEVELOPMENT FACILITY

TECHNICAL PROGRESS REPORT FOR M.W. KELLOGG TRANSPORT REACTOR TRAIN WITH WESTINGHOUSE PARTICULATE CONTROL DEVICE:

JANUARY 1997 – DECEMBER 1997

DOE Cooperative Agreement Number
DE-FC21-90MC25140

VOLUME I

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

January 1999

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor Southern Company Services, Inc., nor any of its employees, nor any of its subcontractors, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161. Phone orders accepted at (703) 487-4650.

CONTENTS

Section Page

VOLUME 1

Inside Cover
Disclaimer

Acknowledgements

Table of Contents and Listing of Tables and Figures i - xxiv

1.0 EXECUTIVE SUMMARY 1.1.1-1

1.1 Operation Status 1.1.1-1
1.1.1 Transport Reactor 1.1.1-2
1.1.2 Westinghouse PCD 1.1.2-1
1.1.3 Balance-of-Plant and Other Auxiliaries 1.1.3-1

1.2 PSDF Accomplishments 1.2.1-1
1.2.1 Transport Reactor Train 1.2.1-1
1.2.2 PCD System 1.2.2-1
1.2.3 Particulate Sampling/Ash Analysis 1.2.3-1
1.2.4 Filter Element Testing 1.2.4-1
1.2.5 Ash Removal 1.2.5-1

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 PARTICLE FILTER SYSTEM 3.1.1-1

3.1 PCD Overview 3.1.1-1
3.1.1 Summary 3.1.1-1
3.1.2 1997 Accomplishments 3.1.2-1
3.1.3 Developmental Areas 3.1.3-1
3.1.4 What's Ahead in 1998 ..... 3.1.4-1

3.2 PCD Operation During Test Run CCT4A 3.2.1-1
3.2.1 Run Summary 3.2.1-1
3.2.2 Test Objectives 3.2.2-1
3.2.3 Observations/Events 3.2.3-1
3.2.4 Run Outcome 3.2.4-1

3.3 PCD Operation During Test Run CCT4B 3.3.1-1
3.3.1 Run Summary 3.3.1-1
3.3.2 Test Objectives 3.3.2-1
3.3.3 Observations/Events 3.3.3-1
3.3.4 Run Outcome 3.3.4-1

3.4 PCD Operation During Test Run CCT4C 3.4.1-1
3.4.1 Run Summary 3.4.1-1
3.4.2 Test Objectives 3.4.2-1
3.4.3 Observations/Events 3.4.3-1
3.4.4 Run Outcome 3.4.4-1

3.5 PCD Inspection CCT4C 3.5.1-1
3.5.1 PCD Inspection 3.5.1-1
3.5.2 Cluster Inspection 3.5.2-1
3.5.3 Filter Element Layout No. 3 ..... 3.5.3-1

3.6 PCD Operation During Test Run CCT4D 3.6.1-1
3.6.1 Run Summary 3.6.1-1
3.6.2 Test Objectives 3.6.2-1
3.6.3 Observations/Events 3.6.3-1
3.6.4 Run Outcome 3.6.4-1

3.7 CCT4 Ash Characteristics and PCD Performance 3.7.1-1
3.7.1 PCD Inlet Particle Concentrations 3.7.1-1
3.7.2 Comparison of In Situ Measurement With PCD Ash Discharge Rates 3.7.2-1
3.7.3 In Situ Measurements of PCD Inlet Particle-Size Distribution 3.7.3-1
3.7.4 Laboratory Analysis of Cascade Cyclone Catches 3.7.4-1
3.7.5 Comparison of Cyclone and Hopper Size Distributions 3.7.5-1
3.7.6 PCD Outlet Particle Concentrations 3.7.6-1
3.7.7 Ash Chemical Composition 3.7.7-1
3.7.8 Characteristics of PCD Dustcake Samples 3.7.8-1

3.8 PCD Operation During Test Run CCT5A 3.8.1-1
3.8.1 Run Summary 3.8.1-1
3.8.2 Test Objectives 3.8.2-1
3.8.3 Observations/Events 3.8.3-1
3.8.4 Run Outcome 3.8.4-1

3.9 PCD Operation During Test Run CCT5B 3.9.1-1
3.9.1 Run Summary 3.9.1-1
3.9.2 Test Objectives 3.9.2-1
3.9.3 Observations/Events 3.9.3-1
3.9.4 Run Outcome 3.9.4-1

3.10 Ash Characteristics and PCD Performance for Test Run CCT5 ..... 3.10.1-1
3.10.1 Measurements of Particulate Mass Loadings 3.10.1-1
3.10.2 Measurements of Particulate-Size Distribution 3.10.2-1
3.10.3 Chemical Analyses 3.10.3-1
3.10.4 Measurements of Permeability and Related Properties 3.10.4-1

3.11 PCD Operation During Test Run CCT6 ..... 3.11.1-1
3.11.1 Run Summary 3.11.1-1
3.11.2 Test Objectives 3.11.2-1
3.11.3 Observations/Events 3.11.3-1
3.11.4 Run Outcome 3.11.4-1

3.12 Ash Characteristics in Test Run CCT6 ..... 3.12.1-1
3.12.1 PCD Inlet Particle Concentrations and Size Distributions 3.12.1-1
3.12.2 Lab Measurements of Ash Characteristics 3.12.2-1

3.13 Inspection Report for Test Run CCT6 ..... 3.13.1-1
3.13.1 Run Summary 3.13.1-1
3.13.2 Filter Element Cluster Inspection 3.13.2-1
3.13.3 Filter Vessel Shroud Ash Deposit Inspection 3.13.3-1
3.13.4 Conclusion 3.13.4-1

3.14 Inspection Report for Test Run TC01A 3.14.1-1
3.14.1 Run Summary 3.14.1-1
3.14.2 Test Objectives 3.14.2-1
3.14.3 Observations/Events 3.14.3-1
3.14.4 Run Outcome 3.14.4-1

3.15 Inspection Report for Test Run TC01A 3.15.1-1
3.15.1 PCD Inspection 3.15.1-1
3.15.2 Cluster Inspection 3.15.2-1
3.15.3 Filter Element Layout No. 5 ..... 3.15.3-1

3.16 PCD Operation During Test Run TC01B 3.16.1-1
3.16.1 Run Summary 3.16.1-1
3.16.2 Test Objectives 3.16.2-1
3.16.3 Observations/Events 3.16.3-1
3.16.4 Run Outcome 3.16.4-1

3.17 PCD Operation During Test Run TC01C 3.17.1-1
3.17.1 Run Summary 3.17.1-1
3.17.2 Test Objectives 3.17.2-1
3.17.3 Observations/Events 3.17.3-1
3.17.4 Run Outcome 3.17.4-1

3.18 PCD Operation During Test Run TC01D 3.18.1-1
3.18.1 Run Summary 3.18.1-1
3.18.2 Test Objectives 3.18.2-1
3.18.3 Observations/Events 3.18.3-1
3.18.4 Run Outcome 3.18.4-1

3.19 PCD Operation During Test Run TC01E 3.19.1-1
3.19.1 Run Summary 3.19.1-1
3.19.2 Test Objectives 3.19.2-1
3.19.3 Observations/Events 3.19.3-1
3.19.4 Run Outcome 3.19.4-1

3.20 PCD Operation During Test Run TC01F 3.20.1-1
3.20.1 Run Summary 3.20.1-1
3.20.2 Test Objectives 3.20.2-1
3.20.3 Observations/Events 3.20.3-1
3.20.4 Run Outcome 3.20.4-1

3.21 PCD Operation During Test Run TC01G 3.21.1-1
3.21.1 Run Summary 3.21.1-1
3.21.2 Test Objectives 3.21.2-1
3.21.3 Observations/Events 3.21.3-1
3.21.4 Run Outcome 3.21.4-1

3.22 Inspection Report for Test Run TC01G 3.22.1-1
3.22.1 Run Summary 3.22.1-1
3.22.2 Thermal Event 3.22.2-1
3.22.3 PCD Inspection and Dustcake Observations 3.22.3-1
3.22.4 Inspection Outcome 3.22.4-1

3.23 PCD Operation During Test Run TC01H 3.23.1-1
3.23.1 Run Summary 3.23.1-1
3.23.2 Test Objectives 3.23.2-1
3.23.3 Observations/Events 3.23.3-1
3.23.4 Run Outcome 3.23.4-1

3.24 PCD Operation During Test Run TC01I 3.24.1-1
3.24.1 Run Summary 3.24.1-1
3.24.2 Test Objectives 3.24.2-1
3.24.3 Observations/Events 3.24.3-1
3.24.4 Run Outcome 3.24.4-1

3.25 TC01 Ash Characteristics and PCD Performance 3.25.1-1
3.25.1 Measurements of Particulate Mass Loadings 3.25.1-1
3.25.2 Measurements of Particle-Size Distribution 3.25.2-1

3.25.3 Chemical Analyses 3.25.3-1
3.25.4 Measurements of Permeability and Related Properties 3.25.4-1

3.26 Inspection Report for Test Run TC01I 3.26.1-1
3.26.1 Run Summary 3.26.1-1
3.26.2 Filter Elements 3.26.2-1
3.26.3 Fail-Safes 3.26.3-1
3.26.4 Gaskets 3.26.4-1
3.26.5 Filter Element Holders 3.26.5-1
3.26.6 Miscellaneous 3.26.6-1
3.26.7 Comments 3.26.7-1

3.27 Pulse Valve Tests and Operations 3.27.1-1
3.27.1 Run Summary 3.27.1-1
3.27.2 Test Objectives 3.27.2-1
3.27.3 Introduction 3.27.3-1
3.27.4 Test Procedure 3.27.4-1
3.27.5 Test Results and Data Analysis 3.27.5-1
3.27.6 Observations and Conclusions 3.27.6-1
3.27.7 Suggestions to Improve Valve Performance 3.27.7-1

3.28 Fines Handling System 3.28.1-1
3.28.1 Operation Summary 3.28.1-1
3.28.2 Significant Observations and Major Events 3.28.2-1
3.28.3 Fines Transporter System (FD0520) 3.28.3-1
3.28.4 Spent Fines Screw Cooler (FD0520) 3.28.4-1
3.28.5 Evaluation and Redesign Possibilities (FD0520/FD0502) 3.28.5-1

VOLUME II

4.0 TRANSPORT REACTOR LOOP OPERATIONS 4.1.1-1

4.1 Progress in Operations 4.1.1-1
4.1.1 CCT4 Series Test Runs 4.1.1-2
4.1.2 CCT5 Series Test Runs 4.1.2-1
4.1.3 CCT6 Series Test Run 4.1.3-1
4.1.4 TC01 Series Test Runs 4.1.4-1

4.2 Performance Analysis 4.2.1-1
4.2.1 Material Balance 4.2.1-1
4.2.2 Disengager Efficiency 4.2.2-1
4.2.3 Particulate Loading to the PCD 4.2.3-1
4.2.4 SO_2 Emissions 4.2.4-1
4.2.5 Solids Analyses 4.2.5-1
4.2.6 NO_x Emissions 4.2.6-1
4.2.7 Circulation Rate 4.2.7-1

4.2.8 Pressure Profile....4.2.8-1
4.2.9 Temperature Profile....4.2.9-1
4.2.10 Skin Temperature Profile.... 4.2.10-1
4.2.11 Reactor Feed System Issues.... 4.2.11-1

4.3 Cyclone Dipleg Operation and Data Analysis....4.3.1-1
4.3.1 Brief History of the Dipleg Problems and Troubleshooting Processes....4.3.1-1
4.3.2 Analyses of Dipleg Upsets....4.3.2-1
4.3.3 The Stable Operation of the Dipleg and Related Design Issues....4.3.3-1
4.3.4 Summary....4.3.4-1

5.0 AUXILIARIES AND BALANCE-OF-PLANT....5.1.1-1

5.1 Feedstock Preparation
5.1.1 Description....5.1.1-1
5.1.2 MWK Coal Pulverizer System Modifications to Improve Grind Consistency....5.1.2-1

5.2 Reactor Feedstock Injection and Ash Removal Systems....5.2-1
5.3 MWK Process Air Compressor....5.3-1
5.4 Transport Air System....5.4-1
5.5 Recycle Gas System....5.5-1
5.6 Process Gas Sampling....5.6-1
5.7 MWK Steam Generation System....5.7-1
5.8 Sulfator....5.8-1
5.9 Baghouse....5.9-1
5.10 Baghouse Ash Removal....5.10-1
5.11 Heat Transfer Fluid System....5.11-1
5.12 Nitrogen Supply....5.12-1
5.13 Propane Supply....5.13-1
5.14 Instrument Air System....5.14-1
5.15 Water Systems (Closed Loop, Cooling Tower, Condensate, Service, Fire, Potable)....5.15-1
5.16 Wastewater Treatment....5.16-1
5.17 Condensate Treatment....5.17-1
5.18 Station Service and UPS (Including Diesel Generator)....5.18-1
5.19 MWK Start-Up Burner....5.19-1
5.20 Transport Reactor Pressure Control Valve PV-287....5.20-1

Listing of Tables

Table Page

VOLUME I

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

3.2.4-1 CCT4A Run Statistics....3-2.4-2
3.2.4-2 CCT4A Major Events 3.2.4-2

3.3.4-1 CCT4B Run Statistics 3.3.4-2
3.3.4-2 CCT4B Major Events.... 3.3.4-2

3.4.4-1 Loss on Ignition Tests for CCT4C Solids Samples 3.4.4-2
3.4.4-2 CCT4C Run Statistics.... 3.4.4-2
3.4.4-3 CCT4C Major Events.... 3.4.4-3

3.6.1-1 CCT4D Run Statistics 3.6.1-2
3.6.1-2 CCT4D Major Events 3.6.1-2

3.7.1-1 Sampling Parameters and Results of Sampling Runs at PCD Inlet.... 3.7.1-3
3.7.2-1 Comparison of Particulate Loadings Obtained From In Situ Measurements With Particulate Loadings Estimated From Rate of Ash Discharge 3.7.2-2
3.7.6-1 Results of Sampling Runs at PCD Outlet 3.7.6-2

3.7.7-1 Results of Chemical Analyses of PCD Hopper Samples and Residual Dustcake.... 3.7.7-2

3.8.3-1 CCT5A Run Statistics.... 3.8.3-2
3.8.3-2 CCT5A Major Events 3.8.3-3

3.9.1-1 CCT5B Run Statistics.... 3.9.1-2
3.9.1-2 CCT4C Major Events 3.9.1-2

3.10.1-1 PCD Inlet Particulate Mass Loading Data for Test Program CCT5.... 3.10.1-2
3.10.3-1 Elemental Analysis of Selected CCT5 Hopper Samples....3.10.3-2
3.10.4-1 Physical Properties of CCT5 In Situ Samples.... 3.10.4-2

3.11.4-1 CCT6 Run Statistics.... 3.11.3-2
3.11.4-2 CCT6 Major Events 3.11.3-2

3.12.1-1 PCD Inlet Particle Mass Concentrations.... 3.12.1-2
3.12.2-1 Physical Properties of In Situ and Candle Samples 3.12.2-2

3.14.4-1 TC01A Run Statistics 3.14.4-2
3.14.4-2 TC01A Major Events 3.14.44-2

3.16.1-1 TC01B Run Statistics 3.16.1-2
3.16.1-2 TC01B Major Events 3.16.1-3

3.17.1-1 TC01C Run Statistics 3.17.1-2
3.17.1-2 TC01C Major Events 3.17.1-2

3.18.1-1 TC01D Run Statistics 3.18.1-2
3.18.1-2 TC01D Major Events 3.18.1-2

3.19.1-1 TC01E Run Statistics 3.19.1-2
3.19.1-2 TC01E Major Events 3.19.1-2

3.20.1-1 TC01F Run Statistics 3.20.1-2
3.20.1-2 TC01F Major Events 3.20.1-2

3.21.1-1 TC01G Run Statistics 3.21.1-2
3.21.1-2 TC01G Major Events 3.21.1-2

3.23.1-1 TC01H Run Statistics 3.23.1-2
3.23.1-2 TC01H Major Events 3.23.1-3

3.24.1-1 TC01H Run Statistics 3.24.1-2
3.24.1-2 TC01H Major Events 3.24.1-3

3.25.1-1 PCD Inlet Particulate Mass Loading Data for Test Program TC01 ..... 3.25.1-5
3.25.1-2 PCD Outlet Particulate Mass Loading Data for Test Program TC01 ..... 3.25.1-6
3.25.1-3 PCD Particulate Collection Efficiencies for Test Program TC01 ..... 3.25.1-7
3.25.3-1A Elemental Analysis of Selected TC01 Hopper Samples 3.25.3-3
3.25.3-1B Elemental Analysis of Selected TC01 Hopper Samples 3.25.3-4
3.25.3-1C Elemental Analysis of Selected TC01 Hopper Samples 3.25.3-5
3.25.3-2 Elemental Analysis of Selected TC01 In Situ Samples 3.25.3-6
3.25.3-3 Elemental Analysis of Selected TC01 Candle Samples 3.25.3-7
3.25.4-1 Physical Properties of In Situ Samples 3.25.4-4
3.25.4-2 Physical Properties of TC01 Candle and Hopper Samples 3.25.4-5

3.27.4-1 Test Arrangements 3.27.4-1
3.27.5-1 SV3112B Valve Test With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 100 psig 3.27.5-3
3.27.5-2 SV3112B Valve Test With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 120 psig 3.27.5-4
3.27.5-3 SV3112B Valve Test With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 140 psig 3.27.5-5
3.27.5-4 SV3112B Valve Test With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 100 psig 3.27.5-6
3.27.5-5 SV3112B Valve Test With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 120 psig 3.27.5-7
3.27.5-6 SV3112B Valve Test With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 140 psig 3.27.5-8

3.27.5-7 SV3112B Valve Test With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 100 psig 3.27.5-9
3.27.5-8 SV3112B Valve Test With Electrical Pulse Duration of 0.9 sec and Pilot Pressure of 120 psig 3.27.5-10
3.27.5-9 SV3112B Valve Test With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 140 psig 3.27.5-11
3.27.5-10 SV3112B Valve Test With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 100 psig 3.27.5-12
3.27.5-11 SV3112B Valve Test With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 120 psig 3.27.5-13
3.27.5-12 SV3112B Valve Test With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 140 psig 3.27.5-14
3.27.5-13 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.3 sec and Pilot Pressure of 100 psig 3.27.5-15
3.27.5-14 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 120 psig 3.27.5-16
3.27.5-15 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 140 psig 3.27.5-17
3.27.5-16 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 100 psig 3.27.5-18
3.27.5-17 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 120 psig 3.27.5-19
3.27.5-18 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 140 psig 3.27.5-20
3.27.5-19 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 100 psig 3.27.5-21
3.27.5-20 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 120 psig 3.27.5-22
3.27.5-21 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 140 psig 3.27.5-23
3.27.5-22 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 100 psig 3.27.5-24
3.27.5-23 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 120 psig 3.27.5-25
3.27.5-24 Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 140 psig 3.27.5-26
3.27.6-1 Maximum Mass Per Pulse and Its Corresponding ΔP 3.27.6-5

3.28.3-1 FD0520 Significant Events 3.28.3-3
3.28.3-2 FD0520 Extrusion Test Results 3.28.3-3
3.28.4-1 Ash Loading Data 3.28.4-3

VOLUME II

4.2.1-1 Bulk Material Balance Information 4.2.1-3
4.2.1-2 Steam Drum Balance 4.2.1-3

4.2.3-1 PCD Inlet Particulate Mass Loading Data MWK Test Programs CCT4, CCT5, and CCT6 ..... 4.2.3-4
4.2.3-2 PCD Inlet Particulate Mass Loading Data MWK Test Program TC01 ..... 4.2.3-4

4.2.4-1 Bomb Samples Data 4.2.4-2

4.2.5-1 Solids Analysis 4.2.5-7
4.2.5-2 Free Lime Analyses 4.2.5-8
4.2.5-3 FD0520 Solids Analyses 4.2.5-8
4.2.5-4 FD0510 Solids Analyses 4.2.5-9

4.2.9-1 Temperature Profile of the Standpipe 4.2.9-3

Listing of Figures

Figure Page

VOLUME I

1.1.1-1 Transport Reactor Test Run Summary for 1997 ..... 1.1.1-4
1.1.1-2 Coal Feed and Circulation Hours for the 1997 Test Runs 1.1.1-4

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

3.2.4-1 CCT4A Temperature and Pressure for March 9 Through 14 ..... 3.2.4-3
3.2.4-2 CCT4A Pulse Pressure and Face Velocity for March 9 Through 14 ..... 3.2.4-4
3.2.4-3 CCT4A Pressure Drop and Permeance for March 9 Through 14 ..... 3.2.4-5
3.2.4-4 CCT4A Temperature and Pressure for March 14 Through 18 ..... 3.2.4-6
3.2.4-5 CCT4A Pulse Pressure and Face Velocity for March 14 Through 18 ..... 3.2.4-7
3.2.4-6 CCT4A Pressure Drop and Permeance for March 14 Through 18 ..... 3.2.4-8

3.3.1-1 Filter Element Layout for CCT4B (Layout No. 2) 3.3.1-2
3.3.1-2 CCT4B Temperature and Pressure for March 18 Through 24, 1997 ..... 3.3.1-3
3.3.1-3 CCT4B Pulse Pressure and Face Velocity for March 18 Through 24, 1997 ..... 3.3.1-4
3.3.1-4 CCT4B PCD Pressure Drop and Permeance for March 18 Through 24, 1997 ..... 3.3.1-5

3.4.4-1 CCT4C Temperature and Pressure for April 5 Through 7 ..... 3.4.4-4
3.4.4-2 CCT4C Pulse Pressure and Face Velocity for April 5 Through 7 ..... 3.4.4-5
3.4.4-3 CCT4C Pressure Drop and Permeance for April 5 Through 7 ..... 3.4.4-6
3.4.4-4 Filter Element Layout for CCT4C (Layout No. 2) 3.4.4-7

3.5.2-1 CCT4C Inspection – Initial Cluster Removal 3.5.2-2
3.5.2-2 CCT4C Inspection – Filter Element Cracking 3.5.2-3
3.5.2-3 CCT4C Inspection – Top Plenum View 3.5.2-4

3.6.1-1 CCT4D Temperature and Pressure for April 16 to 22 ..... 3.6.1-3
3.6.1-2 CCT4D Pulse Pressure and Face Velocity for April 16 to 22 ..... 3.6.1-4
3.6.1-3 CCT4D Pressure Drop and Permeance for April 16 to 22 ..... 3.6.1-5
3.6.1-4 CCT4D Temperature and Pressure for April 22 to 28 ..... 3.6.1-6
3.6.1-5 CCT4D Pulse Pressure and Face Velocity for April 22 to 28 ..... 3.6.1-7
3.6.1-6 CCT4D Pressure Drop and Permeance for April 22 to 28 ..... 3.6.1-8
3.6.1-7 CCT4D Temperature and Pressure for April 28 to May 4 ..... 3.6.1-9
3.6.1-8 CCT4D Pulse Pressure and Face Velocity for April 28 to May 4 ..... 3.6.1-10
3.6.1-9 CCT4D Pressure Drop and Permeance for April 28 to May 4 ..... 3.6.1-11
3.6.1-10 Filter Element Layout for CCT4D (Layout No. 3) 3.6.1-12

3.7.3-1 Differential Mass Distributions Obtained From Cascade Cyclone Runs 3.7.3-2
3.7.3-2 Cumulative Percent Distributions Obtained From Cascade Cyclone Runs 3.7.3-2

3.7.3-3 Differential Mass Distributions Obtained From Cascade Cyclone Runs 3.7.3-3
3.7.4-1 Microtrac Particle-Size Analysis of Cyclone Catches From CCT4ICYC-2 ..... 3.7.4-2
3.7.4-2 Microtrac Particle-Size Analysis of Cyclone Catches From CCT4ICYC-3 ..... 3.7.4-2

3.7.5-1 Comparison of Particle-Size Distributions Measured by Cascade Cyclones With Microtrac and Sieve Analysis of Hopper Samples 3.7.5-2
3.7.5-2 Comparison of Particle-Size Distributions Measured by Sieve and Microtrac Analysis and by Microtrac Analysis Alone 3.7.5-2
3.7.8-1 Comparison of Particle-Size Distributions of Dustcake and of In Situ Sample (chart 1 of 2) 3.7.8-2
3.7.8-1 Comparison of Particle-Size Distributions of Dustcake and of In Situ Sample (chart 2 of 2) 3.7.8-2

3.8.3-1 CCT5A Temperature and Pressure for May 10 Through 16, 1997 ..... 3.8.3-3
3.8.3-2 CCT5A Pulse Pressure and Face Velocity for May 10 Through 16, 1997 ..... 3.8.3-4
3.8.3-3 CCT5A Pressure Drop and Permeance for May 10 Through 16, 1997 ..... 3.8.3-5
3.8.3-4 CCT5A Temperature and Pressure for May 16 Through 21, 1997 ..... 3.8.3-6
3.8.3-5 CCT5A Pulse Pressure and Face Velocity for May 16 Through 21, 1997 ..... 3.8.3-7
3.8.3-6 CCT5A Pressure Drop and Permeance for May 16 Through 21, 1997 ..... 3.8.3-8
3.8.3-7 Layout for CCT5A (Layout 3) 3.8.3-9

3.9.1-1 CCT5B Temperature and Pressure for May 21 to 27, 1997 ..... 3.9.1-3
3.9.1-2 CCT5B Pulse Pressure and Face Velocity for May 21 to 27, 1997 ..... 3.9.1-4
3.9.1-3 CCT5B Pressure Drop and Permeance for May 21 to 27, 1997 ..... 3.9.1-5
3.9.1-4 Filter Element Layout for CCT5B (Layout No. 3) 3.9.1-6

3.11-4-1 CCT6 Temperature and Pressure for June 17 Through 22 ..... 3.11.4-3
3.11-4-2 CCT6 Pulse Pressure and Face Velocity for June 17 Through 22 ..... 3.11.4-4
3.11.4-3 CCT6 Pressure Drop and Permeance for June 17 Through 22 ..... 3.11.4-5
3.11.4-4 CCT6 Temperature and Pressure for June 22 Through 27 ..... 3.11.4-6
3.11.4-5 CCT6 Pulse Pressure and Face Velocity for June 22 Through 27 ..... 3.11.4-7
3.11.4-6 CCT6 Pressure Drop and Permeance for June 22 Through –27 ..... 3.11.4-8
3.11.4-7 Filter Element Layout for CCT6 (Layout No. 3) 3.11.4-9

3.12.1-1 PCD Inlet Particle Size Distribution for CCT4, CCT5, and CCT6 ..... 3.12.2-3

3.13.2-1 CCT6 Inspection – Ash Deposit on Outer Filter Elements 3.13.2-2
3.13.2-2 CCT6 Inspection – Outer Row Filter Elements on Bottom Plenum 3.13.2-3
3.13.2-3 CCT6 Inspection – Windward Ash Deposit 3.13.2-4
3.13.3-1 CCT6 Inspection – Shroud Ash Deposits 3.13.3-2

3.14.4-1 Thermal Event on August 31 Through September 1 ..... 3.14.4-3
3.14.4-2 Filter Element Layout for TC01A (Layout No. 5) 3.14.4-4

3.15.2-1 TC01A Inspection – Failed Elements 3.15.2-2
3.15.2-2 Layout Starting TC01B 3.15.2-3
3.15.2-3 TC01A Inspection – Fracture Points 3.15.2-4

3.15.2-4 TC01A Inspection – Fracture Surfaces 3.15.2-4
3.15.2-5 TC01A Inspection – Remnants of Element B26 ..... 3.15.2-5

3.16.1-1 TC01B Temperature and Pressure for September 5 Through 11 ..... 3.16.1-4
3.16.1-2 TC01B Back-Pulse Pressure and Face Velocity for September 5 Through 11 ..... 3.16.1-5
3.16.1-3 TC01B Pressure Drop and Permeance for September 5 Through 11 ..... 3.16.1-6
3.16.1-4 TC01B Temperature and Pressure for September 11 Through 17 ..... 3.16.1-7
3.16.1-5 TC01B Back-Pulse Pressure and Face Velocity for September 11 Through 17 ..... 3.16.1-8
3.16.1-6 TC01B Pressure Drop and Permeance for September 11 Through 17 ..... 3.16.1-9
3.16.1-7 TC01B Temperature and Pressure for September 17 Through 23 ..... 3.16.1-10
3.16.1-8 TC01B Back-Pulse Pressure and Face Velocity for September 17 Through 23 ..... 3.16.1-11
3.16.1-9 TC01B Pressure Drop and Permeance for September 17 Through 23 ..... 3.16.1-12
3.16.1-10 Filter Element Layout for TC01B (Layout No. 5) 3.16.1-13

3.17.1-1 TC01C Temperature and Pressure for September 23 Through 29 ..... 3.17.1-3
3.17.1-2 TC01C Back-Pulse Pressure and Face Velocity for September 23 Through 29 ..... 3.17.1-4
3.17.1-3 TC01C Pressure Drop and Permeance for September 23 Through 29 ..... 3.17.1-5
3.17.1-4 Filter Element Layout for TC01C (Layout No. 5) 3.17.1-6

3.18.1-1 TC01D Temperature and Pressure for September 29 Through October 6 ..... 3.18.1-3
3.18.1-2 TC01D Back-Pulse Pressure and Face Velocity for September 29 Through October 6 ..... 3.18.1-4
3.18.1-3 TC01D Pressure Drop and Permeance for September 29 Through October 6 ..... 3.18.1-5
3.18.1-4 Filter Element Layout for TC01D (Layout No. 5) 3.18.1-6

3.19.1-1 TC01E Temperature and Pressure for October 8 Through 13 ..... 3.19.1-3
3.19.1-2 TC01E Back-Pulse Pressure and Face Velocity for October 8 Through 13 ..... 3.19.1-4
3.19.1-3 TC01E Pressure Drop and Permeance for October 8 Through 13 ..... 3.19.1-5
3.19.1-4 TC01E Temperature and Pressure for October 13 Through 1 ..... 3.19.1-6
3.19.1-5 TC01E Pulse Pressure and Face Velocity for October 13 Through 17 ..... 3.19.1-7
3.19.1-6 TC01E Pressure Drop and Permeance for October 13 Through 17 ..... 3.19.1-8
3.19.1-7 Filter Element Layout for TC01E (Layout No. 5) 3.19.1-9

3.20.1-1 TC01F Temperature and Pressure for October 18 Through 25 ..... 3.20.1-3
3.20.1-2 TC01F Pulse Pressure and Face Velocity for October 18 Through 25 ..... 3.20.1-4
3.20.1-3 TC01F Pressure Drop and Permeance for October 18 Through 25 ..... 3.20.1-5
3.20.1-4 Filter Element Layout for TC01F (Layout No. 5) 3.20.1-6

3.21.1-1 TC01G Temperature and Pressure for October 24 Through 29 ..... 3.21.1-3
3.21.1-2 TC01G Pulse Pressure and Face Velocity for October 24 Through 29 ..... 3.21.1-4

3.21.1-3 TC01G Pressure Drop and Permeance for October 24 Through 29 ..... 3.21.1-5
3.21.1-4 TC01G Temperature and Pressure for October 29 Through November 3 ..... 3.21.1-6
3.21.1-5 TC01G Pulse Pressure and Face Velocity for October 29 Through November 3 ..... 3.21.1-7
3.21.1-6 TC01G Pressure Drop and Permeance for October 29 Through November 3 ..... 3.21.1-8
3.21.1-7 Thermal Event on November 2, 1997 ..... 3.21.1-9
3.21.1-8 Filter Element Layout for TC01G (Layout No. 5) 3.21.1-10

3.22.2-1 Thermal Event on November 2, 1997 ..... 3.22.2-2
3.22.3-1 Damaged Elements on November 2, 1997 ..... 3.22.3-3
3.22.3-2 Element Layout 3.22.3-4
3.22.3-3 Top Plenum Broken Candles 3.22.3-5
3.22.3-4 Top Plenum Broken Candle Close Up 3.22.3-6
3.22.3-5 Pressure Drop in Fail-safes after TC01G Run 3.22.3-6
3.22.3-6 Filter Element Layout for TC01H (Layout No. 6) 3.22.3-7

3.23.1-1 TC01H Temperature and Pressure for November 16 Through 20 ..... 3.23.1-4
3.23.1-2 TC01H Pulse Pressure and Face Velocity for November 16 Through 20 ..... 3.23.1-5
3.23.1-3 TC01H Pressure Drop and Permeance for November 16 Through 20 ..... 3.23.1-6
3.23.1-4 TC01H Temperature and Pressure for November 16 Through 20 ..... 3.23.1-7
3.23.1-5 TC01H Pulse Pressure and Face Velocity for November 20 Through 24 ..... 3.23.1-8
3.23.1-6 TC01H Pressure Drop and Permeance for November 20 Through 24 ..... 3.23.1-9
3.23.1-7 Filter Element Layout for TC01H (Layout No. 6) 3.23.1-10

3.24.1-1 TC01I Temperature and Pressure for November 24 Through 30 ..... 3.24.1-4
3.24.1-2 TC01I Pulse Pressure and Face Velocity for November 24 Through 30 ..... 3.24.1-5
3.24.1-3 TC01I Pressure Drop and Permeance for November 24 Through 30 ..... 3.24.1-6
3.24.1-4 TC01I Temperature and Pressure for November 30 Through December 5 ..... 3.24.1-7
3.24.1-5 TC01I Pulse Pressure and Face Velocity for November 30 Through December 5 ..... 3.24.1-8
3.24.1-6 TC01I Pressure Drop and Permeance for November 30 Through December 5 ..... 3.24.1-9
3.24.1-7 TC01I Temperature and Pressure for December 5 through 10 ..... 3.24.1-10
3.24.1-8 TC01I Pulse Pressure and Face Velocity for December 5 Through 10 ..... 3.24.1-11
3.24.1-9 TC01I Pressure Drop and Permeance for December 5 Through 10 ..... 3.24.1-12
3.24.1-10 Filter Element Layout for TC01I (Layout No. 6) 3.24.1-13

3.25.1-1 PCD Inlet Mass Concentration as a Function of Cyclone Solids Rate With and Without the Effect of PCD Pulsing 3.25.1-8
3.25.2-1 Cumulative Percentage Mass Distributions Measured at PCD Inlet 3.25.2-3
3.25.2-2 Differential Mass Distributions Measured at PCD Inlet 3.25.2-3
3.25.2-3 Cumulative Percentage Mass Distribution Measured at PCD Outlet 3.25.2-4
3.25.2-4 Differential Mass Distributions Measured at PCD Outlet 3.25.2-4
3.25.2-5 Comparison of Inlet and Outlet Differential Mass Distributions 3.25.2-5

3.25.2-6 Calculated PCD Collection Efficiency as a Function of Particle Size 3.25.2-5
3.25.4-1 Drag-Equivalent Diameter Versus Calcium Content of In Situ Samples 3.25.4-6
3.25.4-2 Drag-Equivalent Diameter Versus Surface Area of Dustcake Samples 3.25.4-6
3.25.4-3 Drag-Equivalent Diameter Versus Surface Area for All Samples 3.25.4-7

3.26.2-1 Filter Element Layout for TC01I (Layout No. 6) 3.26.2-2
3.26.2-2 Filter Element Locations 3.26.2-3
3.26.2-3 Ash Inside the Filter Elements 3.26.2-4
3.26.3-1 Ash on Inlet Screen of the Fail-Safes..... 3.26.3-2
3.26.3-2 Ash on Outlet Screen of the Fail-Safes 3.26.3-3

3.27.4-1 Schematic Presentation of the Back-Pulse System 3.27.4-2
3.27.5-1 Mass Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.3 Seconds..... 3.27.5-27
3.27.5-2 Mass Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.6 Seconds..... 3.27.5-27
3.27.5-3 Mass Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.9 Seconds..... 3.27.5-28
3.27.5-4 Mass Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 1.2 Seconds..... 3.27.5-28
3.27.5-5 Definition of Characteristic Times of Valve Movement..... 3.27.5-29
3.27.5-6 Fully Open Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.3 Seconds 3.27.5-30
3.27.5-7 Response Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.3 Seconds 3.27.5-30
3.27.5-8 Fully Open Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.6 Seconds 3.27.5-31
3.27.5-9 Response Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.6 Seconds 3.27.5-31
3.27.5-10 Fully Open Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.9 Seconds 3.27.5-32
3.27.5-11 Response Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.9 Seconds 3.27.5-32
3.27.5-12 Fully Open Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 1.2 Seconds 3.27.5-33
3.27.5-13 Response Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 1.2 Seconds 3.27.5-33
3.27.6-1 Forces at a Partly Open Position..... 3.27.6-6
3.27.6-2 Representation of the Curve for M/P Vs Valve Differential Pressure..... 3.27.6-6
3.27.6-3 Mass Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 100 psig..... 3.27.6-7
3.27.6-4 Fully Open Time Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 100 psig 3.27.6-7
3.27.6-5 Response Time Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 100 psig..... 3.27.6-8

3.27.6-6 Response Time Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 120 psig 3.27.6-8
3.27.6-7 Response Time Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 140 psig 3.27.6-9

3.28.1-1 FD0520 ..... 3.28.1-2
3.28.1-2 FD0502 ..... 3.28.1-2
3.28.3-1 Failed Silicone Seal 3.28.3-4
3.28.3-2 Wear on FD0520 Dome Valve 3.28.3-4
3.28.3-3 FD0520 Seal Cycle Life 3.28.3-5
3.28.4-1 Worn Ceramic Bushing From FD0502 in November 1997 ..... 3.28.4-4
3.28.4-2 Worn Screw Shaft for FD0502 in November 1997 ..... 3.28.4-4
3.28.4-3 Worn Housing for FD0502 in November 1997 ..... 3.28.4-5
3.28.4-4 Shaft Wear on FD0502 in January 1998 ..... 3.28.4-5
3.28.4-5 Worn Ceramic Bushing From FD0502 in January 1998 ..... 3.28.4-6
3.28.4-6 Shaft Wear From Packing in January 1998 ..... 3.28.4-6

VOLUME II

4.1.1.1-1 CO0201 System Profile 4.1.1.1-9
4.1.1.1-2 Coal Feed System Profile 4.1.1.1-9
4.1.1.1-3 Sorbent Feed System Profile 4.1.1.1-9
4.1.1.1-4 Start-Up Burner Flow/Temperature 4.1.1.1-10
4.1.1.1-5 Total Gas In/Out Flow Rates 4.1.1.1-10
4.1.1.1-6 Reactor Mixing Zone and Riser Temperatures 4.1.1.1-10
4.1.1.1-7 Standpipe Temperatures 4.1.1.1-11
4.1.1.1-8 Cyclone Dipleg Temperatures 4.1.1.1-11
4.1.1.1-9 Temperature Profile Downstream of Reactor 4.1.1.1-11
4.1.1.1-10 System Temperatures Downstream of PCD 4.1.1.1-12
4.1.1.1-11 Mixing Zone Differential Pressure Profile 4.1.1.1-12
4.1.1.1-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.1.1-12
4.1.1.1-13 Standpipe Differential Pressure Profiles 4.1.1.1-13
4.1.1.1-14 Coal Feed Rate Based on Gas Analysis 4.1.1.1-13
4.1.1.1-15 O_2, SO_2, and NO_X Analyzers 4.1.1.1-13
4.1.1.1-16 CO and H_2O Analyzers 4.1.1.1-14
4.1.1.1-17 FD0510 Temperature Profiles 4.1.1.1-14
4.1.1.1-18 FD0206 Profiles 4.1.1.1-14
4.1.1.1-19 FD0520 Pressure Profiles 4.1.1.1-15
4.1.1.1-20 Thermal Oxidizer Air/Fuel Flow 4.1.1.1-15
4.1.1.1-21 Nitrogen/Propane Header Pressure Profiles 4.1.1.1-15
4.1.1.1-22 PCD Temperatures 4.1.1.1-16
4.1.1.1-23 PCD Differential Pressure Profile 4.1.1.1-16
4.1.1.1-24 PCD Pressure and Pulse Pressure 4.1.1.1-16
4.1.1.1-25 Gas Flow Through PCD 4.1.1.1-17
4.1.1.1-26 CO01201 System Profile 4.1.1.1-19
4.1.1.1-27 Coal Feed System Profile 4.1.1.1-19
4.1.1.1-28 Sorbent Feed System Profile 4.1.1.1-19

4.1.1.1-29 Start-Up Burner Flow/Temperature 4.1.1.1-20
4.1.1.1-30 Total Gas In/Out Flow Rates 4.1.1.1-20
4.1.1.1-31 Reactor Mixing Zone and Riser Temperatures 4.1.1.1-20
4.1.1.1-32 Standpipe Temperatures 4.1.1.1-21
4.1.1.1-33 Cyclone Dipleg Temperatures 4.1.1.1-21
4.1.1.1-34 Temperature Profile Downstream of Reactor 4.1.1.1-21
4.1.1.1-35 System Temperatures Downstream of PCD 4.1.1.1-22
4.1.1.1-36 Mixing Zone Differential Pressure Profile 4.1.1.1-22
4.1.1.1-37 Reactor Pressure/Riser Differential Pressure Profiles 4.1.1.1-22
4.1.1.1-38 Standpipe Differential Pressure Profiles 4.1.1.1-23
4.1.1.1-39 Coal Feed Rate Based on Gas Analysis 4.1.1.1-23
4.1.1.1-40 O_2, SO_2, and NO_X Analyzers 4.1.1.1-23
4.1.1.1-41 CO and H_2O Analyzers 4.1.1.1-24
4.1.1.1-42 FD0510 Temperature Profiles 4.1.1.1-24
4.1.1.1-43 FD0206 Profiles 4.1.1.1-24
4.1.1.1-44 FD0520 Pressure Profiles 4.1.1.1-25
4.1.1.1-45 Thermal Oxidizer Air/Fuel Flow 4.1.1.1-25
4.1.1.1-46 Nitrogen/Propane Header Pressure Profiles 4.1.1.1-25
4.1.1.1-47 PCD Temperatures 4.1.1.1-26
4.1.1.1-48 PCD Differential Pressure Profile 4.1.1.1-26
4.1.1.1-49 PCD Pressure and Pulse Pressure 4.1.1.1-26
4.1.1.1-50 Gas Flow Through PCD 4.1.1.1-27

4.1.1.2-1 CO0201 System Profile 4.1.1.2-5
4.1.1.2-2 Coal Feed System Profile 4.1.1.2-5
4.1.1.2-3 Sorbent Feed System Profile 4.1.1.2-5
4.1.1.2-4 Start-Up Burner Flow/Temperature 4.1.1.2-6
4.1.1.2-5 Total Gas In/Out Flow Rates 4.1.1.2-6
4.1.1.2-6 Reactor Mixing Zone and Riser Temperatures 4.1.1.2-6
4.1.1.2-7 Standpipe Temperatures 4.1.1.2-7
4.1.1.2-8 Cyclone Dipleg Temperatures 4.1.1.2-7
4.1.1.2-9 Temperature Profile Downstream of Reactor 4.1.1.2-7
4.1.1.2-10 System Temperatures Downstream of PCD 4.1.1.2-8
4.1.1.2-11 Mixing Zone Differential Pressure Profile 4.1.1.2-8
4.1.1.2-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.1.2-8
4.1.1.2-13 Standpipe Differential Pressure Profiles 4.1.1.2-9
4.1.1.2-14 Coal Feed Rate Based on Gas Analysis 4.1.1.2-9
4.1.1.2-15 O_2, SO_2, and NO_X Analyzers 4.1.1.2-9
4.1.1.2-16 CO and H_2O Analyzers 4.1.1.2-10
4.1.1.2-17 GC Analysis 4.1.1.2-10
4.1.1.2-18 FD0510 Temperature Profiles 4.1.1.2-10
4.1.1.2-19 FD0206 Pressure Profiles 4.1.1.2-11
4.1.1.2-20 FD0520 Pressure Profiles 4.1.1.2-11
4.1.1.2-21 Nitrogen/Propane Header Pressure Profiles 4.1.1.2-11
4.1.1.2-22 PCD Temperatures 4.1.1.2-12
4.1.1.2-23 PCD Differential Pressure Profile 4.1.1.2-12

4.1.1.2-24 PCD Pressure and Pulse Pressure 4.1.1.2-12
4.1.1.2-25 Gas Flow Through PCD 4.1.1.2-13

4.1.1.3-1 CO0201 System Profile 4.1.1.3-3
4.1.1.3-2 Coal Feed System Profile 4.1.1.3-3
4.1.1.3-3 Start-Up Burner Flow/Temperature 4.1.1.3-3
4.1.1.3-4 System Pressure Downstream of PCD 4.1.1.3-4
4.1.1.3-5 Total Gas In/Out Flow Rates 4.1.1.3-4
4.1.1.3-6 Reactor Mixing Zone and Riser Temperatures 4.1.1.3-4
4.1.1.3-7 Standpipe Temperatures 4.1.1.3-5
4.1.1.3-8 Cyclone Dipleg Temperatures 4.1.1.3-5
4.1.1.3-9 Temperature Profile Downstream of Reactor 4.1.1.3-5
4.1.1.3-10 PCD Ash Temperatures 4.1.1.3-6
4.1.1.3-11 System Temperatures Downstream of PCD 4.1.1.3-6
4.1.1.3-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.1.3-6
4.1.1.3-13 Standpipe Differential Pressure Profiles 4.1.1.3-7
4.1.1.3-14 O_2, SO_2, and NO_X Analyzers 4.1.1.3-7
4.1.1.3-15 CO and H_2O Analyzers 4.1.1.3-7
4.1.1.3-16 GC Analysis 4.1.1.3-8
4.1.1.3-17 FD0520 Pressure Profiles 4.1.1.3-8
4.1.1.3-18 PCD Temperatures 4.1.1.3-8
4.1.1.3-19 PCD Differential Pressure Profiles 4.1.1.3-9
4.1.1.3-20 PCD Pressure and Pulse Profiles 4.1.1.3-9
4.1.1.3-21 Gas Flow Through PCD 4.1.1.3-9

4.1.1.4-1 CO0201 System Profile 4.1.1.4-7
4.1.1.4-2 Recycle Gas System Pressure Profiles 4.1.1.4-7
4.1.1.4-3 Transport Air System Profile 4.1.1.4-7
4.1.1.4-4 Coal Feeder System Profile 4.1.1.1-8
4.1.1.4-5 Start-Up Burner Flow/Temperature 4.1.1.1-8
4.1.1.4-6 Total Gas In/Out Flow Rates Reactor 4.1.1.1-8
4.1.1.4-7 Mixing Zone and Riser Temperatures 4.1.1.1-9
4.1.1.4-8 Standpipe Temperatures 4.1.1.1-9
4.1.1.4-9 Cyclone Dipleg Temperatures 4.1.1.1-9
4.1.1.4-10 Temperature Profile Downstream of Reactor 4.1.1.1-10
4.1.1.4-11 System Temperatures Downstream of PCD 4.1.1.1-10
4.1.1.4-12 Mixing Zone Differential Pressure Profile 4.1.1.1-10
4.1.1.4-13 Reactor Pressure/Riser Differential Pressure Profiles 4.1.1.1-11
4.1.1.4-14 Standpipe Differential Pressure Profiles 4.1.1.1-11
4.1.1.4-15 Coal Feed Rate Based on Gas Analysis 4.1.1.1-11
4.1.1.4-16 O_2, SO_2, and NO_X Analyzers 4.1.1.1-12
4.1.1.4-17 CO and H_2O Analyzers 4.1.1.1-12
4.1.1.4-18 FD0510 Temperature Profiles 4.1.1.1-12
4.1.1.4-19 FD0206 Profiles 4.1.1.1-13
4.1.1.4-20 FD0520 Pressure Profiles 4.1.1.1-13
4.1.1.4-21 Thermal Oxidizer Air/Fuel Flow 4.1.1.1-13
4.1.1.4-22 Nitrogen/Propane Header Pressure Profiles 4.1.1.1-14

4.1.1.4-23 PCD Temperatures 4.1.1.1-14
4.1.1.4-24 PCD Differential Pressure Profile 4.1.1.1-14
4.1.1.4-25 PCD Pressure and Pulse Pressure 4.1.1.1-15
4.1.1.4-26 Gas Flow Through PCD 4.1.1.1-15
4.1.1.4-27 CO0201 System Profile 4.1.1.1-17
4.1.1.4-28 Recycle Gas System Pressure Profiles 4.1.1.1-17
4.1.1.4-29 Transport Air System Profile 4.1.1.1-17
4.1.1.4-30 Coal Feeder System Profile 4.1.1.1-18
4.1.1.4-31 Start-Up Burner Flow/Temperature 4.1.1.1-18
4.1.1.4-32 Total Gas In/Out Flow Rates 4.1.1.1-18
4.1.1.4-33 Reactor Mixing Zone and Riser Temperatures 4.1.1.1-19
4.1.1.4-34 Standpipe Temperatures 4.1.1.1-19
4.1.1.4-35 Cyclone Dipleg Temperatures 4.1.1.1-19
4.1.1.4-36 Temperature Profile Downstream of Reactor 4.1.1.1-20
4.1.1.4-37 System Temperatures Downstream of PCD 4.1.1.1-20
4.1.1.4-38 Mixing Zone Differential Pressure Profile 4.1.1.1-20
4.1.1.4-39 Reactor Pressure/Riser Differential Pressure Profiles 4.1.1.1-21
4.1.1.4-40 Standpipe Differential Pressure Profiles 4.1.1.1-21
4.1.1.4-41 Coal Feed Rate Based on Gas Analysis 4.1.1.1-21
4.1.1.4-42 O_2, SO_2, and NO_X Analyzers 4.1.1.1-22
4.1.1.4-43 CO and H_2O Analyzers 4.1.1.1-22
4.1.1.4-44 FD0510 Temperature Profiles 4.1.1.1-22
4.1.1.4-45 FD0206 Profiles 4.1.1.1-23
4.1.1.4-46 FD0520 Pressure Profiles 4.1.1.1-23
4.1.1.4-47 Thermal Oxidizer Air/Fuel Flow 4.1.1.1-23
4.1.1.4-48 Nitrogen/Propane Header Pressure Profiles 4.1.1.1-24
4.1.1.4-49 PCD Temperatures 4.1.1.1-24
4.1.1.4-50 PCD Differential Pressure Profile 4.1.1.1-24
4.1.1.4-51 PCD Pressure and Pulse Pressure 4.1.1.1-25
4.1.1.4-52 Gas Flow Through PCD 4.1.1.1-25
4.1.1.4-53 CO0201 System Profile 4.1.1.1-27
4.1.1.4-54 Recycle Gas System Pressure Profiles 4.1.1.1-27
4.1.1.4-55 Transport Air System Profile 4.1.1.1-27
4.1.1.4-56 Coal Feeder System Profile 4.1.1.1-28
4.1.1.4-57 Start-Up Burner Flow/Temperature 4.1.1.1-28
4.1.1.4-58 Total Gas In/Out Flow Rates 4.1.1.1-28
4.1.1.4-59 Reactor Mixing Zone and Riser Temperatures 4.1.1.1-29
4.1.1.4-60 Standpipe Temperatures 4.1.1.1-29
4.1.1.4-61 Cyclone Dipleg Temperatures 4.1.1.1-29
4.1.1.4-62 Temperature Profile Downstream of Reactor 4.1.1.1-30
4.1.1.4-63 System Temperatures Downstream of PCD 4.1.1.1-30
4.1.1.4-64 Mixing Zone Differential Pressure Profile 4.1.1.1-30
4.1.1.4-65 Reactor Pressure/Riser Differential Pressure Profiles 4.1.1.1-31
4.1.1.4-66 Standpipe Differential Pressure Profiles 4.1.1.1-31
4.1.1.4-67 Coal Feed Rate Based on Gas Analysis 4.1.1.1-31
4.1.1.4-68 O_2, SO_2, and NO_X Analyzers 4.1.1.1-32
4.1.1.4-69 CO and H_2O Analyzers 4.1.1.1-32

4.1.1.4-70 FD0510 Temperature Profiles 4.1.1.1-32
4.1.1.4-71 FD0206 Profiles 4.1.1.1-33
4.1.1.4-72 FD0520 Pressure Profiles 4.1.1.1-33
4.1.1.4-73 Thermal Oxidizer Air/Fuel Flow 4.1.1.1-33
4.1.1.4-74 Nitrogen/Propane Header Pressure Profiles 4.1.1.1-34
4.1.1.4-75 PCD Temperatures 4.1.1.1-34
4.1.1.4-76 PCD Differential Pressure Profile 4.1.1.1-34
4.1.1.4-77 PCD Pressure and Pulse Pressure 4.1.1.1-35
4.1.1.4-78 Gas Flow Through PCD 4.1.1.1-35
4.1.1.4-79 CO0201 System Profile 4.1.1.1-37
4.1.1.4-80 Recycle Gas System Pressure Profiles 4.1.1.1-37
4.1.1.4-81 Transport Air System Profile 4.1.1.1-37
4.1.1.4-82 Coal Feeder System Profile 4.1.1.1-38
4.1.1.4-83 Start-Up Burner Flow/Temperature 4.1.1.1-38
4.1.1.4-84 Total Gas In/Out Flow Rates 4.1.1.1-38
4.1.1.4-85 Reactor Mixing Zone and Riser Temperatures 4.1.1.1-39
4.1.1.4-86 Standpipe Temperatures 4.1.1.1-39
4.1.1.4-87 Cyclone Dipleg Temperatures 4.1.1.1-39
4.1.1.4-88 Temperature Profile Downstream of Reactor 4.1.1.1-40
4.1.1.4-89 System Temperatures Downstream of PCD 4.1.1.1-40
4.1.1.4-90 Mixing Zone Differential Pressure Profile 4.1.1.1-40
4.1.1.4-91 Reactor Pressure/Riser Differential Pressure Profiles 4.1.1.1-41
4.1.1.4-92 Standpipe Differential Pressure Profiles 4.1.1.1-41
4.1.1.4-93 Coal Feed Rate Based on Gas Analysis 4.1.1.1-41
4.1.1.4-94 O_2, SO_2, and NO_X Analyzers 4.1.1.1-42
4.1.1.4-95 CO and H_2O Analyzers 4.1.1.1-42
4.1.1.4-96 FD0510 Temperature Profiles 4.1.1.1-42
4.1.1.4-97 FD0206 Profiles 4.1.1.1-43
4.1.1.4-98 FD0520 Pressure Profiles 4.1.1.1-43
4.1.1.4-99 Thermal Oxidizer Air/Fuel Flow 4.1.1.1-43
4.1.1.4-100 Nitrogen/Propane Header Pressure Profiles 4.1.1.1-44
4.1.1.4-101 PCD Temperatures 4.1.1.1-44
4.1.1.4-102 PCD Differential Pressure Profile 4.1.1.1-44
4.1.1.4-103 PCD Pressure and Pulse Pressure 4.1.1.1-45
4.1.1.4-104 Gas Flow Through PCD 4.1.1.1-45

4.1.2.1-1 CO0201 System Profile 4.1.2.1-7
4.1.2.1-2 Recycle Gas System Pressure 4.1.2.1-7
4.1.2.1-3 Coal Feed System Profile 4.1.2.1-7
4.1.2.1-4 Sorbent Feed System Profile 4.1.2.1-8
4.1.2.1-5 Start-Up Burner Flow/Temperature 4.1.2.1-8
4.1.2.1-6 Total Gas In/Out Flow Rates 4.1.2.1-8
4.1.2.1-7 Reactor Mixing Zone and Riser Temperatures 4.1.2.1-9
4.1.2.1-8 Standpipe Temperatures 4.1.2.1-9
4.1.2.1-9 Cyclone Dipleg Temperatures 4.1.2.1-9
4.1.2.1-10 Temperature Profile Downstream of Reactor 4.1.2.1-10
4.1.2.1-11 System Temperatures Downstream of PCD 4.1.2.1-10

4.1.2.2-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.2.1-10
4.1.2.1-13 Standpipe Differential Pressure Profiles 4.1.2.1-11
4.1.2.1-14 CY0201 Dipleg Differential Pressure Profiles 4.1.2.1-11
4.1.2.1-15 Coal Feed Rate Based on Gas Analysis 4.1.2.1-11
4.1.2.1-16 O_2, SO_2, and NO_X Analyzers 4.1.2.1-12
4.1.2.1-17 CO and H_2O Analyzers 4.1.2.1-12
4.1.2.1-18 FD0510 Temperature Profiles 4.1.2.1-12
4.1.2.1-19 FD0206 Profiles 4.1.2.1-13
4.1.2.1-20 FD0520 Pressure Profiles 4.1.2.1-13
4.1.2.1-21 FD0530 Pressure Profiles 4.1.2.1-13
4.1.2.1-22 PCD Temperatures 4.1.2.1-14
4.1.2.1-23 PCD Differential Pressure Profile 4.1.2.1-14
4.1.2.1-24 PCD Pressure and Pulse Pressure 4.1.2.1-14
4.1.2.1-25 Gas Flow Through PCD 4.1.2.1-15
4.1.2.1-26 CO01201 System Profile 4.1.2.1-17
4.1.2.1-27 Coal Feed System Profile 4.1.2.1-17
4.1.2.1-28 Sorbent Feed System Profile 4.1.2.1-17
4.1.2.1-29 Start-Up Burner Flow/Temperature 4.1.2.1-18
4.1.2.1-30 Total Gas In/Out Flow Rates 4.1.2.1-18
4.1.2.1-31 Reactor Mixing Zone and Riser Temperatures 4.1.2.1-18
4.1.2.1-32 Standpipe Temperatures 4.1.2.1-19
4.1.2.1-33 Cyclone Dipleg Temperatures 4.1.2.1-19
4.1.2.1-34 Temperature Profile Downstream of Reactor 4.1.2.1-19
4.1.2.1-35 System Temperatures Downstream of PCD 4.1.2.1-20
4.1.2.1-36 Mixing Zone Differential Pressure Profile 4.1.2.1-20
4.1.2.1-37 Reactor Pressure/Riser Differential Pressure Profiles 4.1.2.1-20
4.1.2.1-38 Standpipe Differential Pressure Profiles 4.1.2.1-21
4.1.2.1-39 Coal Feed Rate Based on Gas Analysis 4.1.2.1-21
4.1.2.1-40 O_2, SO_2, and NO_X Analyzers 4.1.2.1-21
4.1.2.1-41 CO and H_2O Analyzers 4.1.2.1-22
4.1.2.1-42 FD0510 Temperature Profiles 4.1.2.1-22
4.1.2.1-43 FD0206 Profiles 4.1.2.1-22
4.1.2.1-44 FD0520 Pressure Profiles 4.1.2.1-23
4.1.2.1-45 Thermal Oxidizer Air/Fuel Flow 4.1.2.1-23
4.1.2.1-46 Nitrogen/Propane Header Pressure Profiles 4.1.2.1-23
4.1.2.1-47 PCD Temperatures 4.1.2.1-24
4.1.2.1-48 PCD Differential Pressure Profile 4.1.2.1-24
4.1.2.1-49 PCD Pressure and Pulse Pressure 4.1.2.1-24
4.1.2.1-50 Gas Flow Through PCD 4.1.2.1-25

4.1.2.2-1 CO0201 System Profile 4.1.2.2-5
4.1.2.2-2 Coal Feed System Profile 4.1.2.2-5
4.1.2.2-3 Sorbent Feed System Profile 4.1.2.2-5
4.1.2.2-4 Start-Up Burner Flow/Temperature 4.1.2.2-6
4.1.2.2-5 Total Gas In/Out Flow Rates 4.1.2.2-6
4.1.2.2-6 Reactor Mixing Zone and Riser Temperatures 4.1.2.2-6
4.1.2.2-7 Standpipe Temperatures 4.1.2.2-7

4.1.2.2-8 Cyclone Dipleg Temperatures 4.1.2.2-7
4.1.2.2-9 Temperature Profile Downstream of Reactor 4.1.2.2-7
4.1.2.2-10 System Temperatures Downstream of PCD 4.1.2.2-8
4.1.2.2-11 Mixing Zone Differential Pressure Profile 4.1.2.2-8
4.1.2.2-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.2.2-8
4.1.2.2-13 Standpipe Differential Pressure Profiles 4.1.2.2-9
4.1.2.2-14 CY0201 Dipleg Differential Pressure Profiles 4.1.2.2-9
4.1.2.2-15 Coal Feed Rate Based on Gas Analysis 4.1.2.2-9
4.1.2.2-16 O_2, SO_2, and NO_X Analyzers 4.1.2.2-10
4.1.2.2-17 CO and H_2O Analyzers 4.1.2.2-10
4.1.2.2-18 FD0510 Temperature Profiles 4.1.2.2-10
4.1.2.2-19 FD0206 Pressure Profiles 4.1.2.2-11
4.1.2.2-20 FD0520 Pressure Profiles 4.1.2.2-11
4.1.2.2-21 FD0530 Pressure Profiles 4.1.2.2-11
4.1.2.2-22 PCD Temperatures 4.1.2.2-12
4.1.2.2-23 PCD Differential Pressure Profile 4.1.2.2-12
4.1.2.2-24 PCD Pressure and Pulse Pressure 4.1.2.2-12
4.1.2.2-25 Gas Flow Through PCD 4.1.2.2-13
4.1.2.2-26 CO0201 System Profile 4.1.2.1-15
4.1.2.2-27 Coal Feed System Profile 4.1.2.1-15
4.1.2.2-28 Sorbent Feed System Profile 4.1.2.1-15
4.1.2.2-29 Start-Up Burner Flow/Temperature 4.1.2.1-16
4.1.2.2-30 Total Gas In/Out Flow Rates 4.1.2.1-16
4.1.2.2-31 Reactor Mixing Zone and Riser Temperatures 4.1.2.1-16
4.1.2.2-32 Standpipe Temperatures 4.1.2.1-17
4.1.2.2-33 Cyclone Dipleg Temperatures 4.1.2.1-17
4.1.2.2-34 Temperature Profile Downstream of Reactor 4.1.2.1-17
4.1.2.2-35 System Temperatures Downstream of PCD 4.1.2.1-18
4.1.2.2-36 Mixing Zone Differential Pressure Profile 4.1.2.1-18
4.1.2.2-37 Reactor Pressure/Riser Differential Pressure Profiles 4.1.2.1-18
4.1.2.2-38 Standpipe Differential Pressure Profiles 4.1.2.1-19
4.1.2.2-39 CY0201 Dipleg Differential Pressure Profiles 4.1.2.1-19
4.1.2.2-40 Coal Feed Rate Based on Gas Analysis 4.1.2.1-19
4.1.2.2-41 O_2, SO_2, and NO_X Analyzers 4.1.2.1-20
4.1.2.2-42 CO and H_2O Analyzers 4.1.2.1-20
4.1.2.2-43 FD0510 Temperature Profiles 4.1.2.1-20
4.1.2.2-44 FD0206 Pressure Profiles 4.1.2.1-21
4.1.2.2-45 FD0520 Pressure Profiles 4.1.2.1-21
4.1.2.2-46 FD0530 Feeder Profiles 4.1.2.1-21
4.1.2.2-47 PCD Temperatures 4.1.2.1-22
4.1.2.2-48 PCD Differential Pressure Profile 4.1.2.1-22
4.1.2.2-49 PCD Pressure and Pulse Pressure 4.1.2.1-22
4.1.2.2-50 Gas Flow Through PCD 4.1.2.1-23

4.1.3-1 CO0201 System Profile 4.1.3-5
4.1.3-2 Coal Feed System Profile 4.1.3-5
4.1.3-3 Sorbent Feed System Profile 4.1.3-5

4.1.3-4 Start-Up Burner Flow/Temperature 4.1.3-6
4.1.3-5 Total Gas In/Out Flow Rates 4.1.3-6
4.1.3-6 Reactor Mixing Zone and Riser Temperatures 4.1.3-6
4.1.3-7 Standpipe Temperatures 4.1.3-7
4.1.3-8 Cyclone Dipleg Temperatures 4.1.3-7
4.1.3-9 Temperature Profile Downstream of Reactor 4.1.3-7
4.1.3-10 PCD Ash Temperatures 4.1.3-8
4.1.3-11 System Temperatures Downstream of PCD 4.1.3-8
4.1.3-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.3-8
4.1.3-13 Standpipe Differential Pressure Profiles 4.1.3-9
4.1.3-14 CY0201 Dipleg Differential Pressure Profiles 4.1.3-9
4.1.3-15 O_2, SO_2, and NO_X Analyzers 4.1.3-9
4.1.3-16 CO and H_2O Analyzers 4.1.3-10
4.1.3-17 Solids Withdrawal 4.1.3-10
4.1.3-18 FD0510 Temperature Profiles 4.1.3-10
4.1.3-19 FD0206 Pressure Profiles 4.1.3-11
4.1.3-20 FD0520 Pressure Profiles 4.1.3-11
4.1.3-21 PCD Temperatures 4.1.3-11
4.1.3-22 PCD Differential Pressure Profile 4.1.3-12
4.1.3-23 PCD Pressure and Pulse Pressure 4.1.3-12
4.1.3-24 Gas Flow Through PCD 4.1.3-12
4.1.3-25 CO0201 System Profile 4.1.3-13
4.1.3-26 Coal Feed System Profile 4.1.3-13
4.1.3-27 Sorbent Feed System Profile 4.1.3-13
4.1.3-28 Start-Up Burner Flow/Temperature 4.1.3-14
4.1.3-29 Total Gas In/Out Flow Rates 4.1.3-14
4.1.3-30 Reactor Mixing Zone and Riser Temperatures 4.1.3-14
4.1.3-31 Standpipe Temperatures 4.1.3-15
4.1.3-32 Cyclone Dipleg Temperatures 4.1.3-15
4.1.3-33 Temperature Profile Downstream of Reactor 4.1.3-15
4.1.3-34 PCD Ash Temperatures 4.1.3-16
4.1.3-35 System Temperatures Downstream of PCD 4.1.3-16
4.1.3-36 Reactor Pressure/Riser Differential Pressure Profiles 4.1.3-16
4.1.3-37 Standpipe Differential Pressure Profiles 4.1.3-17
4.1.3-38 CY0201 Dipleg Differential Pressure Profiles 4.1.3-17
4.1.3-39 O_2, SO_2, and NO_X Analyzers 4.1.3-17
4.1.3-40 CO and H_2O Analyzers 4.1.3-18
4.1.3-41 Solids Withdrawal 4.1.3-18
4.1.3-42 FD0510 Temperature Profiles 4.1.3-18
4.1.3-43 FD0206 Pressure Profiles 4.1.3-19
4.1.3-44 FD0520 Pressure Profiles 4.1.3-19
4.1.3-45 PCD Temperatures 4.1.3-19
4.1.3-46 PCD Differential Pressure Profile 4.1.3-20
4.1.3-47 PCD Pressure and Pulse Pressure 4.1.3-20
4.1.3-48 Gas Flow Through PCD 4.1.3-20
4.1.3-49 CO0201 System Profile 4.1.3-21
4.1.3-50 Coal Feed System Profile 4.1.3-21

4.1.3-51 Sorbent Feed System Profile 4.1.3-21
4.1.3-52 Start-Up Burner Flow/Temperature 4.1.3-22
4.1.3-53 Total Gas In/Out Flow Rates 4.1.3-22
4.1.3-54 Reactor Mixing Zone and Riser Temperatures 4.1.3-22
4.1.3-55 Standpipe Temperatures 4.1.3-23
4.1.3-56 Cyclone Dipleg Temperatures 4.1.3-23
4.1.3-57 Temperature Profile Downstream of Reactor 4.1.3-23
4.1.3-58 PCD Ash Temperatures 4.1.3-24
4.1.3-59 System Temperatures Downstream of PCD 4.1.3-24
4.1.3-60 Reactor Pressure/Riser Differential Pressure Profiles 4.1.3-24
4.1.3-61 Standpipe Differential Pressure Profiles 4.1.3-25
4.1.3-62 CY0201 Dipleg Differential Pressure Profiles 4.1.3-25
4.1.3-63 O_2, SO_2, and NO_X Analyzers 4.1.3-25
4.1.3-64 CO and H_2O Analyzers 4.1.3-26
4.1.3-65 Solids Withdrawal 4.1.3-26
4.1.3-66 FD0510 Temperature Profiles 4.1.3-26
4.1.3-67 FD0206 Pressure Profiles 4.1.3-27
4.1.3-68 FD0520 Pressure Profiles 4.1.3-27
4.1.3-69 PCD Temperatures 4.1.3-27
4.1.3-70 PCD Differential Pressure Profile 4.1.3-28
4.1.3-71 PCD Pressure and Pulse Pressure 4.1.3-28
4.1.3-72 Gas Flow Through PCD 4.1.3-28

4.1.4.1-1 CO0201 System Profile 4.1.4.1-5
4.1.4.1-2 Coal Feed System Profile 4.1.4.1-5
4.1.4.1-3 Sorbent Feed System Profile 4.1.4.1-5
4.1.4.1-4 Start-Up Burner Flow/Temperature 4.1.4.1-6
4.1.4.1-5 System Pressures Downstream of PCD 4.1.4.1-6
4.1.4.1-6 Total Gas In/Out Flow Rates 4.1.4.1-6
4.1.4.1-7 Reactor Mixing Zone and Riser Temperatures 4.1.4.1-7
4.1.4.1-8 Standpipe Temperatures 4.1.4.1-7
4.1.4.1-9 Cyclone Dipleg Temperatures 4.1.4.1-7
4.1.4.1-10 PCD Ash Temperatures 4.1.4.1-8
4.1.4.1-11 System Temperatures Downstream of PCD 4.1.4.1-8
4.1.4.1-12 Mixing Zone Differential Pressure Profile 4.1.4.1-8
4.1.4.1-13 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.1-9
4.1.4.1-14 Standpipe Differential Pressure Profiles 4.1.4.1-9
4.1.4.1-15 CY0201 Dipleg Differential Pressure Profiles 4.1.4.1-9
4.1.4.1-16 Coal Feed Rate Based on Gas Analysis 4.1.4.1-10
4.1.4.1-17 O_2, SO_2, and NO_X Analyzers 4.1.4.1-10
4.1.4.1-18 FD0520 Profiles 4.1.4.1-10
4.1.4.1-19 Thermal Oxidizer Blower Discharge Pressure 4.1.4.1-11
4.1.4.1-20 Thermal Oxidizer Air/Fuel Flow 4.1.4.1-11
4.1.4.1-21 Nitrogen/Propane Header Pressure Profiles 4.1.4.1-11
4.1.4.1-22 PCD Temperatures 4.1.4.1-12

4.1.4.2-1 CO0201 System Profile 4.1.4.2-7
4.1.4.2-2 Coal Feed System Profile 4.1.4.2-7
4.1.4.2-3 Sorbent Feed System Profile 4.1.4.2-7
4.1.4.2-4 Start-Up Burner Flow/Temperature 4.1.4.2-8
4.1.4.2-5 System Pressures Downstream of PCD 4.1.4.2-8
4.1.4.2-6 Total Gas In/Out Flow Rates 4.1.4.2-8
4.1.4.2-7 Reactor Mixing Zone and Riser Temperatures 4.1.4.2-9
4.1.4.2-8 Standpipe Temperatures 4.1.4.2-9
4.1.4.2-9 Cyclone Dipleg Temperatures 4.1.4.2-9
4.1.4.2-10 Temperature Profiles Downstream of Reactor 4.1.4.2-10
4.1.4.2-11 System Temperatures Downstream of PCD 4.1.4.2-10
4.1.4.2-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.2-10
4.1.4.2-13 Standpipe Differential Pressure Profiles 4.1.4.2-11
4.1.4.2-14 CY0201 Dipleg Differential Pressure Profiles 4.1.4.2-11
4.1.4.2-15 Coal Feed Rate Based on Gas Analysis 4.1.4.2-11
4.1.4.2-16 O_2, SO_2, and NO_X Analyzers 4.1.4.2-12
4.1.4.2-17 Solids Withdrawal 4.1.4.2-12
4.1.4.2-18 FD0206 Profiles 4.1.4.2-12
4.1.4.2-19 FD0520 Pressure Profiles 4.1.4.2-13
4.1.4.2-20 Thermal Oxidizer Air/Fuel Flow 4.1.4.2-13
4.1.4.2-21 PCD Temperatures 4.1.4.2-13
4.1.4.2-22 PCD Differential Pressure Profile 4.1.4.2-14
4.1.4.2-23 PCD Pressure and Pulse Pressure 4.1.4.2-14
4.1.4.2-24 Gas Flow Through PCD 4.1.4.2-14
4.1.4.2-25 CO0201 System Profile 4.1.4.2-15
4.1.4.2-26 Coal Feed System Profile 4.1.4.2-15
4.1.4.2-27 Sorbent Feed System Profile 4.1.4.2-15
4.1.4.2-28 Start-Up Burner Flow/Temperature 4.1.4.2-16
4.1.4.2-29 System Pressures Downstream of PCD 4.1.4.2-16
4.1.4.2-30 Total Gas In/Out Flow Rates 4.1.4.2-16
4.1.4.2-31 Reactor Mixing Zone and Riser Temperatures 4.1.4.2-17
4.1.4.2-32 Standpipe Temperatures 4.1.4.2-17
4.1.4.2-33 Cyclone Dipleg Temperatures 4.1.4.2-17
4.1.4.2-34 Temperature Profiles Downstream of Reactor 4.1.4.2-18
4.1.4.2-35 System Temperatures Downstream of PCD 4.1.4.2-18
4.1.4.2-36 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.2-18
4.1.4.2-37 Standpipe Differential Pressure Profiles 4.1.4.2-19
4.1.4.2-38 CY0201 Dipleg Differential Pressure Profiles 4.1.4.2-19
4.1.4.2-38 Coal Feed Rate Based on Gas Analysis 4.1.4.2-19
4.1.4.2-40 O_2, SO_2, and NO_X Analyzers 4.1.4.2-20
4.1.4.2-41 Solids Withdrawal 4.1.4.2-20
4.1.4.2-42 FD0206 Profiles 4.1.4.2-20
4.1.4.2-43 FD0520 Pressure Profiles 4.1.4.2-21
4.1.4.2-44 Thermal Oxidizer Air/Fuel Flow 4.1.4.2-21
4.1.4.2-45 PCD Temperatures 4.1.4.2-21
4.1.4.2-46 PCD Differential Pressure Profile 4.1.4.2-22
4.1.4.2-47 PCD Pressure and Pulse Pressure 4.1.4.2-22

4.1.4.2-48 Gas Flow Through PCD 4.1.4.2-22
4.1.4.2-49 CO0201 System Profile 4.1.4.2-23
4.1.4.2-50 Coal Feed System Profile 4.1.4.2-23
4.1.4.2-51 Sorbent Feed System Profile 4.1.4.2-23
4.1.4.2-52 Start-Up Burner Flow/Temperature 4.1.4.2-24
4.1.4.2-53 System Pressures Downstream of PCD 4.1.4.2-24
4.1.4.2-54 Total Gas In/Out Flow Rates 4.1.4.2-24
4.1.4.2-55 Reactor Mixing Zone and Riser Temperatures 4.1.4.2-25
4.1.4.2-56 Standpipe Temperatures 4.1.4.2-25
4.1.4.2-57 Cyclone Dipleg Temperatures 4.1.4.2-25
4.1.4.2-58 Temperature Profiles Downstream of Reactor 4.1.4.2-26
4.1.4.2-59 System Temperatures Downstream of PCD 4.1.4.2-26
4.1.4.2-60 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.2-26
4.1.4.2-61 Standpipe Differential Pressure Profiles 4.1.4.2-27
4.1.4.2-62 CY0201 Dipleg Differential Pressure Profiles 4.1.4.2-27
4.1.4.2-63 Coal Feed Rate Based on Gas Analysis 4.1.4.2-27
4.1.4.2-64 O_2, SO_2, and NO_X Analyzers 4.1.4.2-28
4.1.4.2-65 Solids Withdrawal 4.1.4.2-28
4.1.4.2-66 FD0206 Profiles 4.1.4.2-28
4.1.4.2-67 FD0520 Pressure Profiles 4.1.4.2-29
4.1.4.2-68 Thermal Oxidizer Air/Fuel Flow 4.1.4.2-29
4.1.4.2-69 PCD Temperatures 4.1.4.2-29
4.1.4.2-70 PCD Differential Pressure Profile 4.1.4.2-30
4.1.4.2-71 PCD Pressure and Pulse Pressure 4.1.4.2-30
4.1.4.2-72 Gas Flow Through PCD 4.1.4.2-30
4.1.4.2-73 CO0201 System Profile 4.1.4.2-31
4.1.4.2-74 Coal Feed System Profile 4.1.4.2-31
4.1.4.2-75 Sorbent Feed System Profile 4.1.4.2-31
4.1.4.2-76 Start-Up Burner Flow/Temperature 4.1.4.2-32
4.1.4.2-77 System Pressures Downstream of PCD 4.1.4.2-32
4.1.4.2-78 Total Gas In/Out Flow Rates 4.1.4.2-32
4.1.4.2-79 Reactor Mixing Zone and Riser Temperatures 4.1.4.2-33
4.1.4.2-80 Standpipe Temperatures 4.1.4.2-33
4.1.4.2-81 Cyclone Dipleg Temperatures 4.1.4.2-33
4.1.4.2-82 Temperature Profiles Downstream of Reactor 4.1.4.2-34
4.1.4.2-83 System Temperatures Downstream of PCD 4.1.4.2-34
4.1.4.2-84 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.2-34
4.1.4.2-85 Standpipe Differential Pressure Profiles 4.1.4.2-35
4.1.4.2-86 CY0201 Dipleg Differential Pressure Profiles 4.1.4.2-35
4.1.4.2-87 Coal Feed Rate Based on Gas Analysis 4.1.4.2-35
4.1.4.2-88 O_2, SO_2, and NO_X Analyzers 4.1.4.2-36
4.1.4.2-89 Solids Withdrawal 4.1.4.2-36
4.1.4.2-90 FD0206 Profiles 4.1.4.2-36
4.1.4.2-91 FD0520 Pressure Profiles 4.1.4.2-37
4.1.4.2-92 Thermal Oxidizer Air/Fuel Flow 4.1.4.2-37
4.1.4.2-93 PCD Temperatures 4.1.4.2-37
4.1.4.2-94 PCD Differential Pressure Profile 4.1.4.2-38

4.1.4.2-95 PCD Pressure and Pulse Pressure 4.1.4.2-38
4.1.4.2-96 Gas Flow Through PCD 4.1.4.2-38

4.1.4.3-1 CO0201 System Profile 4.1.4.3-5
4.1.4.3-2 Coal Feed System Profile 4.1.4.3-5
4.1.4.3-3 Sorbent Feed System Profile 4.1.4.3-5
4.1.4.3-4 Start-Up Burner Flow/Temperature 4.1.4.3-6
4.1.4.3-5 System Pressures Downstream of PCD 4.1.4.3-6
4.1.4.3-6 Total Gas In/Out Flow Rates 4.1.4.3-6
4.1.4.3-7 Reactor Mixing Zone and Riser Temperatures 4.1.4.3-7
4.1.4.3-8 Standpipe Temperatures 4.1.4.3-7
4.1.4.3-9 Cyclone Dipleg Temperatures 4.1.4.3-7
4.1.4.3-10 Temperature Profiles Downstream of Reactor 4.1.4.3-8
4.1.4.3-11 System Temperatures Downstream of PCD 4.1.4.3-8
4.1.4.3-12 Mixing Zone Differential Pressure Profile 4.1.4.3-8
4.1.4.3-13 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.3-9
4.1.4.3-14 Standpipe Differential Pressure Profiles 4.1.4.3-9
4.1.4.3-15 CY0201 Dipleg Differential Pressure Profiles 4.1.4.3-9
4.1.4.3-16 Coal Feed Rate Based on Gas Analysis 4.1.4.3-10
4.1.4.3-17 O_2, SO_2, and NO_X Analyzers 4.1.4.3-10
4.1.4.3-18 FD0206 Profiles 4.1.4.3-10
4.1.4.3-19 FD0520 Pressure Profiles 4.1.4.3-11
4.1.4.3-20 PCD Temperatures 4.1.4.3-11
4.1.4.3-21 PCD Differential Pressure Profile 4.1.4.3-11
4.1.4.3-22 PCD Pressure and Pulse Pressure 4.1.4.3-12
4.1.4.3-23 Gas Flow Through PCD 4.1.4.3-12
4.1.4.3-24 CO0201 System Profile 4.1.4.3-13
4.1.4.3-25 Coal Feed System Profile 4.1.4.3-13
4.1.4.3-26 Sorbent Feed System Profile 4.1.4.3-13
4.1.4.3-27 Start-Up Burner Flow/Temperature 4.1.4.3-14
4.1.4.3-28 System Pressures Downstream of PCD 4.1.4.3-14
4.1.4.3-29 Total Gas In/Out Flow Rates 4.1.4.3-14
4.1.4.3-30 Reactor Mixing Zone and Riser Temperatures 4.1.4.3-15
4.1.4.3-31 Standpipe Temperatures 4.1.4.3-15
4.1.4.3-32 Cyclone Dipleg Temperatures 4.1.4.3-15
4.1.4.3-33 Temperature Profiles Downstream of Reactor 4.1.4.3-16
4.1.4.3-34 System Temperatures Downstream of PCD 4.1.4.3-16
4.1.4.3-35 Mixing Zone Differential Pressure Profile 4.1.4.3-16
4.1.4.3-36 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.3-17
4.1.4.3-37 Standpipe Differential Pressure Profiles 4.1.4.3-17
4.1.4.3-38 CY0201 Dipleg Differential Pressure Profiles 4.1.4.3-17
4.1.4.3-39 Coal Feed Rate Based on Gas Analysis 4.1.4.3-18
4.1.4.3-40 O_2, SO_2, and NO_X Analyzers 4.1.4.3-18
4.1.4.3-41 FD0206 Profiles 4.1.4.3-18
4.1.4.3-42 FD0520 Pressure Profiles 4.1.4.3-19
4.1.4.3-43 PCD Temperatures 4.1.4.3-19
4.1.4.3-44 PCD Differential Pressure Profile 4.1.4.3-19

4.1.4.3-45 PCD Pressure and Pulse Pressure 4.1.4.3-20
4.1.4.3-46 Gas Flow Through PCD 4.1.4.3-20

4.1.4.4-1 CO0201 System Profile 4.1.4.4-3
4.1.4.4-2 Coal Feed System Profile 4.1.4.4-3
4.1.4.4-3 Sorbent Feed System Profile 4.1.4.4-3
4.1.4.4-4 Start-Up Burner Flow/Temperature 4.1.4.4-4
4.1.4.4-5 Total Gas In/Out Flow Rates 4.1.4.4-4
4.1.4.4-6 Reactor Mixing Zone and Riser Temperatures 4.1.4.4-4
4.1.4.4-7 Standpipe Temperatures 4.1.4.4-5
4.1.4.4-8 Cyclone Dipleg Temperatures 4.1.4.4-5
4.1.4.4-9 Temperature Profiles Downstream of Reactor 4.1.4.4-5
4.1.4.4-10 System Temperatures Downstream of PCD 4.1.4.4-6
4.1.4.4-11 Mixing Zone Differential Pressure Profile 4.1.4.4-6
4.1.4.4-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.4-6
4.1.4.4-13 Standpipe Differential Pressure Profiles 4.1.4.4-7
4.1.4.4-14 CY0201 Dipleg Differential Pressure Profiles 4.1.4.4-7
4.1.4.4-15 Coal Feed Rate Based on Gas Analysis 4.1.4.4-7
4.1.4.4-16 O_2, SO_2, and NO_X Analyzers 4.1.4.4-8
4.1.4.4-17 PCD Temperatures 4.1.4.4-8
4.1.4.4-18 PCD Differential Pressure Profile 4.1.4.4-8
4.1.4.4-19 PCD Pressure and Pulse Pressure 4.1.4.4-9
4.1.4.4-20 Gas Flow Through PCD 4.1.4.4-9
4.1.4.4-21 CO0201 System Profile 4.1.4.4-11
4.1.4.4-22 Coal Feed System Profile 4.1.4.4-11
4.1.4.4-23 Sorbent Feed System Profile 4.1.4.4-11
4.1.4.4-24 Start-Up Burner Flow/Temperature 4.1.4.4-12
4.1.4.4-25 Total Gas In/Out Flow Rates 4.1.4.4-12
4.1.4.4-26 Reactor Mixing Zone and Riser Temperatures 4.1.4.4-12
4.1.4.4-27 Standpipe Temperatures 4.1.4.4-13
4.1.4.4-28 Cyclone Dipleg Temperatures 4.1.4.4-13
4.1.4.4-29 Temperature Profiles Downstream of Reactor 4.1.4.4-13
4.1.4.4-30 System Temperatures Downstream of PCD 4.1.4.4-14
4.1.4.4-31 Mixing Zone Differential Pressure Profile 4.1.4.4-14
4.1.4.4-32 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.4-14
4.1.4.4-33 Standpipe Differential Pressure Profiles 4.1.4.4-15
4.1.4.4-34 CY0201 Dipleg Differential Pressure Profiles 4.1.4.4-15
4.1.4.4-35 Coal Feed Rate Based on Gas Analysis 4.1.4.4-15
4.1.4.4-36 O_2, SO_2, and NO_X Analyzers 4.1.1.4-16
4.1.4.4-37 PCD Temperatures 4.1.1.4-16
4.1.4.4-38 PCD Differential Pressure Profile 4.1.1.4-16
4.1.4.4-39 PCD Pressure and Pulse Pressure 4.1.1.4-17
4.1.4.4-40 Gas Flow Through PCD 4.1.1.4-17

4.1.4.5-1 CO0201 System Profile 4.1.4.5-5
4.1.4.5-2 Coal Feed System Profile 4.1.4.5-5
4.1.4.5-3 Sorbent Feed System Profile 4.1.4.5-5

4.1.4.5-4 Start-Up Burner Flow/Temperature 4.1.4.5-6
4.1.4.5-5 Total Gas In/Out Flow Rates 4.1.4.5-6
4.1.4.5-6 Reactor Mixing Zone and Riser Temperatures 4.1.4.5-6
4.1.4.5-7 Standpipe Temperatures 4.1.4.5-7
4.1.4.5-8 Cyclone Dipleg Temperatures 4.1.4.5-7
4.1.4.5-9 Temperature Profiles Downstream of Reactor 4.1.4.5-7
4.1.4.5-10 System Temperatures Downstream of PCD 4.1.4.5-8
4.1.4.5-11 Mixing Zone Differential Pressure Profile 4.1.4.5-8
4.1.4.5-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.5-8
4.1.4.5-13 Standpipe Differential Pressure Profiles 4.1.4.5-9
4.1.4.5-14 Cyclone Dipleg Differential Pressure Profiles 4.1.4.5-9
4.1.4.5-15 Coal Feed Rate Based on Gas Analysis 4.1.4.5-9
4.1.4.5-16 O_2, SO_2, and NO_X Analyzers 4.1.4.5-10
4.1.4.5-17 FD0520 Pressure Profiles 4.1.4.5-10
4.1.4.5-18 PCD Temperatures 4.1.4.5-10
4.1.4.5-19 PCD Temperatures 4.1.4.5-11
4.1.4.5-20 PCD Differential Pressure Profile 4.1.4.5-11
4.1.4.5-21 PCD Pressure and Pulse Pressure 4.1.4.5-11
4.1.4.5-22 Gas Flow Through PCD 4.1.4.5-12
4.1.4.5-23 CO0201 System Profile 4.1.4.5-13
4.1.4.5-24 Coal Feed System Profile 4.1.4.5-13
4.1.4.5-25 Sorbent Feed System Profile 4.1.4.5-13
4.1.4.5-26 Start-Up Burner Flow/Temperature 4.1.4.5-14
4.1.4.5-27 Total Gas In/Out Flow Rates 4.1.4.5-14
4.1.4.5-28 Reactor Mixing Zone and Riser Temperatures 4.1.4.5-14
4.1.4.5-29 Standpipe Temperatures 4.1.4.5-15
4.1.4.5-30 Cyclone Dipleg Temperatures 4.1.4.5-15
4.1.4.5-31 Temperature Profiles Downstream of Reactor 4.1.4.5-15
4.1.4.5-32 System Temperatures Downstream of PCD 4.1.4.5-16
4.1.4.5-33 Mixing Zone Differential Pressure Profile 4.1.4.5-16
4.1.4.5-34 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.5-16
4.1.4.5-35 Standpipe Differential Pressure Profiles 4.1.4.5-17
4.1.4.5-36 Cyclone Dipleg Differential Pressure Profiles 4.1.4.5-17
4.1.4.5-37 Coal Feed Rate Based on Gas Analysis 4.1.4.5-17
4.1.4.5-38 O_2, SO_2, and NO_X Analyzers 4.1.4.5-18
4.1.4.5-39 FD0520 Pressure Profiles 4.1.4.5-18
4.1.4.5-40 PCD Temperatures 4.1.4.5-18
4.1.4.5-41 PCD Temperatures 4.1.4.5-19
4.1.4.5-42 PCD Differential Pressure Profile 4.1.4.5-19
4.1.4.5-43 PCD Pressure and Pulse Pressure 4.1.4.5-19
4.1.4.5-44 Gas Flow Through PCD 4.1.4.5-19

4.1.4.6-1 CO0201 System Profile 4.1.4.6-5
4.1.4.6-2 Coal Feed System Profile 4.1.4.6-5
4.1.4.6-3 Start-Up Burner Flow/Temperature 4.1.4.6-5
4.1.4.6-4 Total Gas In/Out Flow Rates 4.1.4.6-6
4.1.4.6-5 Reactor Mixing Zone and Riser Temperature 4.1.4.6-6

4.1.4.6-6 Standpipe Temperatures 4.1.4.6-6
4.1.4.6-7 Cyclone Dipleg Temperatures 4.1.4.6-7
4.1.4.6-8 Temperature Profile Downstream of Reactor 4.1.4.6-7
4.1.4.6-9 System Temperatures Downstream of PCD 4.1.4.6-7
4.1.4.6-10 Mixing Zone Differential Pressure Profile 4.1.4.6-8
4.1.4.6-11 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.6-8
4.1.4.6-12 Standpipe Differential Pressure Profiles 4.1.4.6-8
4.1.4.6-13 Coal Feed Rate Based on Gas Analysis 4.1.4.6-9
4.1.4.6-14 O_2, SO_2, and NO_x Analyzers 4.1.4.6-9
4.1.4.6-15 FD0520 Pressure Profiles 4.1.4.6-9
4.1.4.6-16 PCD Temperatures 4.1.4.6-10
4.1.4.6-17 PCD Differential Pressure Profile 4.1.4.6-10
4.1.4.6-18 PCD Pressure and Pulse Pressure 4.1.4.6-10
4.1.4.6-19 Gas Flow Through PCD 4.1.4.6-11
4.1.4.6-20 CO0201 System Profile 4.1.4.6-13
4.1.4.6-21 Coal Feed System Profile 4.1.4.6-13
4.1.4.6-22 Start-Up Burner Flow/Temperature 4.1.4.6-13
4.1.4.6-23 Total Gas In/Out Flow Rates 4.1.4.6-14
4.1.4.6-24 Reactor Mixing Zone and Riser Temperature 4.1.4.6-14
4.1.4.6-25 Standpipe Temperatures 4.1.4.6-14
4.1.4.6-26 Cyclone Dipleg Temperatures 4.1.4.6-15
4.1.4.6-27 Temperature Profile Downstream of Reactor 4.1.4.6-15
4.1.4.6-28 System Temperatures Downstream of PCD 4.1.4.6-15
4.1.4.6-29 Mixing Zone Differential Pressure Profile 4.1.4.6-16
4.1.4.6-30 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.6-16
4.1.4.6-31 Standpipe Differential Pressure Profiles 4.1.4.6-16
4.1.4.6-32 Coal Feed Rate Based on Gas Analysis 4.1.4.6-17
4.1.4.6-33 O_2, SO_2, and NO_x Analyzers 4.1.4.6-17
4.1.4.6-34 FD0520 Pressure Profiles 4.1.4.6-17
4.1.4.6-35 PCD Temperatures 4.1.4.6-18
4.1.4.6-36 PCD Differential Pressure Profile 4.1.4.6-18
4.1.4.6-37 PCD Pressure and Pulse Pressure 4.1.4.6-18
4.1.4.6-38 Gas Flow Through PCD 4.1.4.6-19

4.1.4.7-1 CO0201 System Profile 4.1.4.7-7
4.1.4.7-2 Coal Feed System Profile 4.1.4.7-7
4.1.4.7-3 Sorbent Feed System Profile 4.1.4.7-7
4.1.4.7-4 Start-Up Burner Flow/Temperature 4.1.4.7-8
4.1.4.7-5 Total Gas In/Out Flow Rates 4.1.4.7-8
4.1.4.7-6 Reactor Mixing Zone and Riser Temperature 4.1.4.7-8
4.1.4.7-7 Standpipe Temperatures 4.1.4.7-9
4.1.4.7-8 Cyclone Dipleg Temperatures 4.1.4.7-9
4.1.4.7-9 Temperature Profile Downstream of Reactor 4.1.4.7-9
4.1.4.7-10 System Temperatures Downstream of PCD 4.1.4.7-10
4.1.4.7-11 Mixing Zone Differential Pressure Profile 4.1.4.7-10
4.1.4.7-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.7-10
4.1.4.7-13 Standpipe Differential Pressure Profiles 4.1.4.7-11

4.1.4.7-14 CY0201 Dipleg Differential Pressure Profiles 4.1.4.7-11
4.1.4.7-15 Coal Feed Rate Based on Gas Analysis 4.1.4.7-11
4.1.4.7-16 O_2, SO_2, and NO_x Analyzers 4.1.4.7-12
4.1.4.7-17 FD0520 Pressure Profiles 4.1.4.7-12
4.1.4.7-18 PCD Temperatures 4.1.4.7-12
4.1.4.7-19 PCD Differential Pressure Profile 4.1.4.7-13
4.1.4.7-20 PCD Pressure and Pulse Pressure 4.1.4.7-13
4.1.4.7-21 Gas Flow Through PCD 4.1.4.7-13
4.1.4.7-22 CO0201 System Profile 4.1.4.7-15
4.1.4.7-23 Coal Feed System Profile 4.1.4.7-15
4.1.4.7-24 Sorbent Feed System Profile 4.1.4.7-15
4.1.4.7-25 Start-Up Burner Flow/Temperature 4.1.4.7-16
4.1.4.7-26 Total Gas In/Out Flow Rates 4.1.4.7-16
4.1.4.7-27 Reactor Mixing Zone and Riser Temperature 4.1.4.7-16
4.1.4.7-28 Standpipe Temperatures 4.1.4.7-17
4.1.4.7-29 Cyclone Dipleg Temperatures 4.1.4.7-17
4.1.4.7-30 Temperature Profile Downstream of Reactor 4.1.4.7-17
4.1.4.7-31 System Temperatures Downstream of PCD 4.1.4.7-18
4.1.4.7-32 Mixing Zone Differential Pressure Profile 4.1.4.7-18
4.1.4.7-33 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.7-18
4.1.4.7-34 Standpipe Differential Pressure Profiles 4.1.4.7-19
4.1.4.7-35 CY0201 Dipleg Differential Pressure Profiles 4.1.4.7-19
4.1.4.7-36 Coal Feed Rate Based on Gas Analysis 4.1.4.7-19
4.1.4.7-37 O_2, SO_2, and NO_x Analyzers 4.1.4.7-20
4.1.4.7-38 FD0520 Pressure Profiles 4.1.4.7-20
4.1.4.7-39 PCD Temperatures 4.1.4.7-20
4.1.4.7-40 PCD Differential Pressure Profile 4.1.4.7-21
4.1.4.7-41 PCD Pressure and Pulse Pressure 4.1.4.7-21
4.1.4.7-42 Gas Flow Through PCD 4.1.4.7-21

4.1.4.8-1 CO0201 System Profile 4.1.4.8-5
4.1.4.8-2 Coal Feed System Profile 4.1.4.8-5
4.1.4.8-3 Start-Up Burner Flow/Temperature 4.1.4.8-5
4.1.4.8-4 Total Gas In/Out Flow Rates 4.1.4.8-6
4.1.4.8-5 Reactor Mixing Zone and Riser Temperature 4.1.4.8-6
4.1.4.8-6 Standpipe Temperatures 4.1.4.8-6
4.1.4.8-7 Cyclone Dipleg Temperatures 4.1.4.8-7
4.1.4.8-8 Temperature Profile Downstream of Reactor 4.1.4.8-7
4.1.4.8-9 System Temperatures Downstream of PCD 4.1.4.8-7
4.1.4.8-10 Mixing Zone Differential Pressure Profile 4.1.4.8-8
4.1.4.8-11 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.8-8
4.1.4.8-12 Standpipe Differential Pressure Profiles 4.1.4.8-8
4.1.4.8-13 CY0201 Dipleg Differential Pressure Profiles 4.1.4.8-9
4.1.4.8-14 Coal Feed Rate Based on Gas Analysis 4.1.4.8-9
4.1.4.8-15 FD0520 Pressure Profiles 4.1.4.8-9
4.1.4.8-16 FD0530 Feeder Profile 4.1.4.8-10
4.1.4.8-17 Thermal Oxidizer Air/Fuel Flow 4.1.4.8-10

4.1.4.8-18 PCD Temperatures 4.1.4.8-10
4.1.4.8-19 PCD Differential Pressure Profile 4.1.4.8-11
4.1.4.8-20 PCD Pressure and Pulse Pressure 4.1.4.8-11
4.1.4.8-21 Gas Flow Through PCD 4.1.4.8-11
4.1.4.8-22 CO0201 System Profile 4.1.4.8-13
4.1.4.8-23 Coal Feed System Profile 4.1.4.8-13
4.1.4.8-24 Start-Up Burner Flow/Temperature 4.1.4.8-13
4.1.4.8-25 Total Gas In/Out Flow Rates 4.1.4.8-14
4.1.4.8-26 Reactor Mixing Zone and Riser Temperature 4.1.4.8-14
4.1.4.8-27 Standpipe Temperatures 4.1.4.8-14
4.1.4.8-28 Cyclone Dipleg Temperatures 4.1.4.8-15
4.1.4.8-29 Temperature Profile Downstream of Reactor 4.1.4.8-15
4.1.4.8-30 System Temperatures Downstream of PCD 4.1.4.8-15
4.1.4.8-31 Mixing Zone Differential Pressure Profile 4.1.4.8-16
4.1.4.8-32 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.8-16
4.1.4.8-33 Standpipe Differential Pressure Profiles 4.1.4.8-16
4.1.4.8-34 CY0201 Dipleg Differential Pressure Profiles 4.1.4.8-17
4.1.4.8-35 Coal Feed Rate Based on Gas Analysis 4.1.4.8-17
4.1.4.8-36 FD0520 Pressure Profiles 4.1.4.8-17
4.1.4.8-37 FD0530 Feeder Profile 4.1.4.8-18
4.1.4.8-38 Thermal Oxidizer Air/Fuel Flow 4.1.4.8-18
4.1.4.8-39 PCD Temperatures 4.1.4.8-18
4.1.4.8-40 PCD Differential Pressure Profile 4.1.4.8-19
4.1.4.8-41 PCD Pressure and Pulse Pressure 4.1.4.8-19
4.1.4.8-42 Gas Flow Through PCD 4.1.4.8-19

4.1.4.9-1 CO0201 System Profile 4.1.4.9-7
4.1.4.9-2 Coal Feed System Profile 4.1.4.9-7
4.1.4.9-3 Sorbent Feed System Profile 4.1.4.9-7
4.1.4.9-4 Start-Up Burner Flow/Temperature 4.1.4.9-8
4.1.4.9-5 Total Gas In/Out Flow Rates 4.1.4.9-8
4.1.4.9-6 Reactor Mixing Zone and Riser Temperature 4.1.4.9-8
4.1.4.9-7 Standpipe Temperatures 4.1.4.9-9
4.1.4.9-8 Cyclone Dipleg Temperatures 4.1.4.9-9
4.1.4.9-9 Temperature Profile Downstream of Reactor 4.1.4.9-9
4.1.4.9-10 System Temperatures Downstream of PCD 4.1.4.9-10
4.1.4.9-11 Mixing Zone Differential Pressure Profile 4.1.4.9-10
4.1.4.9-12 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.9-10
4.1.4.9-13 Standpipe Differential Pressure Profiles 4.1.4.9-11
4.1.4.9-14 Cyclone Dipleg Differential Pressure Profiles 4.1.4.9-11
4.1.4.9-15 Coal Feed Rate Based on Gas Analysis 4.1.4.9-11
4.1.4.9-16 FD0206 Profiles 4.1.4.9-12
4.1.4.9-17 FD0520 Pressure Profiles 4.1.4.9-12
4.1.4.9-18 FD0530 Feeder Profile 4.1.4.9-12
4.1.4.9-19 PCD Temperatures 4.1.4.9-13
4.1.4.9-20 PCD Differential Pressure Profile 4.1.4.9-13
4.1.4.9-21 PCD Pressure and Pulse Pressure 4.1.4.9-13

4.1.4.9-22 Gas Flow Through PCD 4.1.4.9-14
4.1.4.9-23 CO0201 System Profile 4.1.4.9-15
4.1.4.9-24 Coal Feed System Profile 4.1.4.9-15
4.1.4.9-25 Sorbent Feed System Profile 4.1.4.9-15
4.1.4.9-26 Start-Up Burner Flow/Temperature 4.1.4.9-16
4.1.4.9-27 Total Gas In/Out Flow Rates 4.1.4.9-16
4.1.4.9-28 Reactor Mixing Zone and Riser Temperature 4.1.4.9-16
4.1.4.9-29 Standpipe Temperatures 4.1.4.9-17
4.1.4.9-30 Cyclone Dipleg Temperatures 4.1.4.9-17
4.1.4.9-31 Temperature Profile Downstream of Reactor 4.1.4.9-17
4.1.4.9-32 System Temperatures Downstream of PCD 4.1.4.9-18
4.1.4.9-33 Mixing Zone Differential Pressure Profile 4.1.4.9-18
4.1.4.9-34 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.9-18
4.1.4.9-35 Standpipe Differential Pressure Profiles 4.1.4.9-19
4.1.4.9-36 Cyclone Dipleg Differential Pressure Profiles 4.1.4.9-19
4.1.4.9-37 Coal Feed Rate Based on Gas Analysis 4.1.4.9-19
4.1.4.9-38 PCD Temperatures 4.1.4.9-20
4.1.4.9-39 PCD Differential Pressure Profile 4.1.4.9-20
4.1.4.9-40 PCD Pressure and Pulse Pressure 4.1.4.9-20
4.1.4.9-41 Gas Flow Through PCD 4.1.4.9-21
4.1.4.9-42 No Figure Assigned ..... N/A
4.1.4.9-43 No Figure Assigned ..... N/A
4.1.4.9-44 No Figure Assigned ..... N/A
4.1.4.9-45 CO0201 System Profile 4.1.4.9-23
4.1.4.9-46 Coal Feed System Profile 4.1.4.9-23
4.1.4.9-47 Sorbent Feed System Profile 4.1.4.9-23
4.1.4.9-48 Start-Up Burner Flow/Temperature 4.1.4.9-24
4.1.4.9-49 Total Gas In/Out Flow Rates 4.1.4.9-24
4.1.4.9-50 Reactor Mixing Zone and Riser Temperature 4.1.4.9-24
4.1.4.9-51 Standpipe Temperatures 4.1.4.9-25
4.1.4.9-52 Cyclone Dipleg Temperatures 4.1.4.9-25
4.1.4.9-53 Temperature Profile Downstream of Reactor 4.1.4.9-25
4.1.4.9-54 System Temperatures Downstream of PCD 4.1.4.9-26
4.1.4.9-55 Mixing Zone Differential Pressure Profile 4.1.4.9-26
4.1.4.9-56 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.9-26
4.1.4.9-57 Standpipe Differential Pressure Profiles 4.1.4.9-27
4.1.4.9-58 Cyclone Dipleg Differential Pressure Profiles 4.1.4.9-27
4.1.4.9-59 Coal Feed Rate Based on Gas Analysis 4.1.4.9-27
4.1.4.9-60 FD0206 Profiles 4.1.4.9-28
4.1.4.9-61 FD0520 Pressure Profiles 4.1.4.9-28
4.1.4.9-62 FD0530 Feeder Profile 4.1.4.9-28
4.1.4.9-63 PCD Temperatures 4.1.4.9-29
4.1.4.9-64 PCD Differential Pressure Profile 4.1.4.9-29
4.1.4.9-65 PCD Pressure and Pulse Pressure 4.1.4.9-29
4.1.4.9-66 Gas Flow Through PCD 4.1.4.9-30
4.1.4.9-67 CO0201 System Profile 4.1.4.9-31
4.1.4.9-68 Coal Feed System Profile 4.1.4.9-31

4.1.4.9-69 Sorbent Feed System Profile 4.1.4.9-31
4.1.4.9-70 Start-Up Burner Flow/Temperature 4.1.4.9-32
4.1.4.9-71 Total Gas In/Out Flow Rates 4.1.4.9-32
4.1.4.9-72 Reactor Mixing Zone and Riser Temperature 4.1.4.9-32
4.1.4.9-73 Standpipe Temperatures 4.1.4.9-33
4.1.4.9-74 Cyclone Dipleg Temperatures 4.1.4.9-33
4.1.4.9-75 Temperature Profile Downstream of Reactor 4.1.4.9-33
4.1.4.9-76 System Temperatures Downstream of PCD 4.1.4.9-34
4.1.4.9-77 Mixing Zone Differential Pressure Profile 4.1.4.9-34
4.1.4.9-78 Reactor Pressure/Riser Differential Pressure Profiles 4.1.4.9-34
4.1.4.9-79 Standpipe Differential Pressure Profiles 4.1.4.9-35
4.1.4.9-80 Cyclone Dipleg Differential Pressure Profiles 4.1.4.9-35
4.1.4.9-81 Coal Feed Rate Based on Gas Analysis 4.1.4.9-35
4.1.4.9-82 FD0206 Profiles 4.1.4.9-36
4.1.4.9-83 FD0520 Pressure Profiles 4.1.4.9-36
4.1.4.9-84 FD0530 Feeder Profile 4.1.4.9-36
4.1.4.9-85 PCD Temperatures 4.1.4.9-37
4.1.4.9-86 PCD Differential Pressure Profile 4.1.4.9-37
4.1.4.9-87 PCD Pressure and Pulse Pressure 4.1.4.9-37
4.1.4.9-88 Gas Flow Through PCD 4.1.4.9-38

4.2.2-1 Change in Disengager Efficiency and Circulation Rate Over Several Days 4.2.2.-2
4.2.2-2 Effect of Density on Disengager Efficiency 4.2.2.-2
4.2.2-3 Effect of Inlet Velocity on Disengager Efficiency (October 10, 1997, During TC01E and October 20, 1997, During TC01F 4.2.2.-3
4.2.2-4 Effect of Circulation Rate on Disengager Efficiency (October 10, 1997, During TC01E, and October 20, 1997, During TC01F 4.2.2-3

4.2.3-1 Cyclone Emissions – Pressure Drop (Cyclone Pressure Drop, inH_2O 4.2.3-5
4.2.3-2 Cyclone Pressure – Flow (Cyclone Inlet Velocity, FPS) 4.2.3-5
4.2.3-3 Cyclone Pressure – Inlet Loading 4.2.3-6
4.2.3-4 Cyclone Efficiency – Inlet Loading (Slip Velocity = 2) Cyclone Inlet Loading Wt%) 4.2.3-6
4.2.3-5 TC01 Cyclone Efficiency – Inlet Loading (Slip Velocity = 2 (Cyclone Inlet Loading, Wt%) 4.2.3-7
4.2.3-6 Cyclone Efficiency – Pressure Drop (slip Velocity = 2) (Cyclone Pressure Drop, inH_2O 4.2.3-7
4.2.3-7 TC01 Cyclone Efficiency – Pressure Drop (Slip Velocity = 2) (Cyclone Pressure Drop, inH_2O 4.2.3-8
4.2.3-8 Cyclone Efficiency – Inlet Loading (Slip Velocity = 2) (Cyclone Inlet Velocity, FPS) 4.2.3-8
4.2.3-9 TC01 Cyclone Efficiency – Inlet Velocity (Slip Velocity = 2) (Cyclone Inlet Velocity, FPS) 4.2.3-9
4.2.3-10 S = 2 Vs KS Circulation Rates 4.2.3-9
4.2.3-11 S = 2 Vs KS Solids Loading (Slip = 2) (Solids Loading, Wt%) 4.2.3-10

4.2.4-1 CCT4 SO_2 Concentrations 4.2.4-2
4.2.4-2 CCT4D PCD Solids Analysis, SO_2 Removal 4.2.4-3
4.2.4-3 Effect of Dolomite Addition on SO_2 Concentrations 4.2.4-3

4.2.5-1 Standpipe and PCD Inerts 4.2.5-10
4.2.5-2 Standpipe and PCD Feed Sand% 4.2.5-10
4.2.5-3 Standpipe and PCD Ca/S Ratio 4.2.5-11
4.2.5-4 CCT5A PCD Solids Feeds 4.2.5-11
4.2.5-5 TC01B Solids Analysis 4.2.5-12
4.2.5-6 TC01G PCD Solids Analysis 4.2.5-12
4.2.5-7 TC01G PCD Solids Analysis 4.2.5-13
4.2.5-8 TC01H Ca/S Ratios 4.2.5-13
4.2.5-9 TC01I PCD Solids 4.2.5-14
4.2.5-10 TC01I Standpipe Slids 4.2.5-14
4.2.5-11 TC01I SP Solids 4.2.5-15
4.2.5-12 TC01I SP Solids Analysis 4.2.5-15
4.2.5-13 TC01I Solids Analysis 4.2.5-16
4.2.5-14 TC01I Solids Analysis 4.2.5-16

4.2.6-1 CCT5B NO_X Emissions 5.2.6-3
4.2.6-2 TC01 NO_X Emissions 4.2.6-3
4.2.6-3 1997 NO_X Emissions and Staged Air 4.2.6-4
4.2.6-4 1997 NO_X Emissions and O_2 ..... 4.2.6-4
4.2.6-5 1997 NO_X Emissions and Riser Temperature 4.2.6-5

4.2.7-1 Effect on Overall Circulation Rate by Changing Heat Exchanger J-leg Aeration 4.2.7-4
4.2.7-2 Change in Circulation Rate With Increasing Standpipe Solids Level 4.2.7-4
4.2.7-3 Change in Circulation Rate With Increasing Standpipe Solids Level 4.2.7-5
4.2.7-4 Relationship Between the Standpipe and Heat Exchanger Solids Level 4.2.7-5
4.2.7-5 Change in Circulation Rate With Increasing Heat Exchanger Solids Level 4.2.7-6
4.2.7-6 Lack of Change in the Circulation Rate as Solids level Increases In Upper HX 4.2.7-6
4.2.7-7 Circulation Rate Fails to Increase Once PD1389 Reaches Certain Value 4.2.7-7
4.2.7-8 Overall Circulation Rate and Heat Exchanger Circulation Rate 4.2.7-7
4.2.7-9 Overall Circulation Rate and Heat Exchanger Circulation Rate 4.2.7-8
4.2.7-10 Effect of Overall Circulation Rate on Heat Exchanger J-leg Temperature (T1378 at Top of J-leg, T1379 at Bottom of J-leg) 4.2.7-8

4.2.8-1 Typical Pressure Profile in Transport Reactor From 12:00 on October 23, 1997, in TC01F 4.2.8-2
4.2.8-2 Effect of Circulation Rate on Pressure Drop in Areas of Transport Reactor With High Voidages From October 12, 1997, During TC01E 4.2.8-2
4.2.8-3 Effect of Circulation Rate on Pressure Drop in Areas of Transport Reactor Filled With Solids From October 14, 1997, During TC01E 4.2.8-3

4.2.8-4 Change in Pressure Drop in Dense-Phase Areas as Ash and Dolomite Replace Sand as the Bed Material From the Start of TC01D on October 2, 1997 ....4.2.8-3

4.2.9-1 Temperature Profile of the Reactor Mixing Zone 4.2.9-3
4.2.9-2 Temperature Profile of the Riser 4.2.9-4
4.2.9-3 Temperature Profile of the Standpipe....4.2.9-4
4.2.9-4 Highest and Lowest Temperatures in the Riser....4.2.9-5
4.2.9-5 Highest and Lowest Temperature in the Dipleg 4.2.9-5
4.2.9-6 Temperature in the Heat Exchanger J-leg and the Mixing Zone 4.2.9-6
4.2.9-7 Estimated and Actual Reactor J-leg Temperatures at Top of J-leg 4.2.9-6

4.2.10-1 Differential Thermal Profile 4.2.10-4
4.2.10-2 Average Skin Temperature in Reactor Loop 4.2.10-5
4.2.10-3A Dipleg Skin Temperature Profiles (December 4 to 6, 1997) 4.2.10-6
4.2.10-3B Dipleg Skin Temperature Profile (December 4 to 6, 1997).... 4.2.10-6

4.2.11-1 CCT4D Coal Feed Rate (lb/hr) Via Silo Refill Vs Time (Date: May 4, 1997).... 4.2.11-2
4.2.11-2 CCT5A and CCT5B Coal Feed Rate (lb/hr) Vs Time.... 4.2.11-2
4.2.11-3 CCT6A Coal Feed Rates (lb/hr) and FD0220 Feeder Speed (RPM) Vs Time.... 4.2.11-3
4.2.11-4 CCT6a Lock Hopper Refill Weight Vs Time 4.2.11-3
4.2.11-5 TC01 Coal Feed Rates (lb/hr) and FD0210 Feeder Speed (RPM) Vs Times.... 4.2.11-4
4.2.11-6 TC01 FD0210 Lock Hopper Refill Weight Vs Time 4.2.11-4
4.2.11-7 TC01 Coal Feed Rate (lb/hr) Vs FD020 Feeder Speed (RPM)

4.3.1-1 Typical Example of High-Solids Carryover Rate When the Dipleg DP Stays in Negative Values (April 22, 1997)....4.3.1-5
4.3.1-2 Example of Coal Feeder Failure-Induced Dipleg Upset (May 20, 1997) 4.3.1-5
4.3.1-3 Example of PCD Back Pulse–Induced Dipleg Upset in CCT5A (May 19, 1997) 4.3.1-6
4.3.1-4 Example of Dipleg Upset Due to Changes of Bed Materials (June 26, 1997)...4.3.1-6
4.3.1-5 Example of Dipleg Upset Due to Change in Solids Circulation Rate (June 21, 1997)....4.3.1-7
4.3.1-6 Example of Solids Circulation Rate – Time Period of Dipleg Upset May 17, 1997 ....4.3.1-7

4.3.2-1 Illustration of Drift-Flux Plot.... 4.3.2-17
4.3.2-2 Illustration of the Experimental Drift-Flux Plot 4.3.2-17
4.3.2-3 Plot of Flooding Lines at Different Void Fractions 4.3.2-18
4.3.2-4 Wave Lines for Different Initial Time and Locations 4.3.2-18

4.3.3-1 Example of Stable Operation of Dipleg....4.3.3-3
4.3.3-2 Variation of the Bulk Density With Height in the Dipleg to Show Density is Decreasing Along the Flow Direction Measured by Gamma Transmission Scans....4.3.3-3

5.1.2-1 Mean Coal Particle Size Before Process Change.... 51.2-3
5.1.2-2 Mean Coal Particle Size After Process Change 5.1.2-3

1.0 EXECUTIVE SUMMARY

1.1 OPERATION STATUS

This report discusses the 1997 operation of the transport reactor train with a Westinghouse particle filter system at the Power Systems Development Facility (PSDF) located in Wilsonville, Alabama. The transport reactor is an advanced circulating fluidized bed reactor designed to operate as either a combustor or a gasifier using one of two possible hot gas clean-up filter technologies (particulate control device technology or PCDs). The transport reactor was operated as a pressurized combustor during all the test runs in 1997.

The objectives of the PSDF are to:

1. Develop advanced coal-fired power generation technologies through testing and evaluation of hot gas clean-up systems and other major components at the pilot scale.

2. Assess and demonstrate the performance of the components in an integrated mode of operation.

The primary focus of the PSDF project is to demonstrate and evaluate high-temperature PCDs that are the single most important component required for successful development of advanced power generation systems. High-temperature PCDs are a common component of advanced gasification and advanced pressurized fluidized-bed combustion (APFBC) technologies, both of which will be evaluated at the facility. The facility is sized to test the components at capacities that are readily scaleable to commercial systems.

Commissioning activities began in September 1995 and proceeded in parallel with construction activities. Construction of the transport reactor and associated equipment was completed in early summer of 1996. By midsummer all separate components and subsystems were fully operational and commissioning work was focused on integration issues for the entire transport reactor train. The first coal fire was achieved on August 18, 1996. A series of characterization tests was initiated to develop an understanding of reactor system operations.

Test runs CCT1, CCT2, and CCT3 were completed by December 1996. During these test runs it was found that there were excessive solids carryover from the reactor to the PCD. A number of start-up and design problems associated with various equipment were successfully addressed.

During 1997 three additional sets of characterization test runs, CCT4, CCT5, and CCT6, and one major test campaign, TC01, were undertaken. Figure 1.1.1-1 gives a summary of the test runs in 1997 and figure 1.1.1-2 shows the coal feed and circulation hours for the 1997 test runs. The major accomplishments in 1997 include:

1. Operating the Westinghouse PCD for over 1,200 hours on coal in combustion without ash bridging at PCD inlet temperatures between 1,350 and 1,400°F.

2. Demonstrating stable reactor operations by successfully addressing the excessive solids carryover problem.

3. Achieving over 1,980 hours on coal and approximately 2,600 hours of solids circulation in 1997.

4. Achieving nearly 100 percent on-line availability during the last 12 days of test run TC01.

The on-line availability (based on coal) for the entire TC01 test run was about 54 percent. The major bottleneck for sustained high on-line availability is the unreliability of the coal feed system.

1.1.1 Transport Reactor

The major goals of CCT4 and CCT5 were to:

1. Establish the underlying causes and develop solutions for the high solids carryover rate from the transport reactor to the PCD.

2. Increase the coal feed and solid circulation rates.

3. Explore the influence of staged air on reactor operations and NO_X emissions.

The high solids carryover rate was suspected to result from the solids improperly draining from the cyclone dipleg. Solids flowability in the cyclone dipleg was substantially improved through the addition of aeration to the cyclone dipleg and feeding a certain amount of finer-size particles to the reactor. The result is significant in that with the substantial reduction in solid carryover rate, the solid inventory in the reactor gradually increased. With the increase in the reactor inventory and the solid carryover rate under control, the solid circulation rate from the combustion heat exchanger was increased. The coal feed rate was also increased. Both the coal feed rate and the solid circulation rate achieved in the CCT5B test run were above the expected values for the corresponding reactor operating pressure.

The primary purpose of CCT6 test run was to better understand the operability of the cyclone dipleg. To achieve this test goal, various operating conditions were tested. The results show that the dipleg can be operated at stable conditions with proper setting of the aeration rate for a certain bed material regardless of the solids level in the standpipe. The dipleg operation was found to be quite sensitive to the variation of the particle size and dipleg aeration. Changing the particle size without adjusting the dipleg aeration flow rate can cause upsets in the dipleg operation. Also, most of the dipleg upsets occurred when the solids circulation rate and the dipleg level were high.

The major objective of TC01 was to expose the candles at a temperature of 1,350°F for at least 1,000 hours. This goal was achieved in December 1997. Approximately 90 percent of the outage time during the early part of this run was due to problems with the seal mechanism in the filter fines transport system. After the seal material was changed and the seal pressure was

lowered, there were no additional outages caused by this system. The remaining outages were primarily due to the coal feeder system. Modifications to equipment, logic, and operating procedures significantly improved the reliability of the coal feed system. By addressing these problems the unit availability on coal reached 54 percent. Other notable achievements during this test run include the highest coal feed rate (~1,500 lb/hr) and highest operating pressure (215 psig) to date for the unit. Also, the longest continuous run on coal feed was completed at 289 hours. Additional accomplishments are detailed in section 1.2.1.

Data collected in 1997 was analyzed to evaluate different areas of reactor operation and performance. Some of the major observations are described below. The disengager efficiency increases with increasing solid density and decreases with increasing inlet velocity. The efficiency also shows a slight increase with increasing solids loading, but the sensitivity to circulation rate is low. Particulate loading to the PCD was found to be higher during periods that included a PCD backpulse due to the instability sometimes created in reactor operations. When dolomite was added the SO_2 analyzer did not have a detectable reading, which indicated a high sulfur capture. The NO_X emissions were low, but the expected NO_X emission trends were not seen due to insufficient variability in the operating parameters that affect the NO_X emissions.

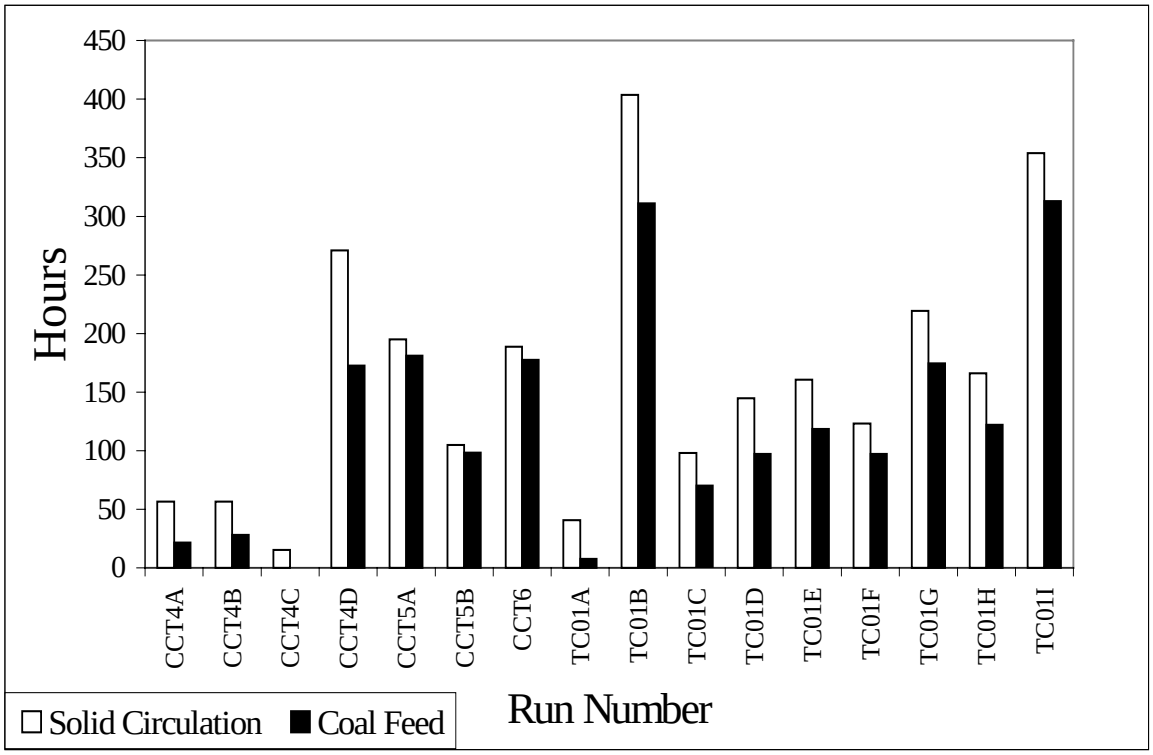


Figure 1.1.1-1 Transport Reactor Test Run Summary for 1997

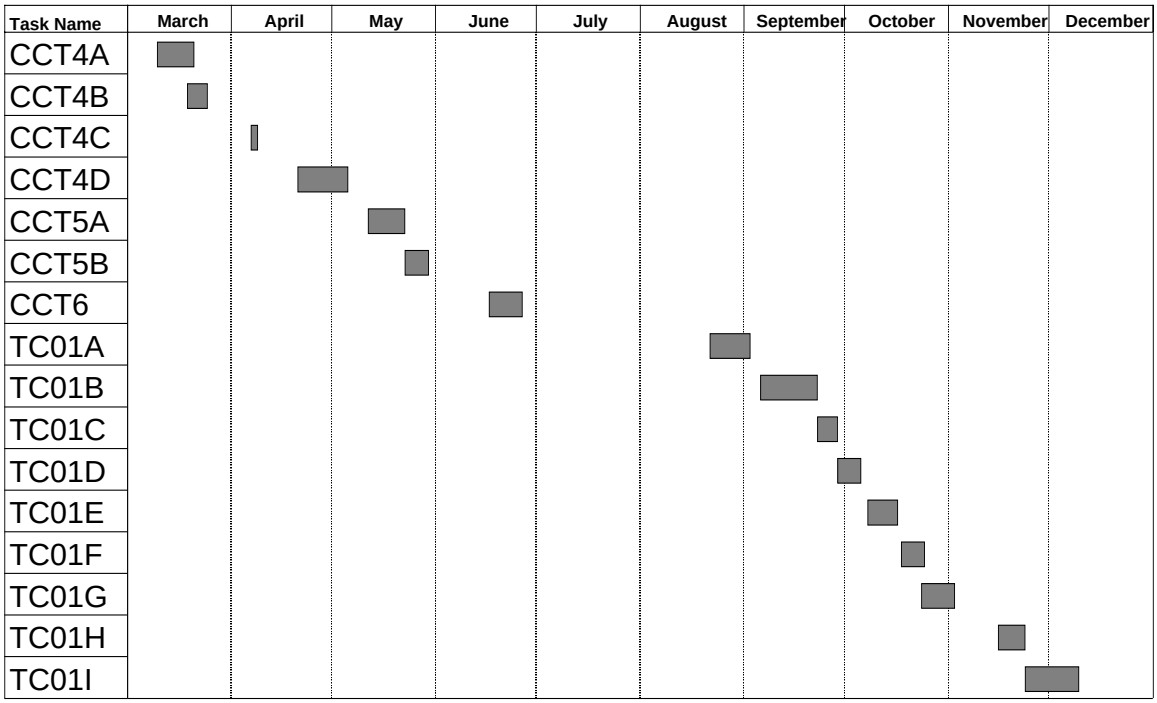


Figure 1.1.1-2 Coal Feed and Circulation Hours for the 1997 Test Runs

1.1.2 Westinghouse PCD

In 1996, the Westinghouse PCD was operated on coal for slightly over 200 hours. On its initial operation on coal the filter was filled with ash, which lead to the failure of nearly all of the filter elements. In the runs to follow, through the remainder of 1996, a significant problem was diagnosed with the operation of the M.W. Kellogg (MWK) primary cyclone. The particle size of the material entering the filter system was essentially the same as the material being fed to the transport reactor. Additionally, the loading varied and ranged from 4,000 to 100,000 ppm (design range was 4,000 to 16,000 ppm).

During 1997, operation greatly improved as was evidenced by logging over 1,900 hours on coal. Southern Research Institute (SRI) outlet particulate collection system came on-line and it was realized that the Westinghouse filter system is capable of greater than 99.99 percent collection efficiency with outlet loadings below 1 ppm. Monitoring ash level in the filter system became routine and the responsibility for day-to-day operation of the PCD during testing was turned over to the operations staff. Several times during the year rising ash levels became an issue for concern, but at no time did they cause damage to the filter elements. Through the work of the transport reactor staff, particulate size and loading became very consistent and well within design values.

However, 1997 did not pass without problems. Early in the year, on April 7, a combustion inside the PCD caused failure of all the filter elements. Also, in the same time span it was realized that the pulse valves had an unusual flow characteristic: they decreased flow with increasing differential pressure. This was caused by a design flaw in the valves which has been corrected and will be verified early in 1998. Similar valves at the Pinon Pines project have also been modified.

One of the biggest, and unexpected, problems to date has been with the performance of the Coors P100A filter elements. Coors P100A elements began failing in September, and a thermal excursion of the entire process due to a pluggage in the coal feeder lead to a complete failure of the Coors P100A elements in November. With only one exception, the Coors P100A failures have been associated with some type of thermal transient that can be blamed on operations: twice while transitioning from the start-up burner to coal and the thermal transient in November. However, what is significant is that no monolithic SiC filter elements that had been through the exact same conditions failed during operation. The root cause of the Coors P100A filters is still under investigation.

1.1.3 Balance-of-Plant and Other Auxiliaries

The Auxiliaries and Balance-of-Plant section of this report briefly discusses equipment operation outside that of the transport reactor and PCD. There were a number of operational issues associated with these pieces of equipment that were addressed during 1997 to improve reliability. There were significant modifications made to the pulverizers to provide a consistent grind size. Control enhancements were implemented on the process air compressor to address tuning problems and cope with variations in operations. There were some chlorine- and fluorine-related corrosion issues in the process gas sampling and draw-off lines which are being addressed. The reactor start-up burner performed much better with changes that were made to the pilot and flame detection system. The process pressure letdown valve experienced high frequency plug stem vibrations due to flow induced resonance. After several unsuccessful on-line measures, the trim was changed to correct the problem. There were a number of challenges in feeding fuel to and removing ash from high-pressure vessels with the solids-handling system chosen to explore operability for the train.

Other issues are:

- Corrective actions taken on the transport air and recycle gas systems.
- The status of the process gas analysis system and sulfator.
- Evolution of the steam generation package.
- Operational findings of the baghouse and propane supply system.
- Experiences with the instrument air, station service, and myriad water systems.

In most cases, a brief description of any shortfall is included in this report, as well as a similar description of resulting work performed. While there is no explicit analysis of various equipment design or operation, much can be inferred as to the impact each component or system had on the successful operation of the M. W. Kellogg (MWK) transport reactor train.

1.2 PSDF ACCOMPLISHMENTS

1. The transport reactor was successfully commissioned and operated in combustion mode and achieved over 2,200 hours of operation on coal and over 3,500 hours of solids circulation between August 1996 and December 1997.

2. The Westinghouse PCD operated over 1,350 hours on coal in combustion without ash bridging at PCD inlet temperatures of over 1,350˚F and up to 1,400˚F.

1.2.1 Transport Reactor Train

1. A turndown ratio of 4 to 1 was achieved.

2. Successful cyclone dipleg operating concepts were developed, backed by theoretical understanding.

3. High carbon conversions were achieved in combustion (99.95 percent) at low operating temperatures.

4. A viable mechanical design of reactor configuration was developed with no expansion joints.

5. A high solid circulation rate (100 to 1, solid to coal) was established.

6. High carbon conversion and high sulfur capture in the first pass were promoted with highly effective gas-solid contacting (in combustion). Expectations in gasification are similar.

7. Little refractory eroded in riser crossover and no erosion occurred at other places with more than 3,500 hours of solid circulation. Operation was often at high velocities that were detrimental to refractory. Good expanding cap design on riser top minimized the crossover refractory erosion.

8. The external combustion heat exchanger design concept is feasible and attractive.

9. The link between the PCD backpulse and transport reactor is manageable during current operation (without a downstream combustion turbine).

10. The disengager cyclone design facilitates the feeding of a larger particle size to the PCD, which improves its operation.

11. First-of-a-kind process flow sheet, piping and instrumentation diagrams (P&IDs); equipment designs; detailed mechanical, civil, electrical, and control engineering designs; operations and control philosophy; and operating procedures are complete, proven, and ready to be used as the basis for the next generation/scaleup of transport reactor in combustion.

12. Various problems with the coal feed and ash removal systems were addressed. About 90 percent of outages were caused by these systems.

13. With the experience gained, significant improvements were identified that can be incorporated in the development of bid specification packets for commercial equipment (e.g., coal-feed and ash-removal systems, reactor start-up burner, the disengager, and the coal preparation system).

1.2.2 PCD System

1. The pulse valves supplied with the PCD demonstrated a flow-restricting phenomenon that resulted due to the valve internal geometry. Pulse valves were characterized, the problem identified, and work is underway with Westinghouse and the valve manufacturer to resolve the issue, both here and at Pinon Pine.

2. The ability to monitor and control ash level in the PCD was demonstrated.

3. PSDF demonstrated that the outlet particulate loading of the Westinghouse PCD can be less than 1 ppm with proper installation and filter elements intact.

4. PSDF demonstrated that with two broken filter elements and plugged fail-safes (current fail-safe design circa fourth-quarter 1997), the outlet loading was about 10 ppm with an inlet loading of about 10,000 ppm.

5. The current Westinghouse fail-safe design (circa fourth-quarter 1997) was shown to not always plug when a filter element breaks. The fail-safe design is currently under evaluation and changes are being made to improve performance.

6. A leak path was identified in the previous (circa fourth-quarter 1997) Westinghouse fail-safe design. This design flaw has been corrected on-site and is currently part of the Westinghouse design.

7. Problems were identified with the current Westinghouse filter element gasket arrangement and installation. Since there is no way to "proof" the gasket in the Westinghouse system as would be done with a conventional baghouse, the gasket must be foolproof. PSDF is working with Westinghouse to improve both the gaskets and their installation.

8. The Westinghouse plenum/tube sheet has a different metallurgy than at Karhula and Tidd. Whereas the previous installations experienced serious creep, cracking, and corrosion problems, the metallic components of the PSDF filter system seem to be holding up well under current conditions.

1.2.3 Particulate Sampling/Ash Analysis

1. Isokinetic ash samples both on PCD inlet and outlet were reliably, safely, and routinely taken.

2. The inlet loadings measured by the SRI sampling system were verified by collecting all of the ash exiting the PCD hopper during the sampling run.

3. PSDF successfully operated a high-temperature cascading impactor.

4. The properties of the ashcake (i.e., system pressure drop) have been very different during each test series (CCT4, CCT5, CCT6, and TCO1) even though the same coal/sorbent was used throughout. PSDF is just beginning to understand why, but indications are that how a reactor is operated may be as important as what is fed into it.

5. Acoustic detector performance was evaluated. During initial testing a design flaw was discovered which led to their removal. The detectors have been redesigned and will be installed prior to 1998 tests.

1.2.4 Filter Element Testing

1. There are currently 1,870 hours of coal combustion experienced on a significant number of Pall 442T (21) and Pall 326 (4) filter elements. Six types of filter elements (Coors, Pall 326, Pall 442T, Schumacher TF20, Schumacher T10-20, and 3M Type 203) have been tested to date, and these elements are at various levels of exposure.

2. Current material testing results indicate that the Coors material appears to be losing significant strength just below the candle flange. This makes the Coors filter elements more susceptible to failure during a thermal transient. The loss of strength at the flange *may* be due to repeated microcracking during backpulsing. It is interesting that both Coors and Pall SiC elements were installed at the same time in FL0301 during the April 1997 outage, and while most of the Coors have failed the Pall filters are still intact.

3. Karhula data was confirmed also at PSDF by showing that SiC elements (Pall/Schumacher) have not elongated significantly (± 1 mm) after exposure to 1,350˚F for 650 hours. Data for exposure at 1,000 hours should be available by midyear 1998. There are few alternatives if Coors elements prove unsuitable for commercial operation because of susceptibility to thermal shock.

4. PSDF is working with Dr. Roger Chen to develop acoustic methods for nondestructive evaluation of monolithic ceramic filter material. The first elements to be shipped back to Dr. Chen will leave the PSDF in February 1998 with nominally 500 hours on-coal exposure. Additional elements will be exposed during 1998 tests and on the FW PCD.

5. PSDF has been successful in opening up a direct line of communication with the filter element suppliers. This is one of the strengths of the test program at the PSDF and has manifested itself in many ways, including:

   - Six filter element types have been tested to date and during 1998 an additional six (possibly seven) types of filter elements will be evaluated. These will include essentially all "promising" candle filter elements, including metal filters.

   - From the beginning of the testing program at the PSDF, both metal and ceramic samples have been exposed in a nonflow mode, on both the clean and dirty side of the tube sheet, to support the development programs of the element manufacturers.

   - The first element supplier review meeting was planned for January 1998 at the PSDF facility. A hot gas clean-up symposium, jointly sponsored by the U. S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI), will be held in April 1998 in Birmingham.

1.2.5 Ash Removal

1. Problems with the existing seal material on the ash removal lockhopper hemispherical valves were identified. By working with the manufacturer through on-site testing, the problem was temporarily resolved by using a material with a lower temperature rating. Work is underway with the manufacturer to support their testing of a higher temperature seal. The PSDF experience is being shared since similar problems may occur at Pinon Pine.

2. The internal bearing on the ash removal screw cooler is currently experiencing accelerated wear. PSDF is working with the manufacturer to resolve the bearing issues and will pass this information on to MWK for future designs.

2.0 INTRODUCTION

This report provides an account of the 1997 test campaign with the M. W. Kellogg Company (MWK) transport reactor and the Westinghouse filter vessel at the Power Systems Development Facility (PSDF) located in Wilsonville, Alabama, 40 miles southeast of Birmingham. The PSDF is sponsored by the U. S. Department of Energy (DOE) and is an engineering scale demonstration of two advanced coal-fired power systems. In addition to DOE, Southern Company Services, Inc., (SCS), Peabody Coal Company, and the Electric Power Research Institute (EPRI) are cofunders. Other cofunding participants supplying services or equipment include MWK, Foster Wheeler (FW), Westinghouse, Industrial Filter & Pump, and Combustion Power Company. SCS is responsible for constructing, commissioning, and operating the PSDF.

The transport reactor is an advanced circulating fluidized-bed reactor acting as either a combustor or as a gasifier using one of three possible hot gas clean-up filter technologies (particulate control devices or PCDs) at a component size readily scaleable to commercial systems. Design and construction of the transport reactor and required associated equipment were completed in early summer of 1996. By midsummer all separate components and subsystems were fully operational and commissioning work focused on integration issues for the entire reactor system. At the same time, the first set of ceramic candles was loaded into the Westinghouse PCD. Initial operation of the transport reactor as a combustor was completed in late August, with further combustion commissioning tests completed in the last quarter of 1996.

2.1 THE POWER SYSTEMS DEVELOPMENT FACILITY

SCS entered into an agreement with DOE/FETC for the design, construction, and operation of a hot gas clean-up test facility for gasification and pressurized combustion. The purpose of the PSDF is to provide a flexible test facility that can be used to develop advanced power system components, evaluate advanced turbine system configurations, and assess the integration and control issues of these advanced power systems. The facility would provide a resource for rigorous, long-term testing and performance assessment of hot gas stream clean-up devices and other components in an integrated environment.

The PSDF will consist of five modules for systems and component testing. These modules include:

- An advanced pressurized fluidized-bed combustion module (APFBC).
- An advanced gasifier module.
- A hot gas clean-up module.

- A compressor/turbine module.
- A fuel cell module.

The APFBC module consists of FW technology for second-generation PFBC. This module relies on the partial conversion of the coal to a fuel gas in a carbonizer, with the remaining char converted in a PFBC. Both the fuel gas and PFBC exhaust gas streams are filtered to remove particulates, then combined to fire a combustion turbine. The advanced gasifier module consists of an MWK transport reactor for pressurized combustion and gasification to provide either an oxidizing or reducing gas for parametric testing of hot particulate control devices.

The filter systems that will be tested at PSDF include PCDs supplied by Combustion Power Company from Menlo Park, California; Industrial Filter & Pump (IF&P) from Cicero, Illinois; and Westinghouse from Pittsburgh, Pennsylvania.

Construction of the transport reactor train and necessary balance-of-plant systems was completed by mid-1996. Various equipment and systems were commissioned during the final stages of construction. This was followed by start-up of the entire train and commissioning and combustion characterization tests.

The major activities in 1997 on the APFBC system were: (1) final modifications in design, (2) renewal of construction activities, and (3) commissioning activities associated with simple cycle operation. A separate progress report will be issued to cover the completion of commissioning activities for the APFBC.

2.2 TRANSPORT REACTOR SYSTEM DESCRIPTION

The transport reactor train operating in the combustion mode is shown schematically in figure 2.2-1. A taglist of all major equipment in the process train and associated balance-of-plant is provided in tables 2.2-1 and 2.2-2. Two PCDs are shown in this flow diagram; however, during operations only one PCD is tested with the transport reactor at a given time. The intent is to be able to install, change out, or provide maintenance on a second PCD while one is being tested. This provides increased flexibility for the test facility and reduces downtime. The facility is sized to process nominally 2 tons/hour of coal. This size generates sufficient gas to test the PCDs at a minimum of 1,000 ACFM of gas at the PCD inlet. Indirect cooling of the gas from the transport reactor allows testing of the PCDs with inlet temperatures between 600 and 1,400°F and at pressures ranging from 150 to 305 psia. The PCD in this train receives particulate laden gas from the transport reactor, which can operate in either gasification or combustion mode. In the gasification mode, the gas exiting the PCDs is oxidized, cooled, and filtered in a baghouse before being discharged from a stack. The ash produced in the gasification mode is sulfated prior to disposal.

Coal is ground to an average particle diameter of about 100 microns when the transport reactor is operated in gasification mode and to 200 microns average particle diameter in combustion mode. Sorbent is ground to an average particle diameter of about 100 microns. Both coal and sorbent are fed continuously at a controlled rate by feeders to a transfer line where they are picked up by the conveying gas and fed to the transport gasifier/combustor.

Air is compressed to about 350 psia in the main air compressor and fed directly to the transport reactor. For start-up purposes, a burner (BR0201) is provided at the reactor mixing zone. Liquefied propane gas (LPG) is used as start-up fuel. Solids and gas feeds enter the reactor in a mixing zone at the bottom where they mix with recycle solids from the disengager cyclone. Coal conversion begins in this zone and the reaction mixture flows upward into the more narrow riser section at high velocity and then flows to the disengager.

The reactor typically operates at temperatures of 1,600 to 1,625°F in combustion mode. Provision is made to inject air at several different points along the riser to control the formation of NO_X. Limestone/dolomitic sorbents fed with the coal are used for sulfur capture, thus eliminating the need for downstream facilities to reduce plant sulfur emissions.

Solids and gases leaving the reactor flow to the disengager for bulk separation of the two phases. Most of the solids collected in the disengager are recycled to the reactor. The net solids (consisting of coal ash and spent sorbent) are sent to a solids cooler for cooling prior to disposal. In the combustion mode, heat removal from the reactor system is necessary to control the reactor temperature. This is accomplished by removing solids from the disengager, cooling the solids in the combustor heat exchanger (HX0203), and returning the solids to the reactor system.

The gas leaving the disengager still contains a high loading of particulates. It is then sent to a cyclone system for additional solids recovery prior to being fed to the PCDs. The cyclone is provided with spoiling gas to vary the solids loading into the effluent gas. The conditioned gas enters the PCD where essentially all of the remaining particulates in the gas are removed. The cleaned gas leaving the PCD is sent to a secondary gas cooler (HX0402) and ultimately cooled to about 600°F. All gas and solids cooling are accomplished by generating steam. A portion of the

cooled gas is further cooled in the compressor feed cooler (HX0405) and sent to the recycle gas booster compressor (CO0401) which increases the pressure to about 400 psia. This gas is used as carrier gas for coal/limestone feed, for aeration gas, and as fluidization gas for the solids coolers.

The main gas stream from the secondary gas cooler is cooled further by dilution air and cleaned of any remaining particulates in a baghouse before being discharged to a stack.

Table 2.2-1

Major Equipment in the Transport Reactor Train

TAG NAME	DESCRIPTION
BR0201	Reactor Start-Up Burner
BR0401	Thermal Oxidizer
BR0602	Sulfator Start-Up/PCD Preheat Burner
CO0201	Main Air Compressor
CO0401	Recycle Gas Booster Compressor
CO0601	Sulfator Air Compressor
CY0201	Primary Cyclone in the Reactor Loop
CY0207	Disengager in the Reactor Loop
CY0601	Sulfator Cyclone
DR0402	Steam Drum
DY0201	Feeder System Air Dryer
FD0206	Spent Solids Screw Cooler
FD0210	Coal Feeder System
FD0220	Sorbent Feeder System
FD0502	Fines Screw Cooler
FD0510	Spent Solids Transporter System
FD520	Fines Transporter System
FD0530	Spent Solids Feeder System
FD0602	Sulfator Solids Screw Cooler
FD0610	Sulfator Sorbent Feeder System
FL0301	PCD — Westinghouse
FL0302	PCD — Combustion Power
FL0401	Compressor Intake Filter
HX0202	Primary Gas Cooler
HX0203	Combustor Heat Exchanger
HX0204	Transport Air Cooler
HX0402	Secondary Gas Cooler
HX0405	Compressor Feed Cooler
HX0601	Sulfator Heat Recovery Exchanger
ME0540	Heat Transfer Fluid System
RX0201	Transport Reactor
SI0602	Spent Solids Silo
SU0601	Sulfator

Table 2.2-2 (Page 1 of 3)

Major Equipment in the Balance-of-Plant

TAG NAME	DESCRIPTION
BO2920	Auxiliary Boiler
BO2921	Auxiliary Boiler - Superheater
CL2100	Cooling Tower
CO2201A-D	Service Air Compressor A-D
CO2202	Air-Cooled Service Air Compressor
CO2203	High-Pressure Air Compressor
CO2601A-C	Reciprocating N_2 Compressor A-C
CR0104	Coal and Sorbent Crusher
CV0100	Crushed Feed Conveyor
CV0101	Crushed Material Conveyor
DP2301	Baghouse Bypass Damper
DP2303	Inlet Damper on Dilution Air Blower
DP2304	Outlet Damper on Dilution Air Blower
DY-2201A-D	Service Air Dryer A-D
DY2202	Air-Cooled Service Air Compressor Air Dryer
DY2203	High-Pressure Air Compressor Air Dryer
FD0104	MWK Coal Transport System
FD0111	MWK Coal Mill Feeder
FD0113	Sorbent Mill Feeder
FD0140	Coke Breeze and Bed Material Transport System
FD0154	MWK Limestone Transport System
FD0810	Ash Unloading System
FD0820	Baghouse Ash Transport System
FL0700	Baghouse
FN0700	Dilution Air Blower
HO0100	Reclaim Hopper
HO0105	Crushed Material Surge Hopper
HO0252	Coal Surge Hopper
HO0253	Sorbent Surge Hopper
HT2101	MWK Equipment Cooling Water Head Tank
HT2103	SCS Equipment Cooling Water Head Tank
HT0399	60-Ton Bridge Crane
HX2002	MWK Steam Condenser
HX2003	MWK Feed Water Heater

Table 2.2-2 (Page 2 of 3)

Major Equipment in the Balance-of-Plant

TAG NAME	DESCRIPTION
HX2004	MWK Subcooler
HX2103A	SCS Cooling Water Heat Exchanger
HX2103C	MWK Cooling Water Heat Exchanger
LF0300	Propane Vaporizer
MC3001-3017	MCCs for Various Equipment
ME0700	MWK Stack
ME0701	Flare
ME0814	Dry Ash Unloader for MWK Train
ML0111	Coal Mill for MWK Train
ML0113	Sorbent Mill for Both Trains
PG2600	Nitrogen Plant
PU2000A-B	MWK Feed Water Pump A-B
PU2100A-B	Raw Water Pump A-B
PU2101A-B	Service Water Pump A-B
PU2102A-B	Cooling Tower Make-Up Pump A-B
PU2103A-D	Circulating Water Pump A-D
PU2107	SCS Cooling Water Make-Up Pump
PU2109A-B	SCS Cooling Water Pump A-B
PU2111A-B	MWK Cooling Water Pump A-B
PU2300	Propane Pump
PU2301	Diesel Rolling Stock Pump
PU2302	Diesel Generator Transfer Pump
PU2303	Diesel Tank Sump Pump
PU2400	Fire Protection Jockey Pump
PU2401	Diesel Fire Water Pump #1
PU2402	Diesel Fire Water Pump #2
PU2504A-B	Waste Water Sump Pump A-B
PU2507	Coal and Limestone Storage Sump Pump
PU2700A-B	Demineralizer Forwarding Pump A-B
PU2701	SCS Closed-Loop System Make-Up Pump
PU2711	Corrosion Inhibitor Pump
PU2713	Waste Water Alum Pump
PU2714	Waste Water Caustic Pump
PU2720	Acid Pump
PU2721	Waste Water Acid Pump

Table 2.2-2 (Page 3 of 3)

Major Equipment in the Balance-of-Plant

TAG NAME	DESCRIPTION
PU2730	MWK Steam System Phosphate Pump
PU2740	Cooling Tower Sodium Bisulfate Pump
PU2741	Cooling Tower Sodium Bisulfate Pump
PU2750	MWK Steam System O_2 Scavenger and pH Pump
PU2900A-C	Chemical Injection Pump A-C
PU2920A-B	Auxiliary Boiler Feed Water Pump A-B
SB3001	125V DC Station Battery
SB3002	UPS
SC0700	Baghouse Screw Conveyor
SG3000-3005	4160V, 480V Switchgear Buses
SI0101	MWK Crushed Coal Storage Silo
SI0103	Crushed Sorbent Storage Silo
SI0111	MWK Pulverized Coal Storage Silo
SI0113	MWK Limestone Silo
SI0114	FW Limestone Silo
SI0810	Ash Silo
ST2601	N_2 Storage Tube Bank
TK2000	MWK Condensate Storage Tank
TK2001	FW Condensate Tank
TK2100	Raw Water Storage Tank
TK2300A-D	Propane Storage Tank A-D
TK2301	Diesel Storage Tank
TK2401	Fire Water Tank
XF3000A	230/4.16 kV Main Power Transformer
XF3001B-5B	4160/480V SS Transformer No. 1-5
XF3001G	480/120V Miscellaneous Transformer
XF3010G	120/208 Distribution Transformer
XF3012G	UPS Isolation Transformer
VS2203	High-Pressure Air Receiver

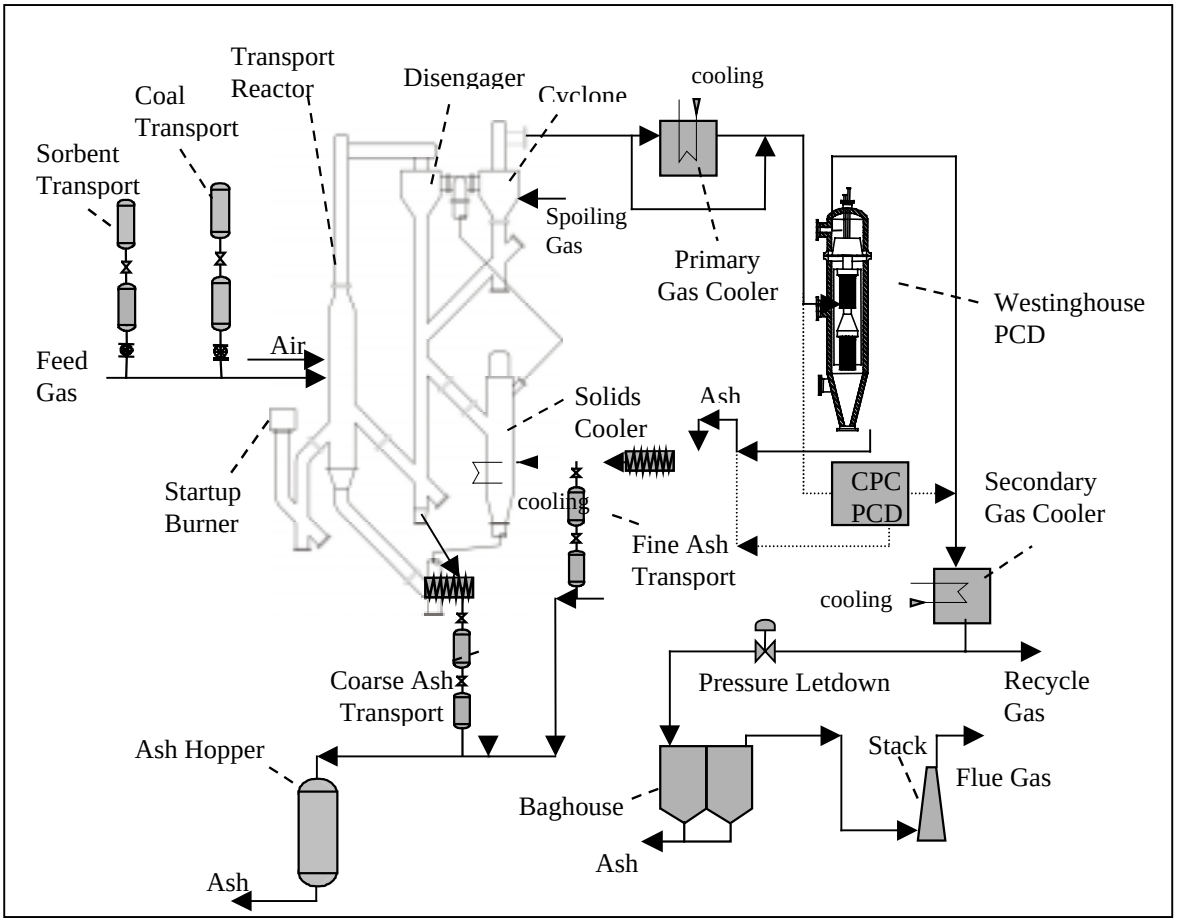


Figure 2.2-1 Flow Diagram of the Transport Reactor Train

2.3 WESTINGHOUSE PARTICULATE CONTROL DEVICE

Three different PCDs will be evaluated on the transport reactor train. The first PCD that was commissioned in 1996 and used in the 1997 testing was the filter system designed by Westinghouse. The dirty gas enters the PCD below the tubesheet, flows through the filter elements, and the ash collects on the outside of the filter elements. The clean gas passes from the plenum/filter element assembly through the plenum pipe to the outlet pipe. As the ash collects on the outside surface of the filter elements, the pressure drop across the filter system gradually increases. The filter cake is periodically dislodged by injecting a high-pressure gas pulse to the clean side of the candles. The cake then falls to the discharge hopper.

During the 1997 operations, the transport reactor was operated in combustion mode. Initially, high-pressure air was used as the pulse gas. However, the pulse gas was changed to nitrogen early in 1997. The two primary reasons for this change were:

1. To accomplish an early check on the high-pressure nitrogen compressors prior to gasification.

2. To resolve a potential pulse valve mass flow problem resulting from suspect excessive moisture in the high-pressure air. Moisture was later eliminated as a possible cause of the mass flow problems. A design flaw in the valves that has since been corrected caused the problem.

The pulse gas was routed individually to the two-plenum/filter element assemblies via injection tubes mounted on the top head of the PCD vessel. The pulse duration was typically 0.1 to 0.5 seconds.

2.4 BALANCE-OF-PLANT

Balance-of-plant (BOP) to support the operation of the transport reactor train consists of a number of systems, most of which are of conventional design and commercially available. Major BOP system performance highlights are summarized in section 5.0 (major observations from normal operations and significant problems and their resolution). Major BOP components are listed in table 2.2-2.

3.0 PARTICLE FILTER SYSTEM

3.1 PCD OVERVIEW

3.1.1 Summary

The Westinghouse PCD was operated on coal for slightly over 200 hours in 1996. On its initial operation on coal the filter was filled with ash, which lead to the failure of nearly all of the filter elements. In the runs to follow, through the remainder of 1996, a significant problem was diagnosed with the operation of the M. W. Kellogg (MWK) primary cyclone. The particle size of the material entering the filter system was essentially the same as the material being fed to the transport reactor. Additionally, the loading varied from 4,000 to 100,000 ppm (design range was 4,000 to 16,000).

During 1997, operation greatly improved as was evidenced by logging over 1,900 hours on coal. Southern Research Institute (SRI) outlet particulate collection system came on-line and it was realized that the Westinghouse filter system is capable of greater than 99.99 percent collection efficiency with outlet loadings below 1 ppm. Monitoring ash level in the filter system became routine and the responsibility for day-to-day operation of the PCD during testing was turned over to the operations staff. Several times during the year rising ash levels became an issue for concern, but at no time did they cause damage to the filter elements. Through the work of the transport reactor staff, particulate size and loading became very consistent and well within design values.

However, 1997 did not pass without problems. Early in the year, on April 7, a combustion inside the PCD caused failure of all the filter elements. Also, in the same time span it was realized that the pulse valves had an unusual flow characteristic: they decreased flow with increasing differential pressure. This was caused by a design flaw in the valves which has been corrected and will be verified early in 1998. Similar valves at the Pinon Pines project have also been modified.

One of the biggest, and unexpected, problems to date has been with the performance of the Coors P100A filter elements. Coors P100A elements began failing in September, and a thermal excursion of the entire process due to a pluggage in the coal feeder lead to a complete failure of the Coors P100A elements in November. With only one exception, the Coors P100A failures have been associated with some type of thermal transient that can be blamed on operations: twice while transitioning from the start-up burner to coal and the thermal transient in November. However, what is significant is that no monolithic SiC filter elements that had been through the exact same conditions failed during operation. The root cause of the Coors P100A filters is still under investigation.

3.1.2 1997 Accomplishments

The accomplishments for 1997 are listed below:

- The Westinghouse PCD was operated for over 1,900 hours with coal in combustion without ash bridging, with one coal/sorbent at PCD inlet temperatures over 1,450°F.
- The ability to monitor and control ash level in the PCD was demonstrated.
- The pulse valves supplied with the PCD demonstrated a flow-restricting phenomena due to the internal geometry of the valve. Work was completed with Westinghouse and the valve manufacturer to resolve, both here and at Pinon Pines.
- PSDF demonstrated that the outlet loading of Westinghouse PCD is less than 1 ppm with proper installation and filter elements intact.
- PSDF demonstrated that with two broken filter elements and current failsafe design (circa fourth quarter 1997), the outlet loading was about 10 ppm with an inlet loading of about 10,000 ppm.
- The current Westinghouse failsafe design (circa fourth quarter 1997) was shown to not always plug when a filter element breaks. The failsafe design is currently under evaluation and changes are being made to improve performance.
- A leak path was identified in the previous (circa fourth quarter 1997) Westinghouse failsafe design. This design flaw has been corrected on-site and is currently part of Westinghouse's design.
- Concerns were identified with the current filter element gasketing arrangement and installation. Work is underway with Westinghouse to improve both the gaskets, and the installation of gaskets.
- The Westinghouse plenum/tubesheet has a different metallurgy than at Karhula and Tidd. Whereas the previous installations experienced serious creep, cracking, and corrosion problems, the metallic components of the filter system seem to be holding up well.
- During initial testing, the tubesheet near the vessel wall and manways doors experienced acid dew point corrosion during shutdown. This has been effectively managed and is no longer a concern.
- Isokinetic ash samples both on PCD inlet and outlet were reliably, safely, and routinely taken.

- Inlet loadings, measured on PCD inlet to verify loadings from the SRI sampling system, were confirmed.

- A high-temperature cascading impactor was successfully operated.

- The properties of the ashcake (i.e., system pressure drop) have been very different during each test series (CCT4, CCT5, CCT6, and TCO1), even though the same coal/sorbent was used throughout. A general understanding of why this has occurred is still under development, but it indicates that *how* the reactor is operated may be as important as what is fed into it.

- Acoustic detector performance was evaluated. During initial testing a design flaw was discovered which lead to their removal. The detectors have been redesigned and will be installed prior to TC02.

- There are currently 1,870 hours of coal combustion experienced on a significant number (21) of Pall 442T filter elements and (4) Pall 326 filter elements. Six types of filter elements (Coors P100A, Pall 326, Pall 442T, Schumacher TF20, Schumacher T10-20, and 3M Type 203) have been tested to date and these elements are at various levels of exposure.

- The SiC elements (Pall/Schumacher) have not elongated significantly (± 1 mm) after exposure to 1,350°F for 650 hours.

- PSDF is working with Dr. Roger Chen to develop acoustic methods for nondestructive evaluation of monolithic ceramic filter material.

- Problems with the existing seal material on the spent fines transport system lockhopper hemispherical valves were identified. By working with the manufacturer through on-site testing, the problem was temporarily resolved by using a material with a lower temperature rating. Work is underway with the manufacturer to support their testing of a higher temperature seal.

- The internal bearing on the spent fines transport system screw cooler has experienced accelerated wear. PSDF is working with the manufacturer to resolve the bearing issues and will pass this information on to MWK for future designs.

3.1.3 Developmental Areas

From the list in section 3.1.2, it is evident that operation in 1997 uncovered several issues that are still unresolved at the time of this writing. A fairly common comment at the PSDF is that in mid-1997 the biggest goal of the run was "survival." By the end of 1997 the focus was on eliminating a few ppm of dust emission. This speaks well of both the improved operation of the PSDF and the design of the Westinghouse filter system. However, there are still areas of concern that will require evaluation in 1998. These include the following:

- After modification, the pulse valves will need characterization to determine if the changes were successful.

- The existing fail-safes are a tremendous step in the right direction when it comes to extending the operation of the PCD. However, the failsafe does not totally plug when a filter element fails and completely fails to plug in the event of a small gasket leakage. This may extend the operation of the system during a run if the outlet loading is below turbine limits, but the dust emissions from the failsafe can (and do) enter the inner bore of the filter element during pulse cleaning. Over time the elements become irreversibly plugged, raising the pressure drop of the system over time. To recover to the baseline pressure drop, the elements require cleaning and/or replacement. The PSDF staff is working with Westinghouse to improve the failsafe performance.

- Second to the failsafe performance is the performance of the filter gaskets. During the latter part of TC01, there was a continuous emission of dust (~4 ppm) from the filter system. On inspection this particulate came from the gaskets (i.e., all filter elements were intact). Most probably, the leakage was caused by improper installation. However, since there is no way to "proof" the element gaskets prior to operation the gasketing must be made reliable and "foolproof." Again, the PSDF staff is working with Westinghouse to improve both the design and the installation of the filter gaskets.

- The failure of the Coors P100A filter elements is still very much under investigation. Thermocouples have been added to the filter system for the runs in 1998 to measure the thermal transients across the filter walls during start-up and shutdown. It is hoped that this information will shed additional light on why the filter elements failed.

- The failure of the seal within the acoustic detectors was a disappointment because they had just started producing operational information. They will require significant development in 1998 to interpret the signal produced in relation to the information from other sampling sources.

- The residual cake left on the filter elements after TC01I ended in December 1997 was different physically than the cake in November. In fact, every time the PCD was opened in 1997 the residual cake was different in thickness, texture, and tenacity.

The same coal and sorbent were used throughout 1997. This may demonstrate that the operation of the combustor is just as important as the feedstock in determining cake filter behavior. Developing an understanding of these differences is still underway and will continue into 1998, and probably beyond.

- Sampling of the residual cake throughout the PCD inspections reveals that there is a significant difference in particle size between the residual cake and the PCD inlet samples. The median particle size of the residual cake is significantly finer that the samples at the PCD inlet. It is suspected that there is a separation occurring in the PCD that removes a percentage of the larger particulate. Having a tangential entry and a shroud inside the vessel certainly contributes to this separation. However, there is evidence suggesting the bulk flow of gas inside the shroud *may* be from the bottom upwards. This would also aid in separation of larger particulate. CFD modeling of FL0301 should begin in 1998 to verify this assumption and correct the problem if necessary.

3.1.4 What's Ahead in 1998

There is no doubt that 1998 will be a busier year than 1997 as the PSDF continues "maturing" as a filter test facility.

- The biggest "hurdle" of the year will be the start-up of the Foster Wheeler combustion system with its PCD containing 273 filters. Installation of the plenums and filter elements will begin in the second quarter of 1998.

- At the time of this writing the decision had been made to stay in combustion on the MWK transport reactor throughout 1998. This will allow operational hours to continue development on the issues raised in section 3.1.3.

- A system will be built essentially identical to FL0301 as the PCD for the Foster Wheeler carbonizer. Finalizing design changes is underway and development of a bid package is expected in the second quarter of 1998.

- Material testing, both destructive and nondestructive, will gain momentum in 1998 as materials gain hours of exposure.

- Several filter elements will be introduced into the filter system for the first time at the PSDF in early 1998. These include elements from DuPont, Blasch Precision Ceramics, McDermott, IF&P, Specific Surface, 3M (Oxide), and Fe-Al elements from Pall.

3.2 PCD OPERATION DURING TEST RUN CCT4A

3.2.1 Run Summary

Combustion characterization test CCT4A was the first run of 1997. One of the primary objectives of the run was to evaluate the modifications made to the MWK cyclone at the end of 1996. Coal was fed for only 24 hours of the run and during the periods before and during coal feed it was apparent that the cyclone modifications did not completely resolve the carryover of large quantities of relatively large particulate into the PCD. The large particulate size had a positive impact on the PCD performance, but the loss of large quantities of sand into the PCD caused a continual loss of bed material in the transport reactor. This was managed by constantly feeding sand into the reactor. However, when the spheri valve seal blew on the feeder being used for sand addition (FD0220), coal feed had to be stopped due to loss of bed material.

One of the primary PCD objectives was to raise the temperature of the gas entering the PCD. The temperature of the gas is controlled by the amount of gas bypassing the primary gas cooler (HX0202). Throughout 1996, all of the gas from the transport reactor flowed through HX0202. Prior to CCT4A, the blinds on the bypass were removed and the largest orifice (6.625-in. orifice bore) on-site was installed into the bypass. The primary reason for selecting this orifice was concerns of eroding on the orifice metal insert. However, when the orifice was removed at the end of CCT4D there was little-to-no erosion of the insert. With the addition of the orifice in the bypass, the split of gas going through the bypass and HX0202 was controlled by the pressure drop through the two legs. Calculations suggested that the temperature of gas entering the PCD would be about 1,200°F (649°C), however, the actual temperature entering the PCD was below 1,000°F (538°C).

As previously mentioned, the PCD performed well due to the carryover of large particulate from the transport reactor. While on coal, the baseline pressure drop was about 20 inWG (50 mbar) at a face velocity of 4 ft/min (73 m/hr). Over the 30 minutes between back-pulses the pressure drop only rose about 5 inWG (12.5 mbar).

In addition to the blown seal in FD0220 there were some major difficulties within the transport reactor system which impacted the operation and duration of the run. One of the primary problems was the surge control system on the main air compressor. Due to improper tuning of the surge control system there were several occasions when the compressor opened the "dump" valve, significantly impacting the pressure and flow through the system. Since this usually tripped the start-up burner, these surges caused temperature swings in the reactor and PCD. Additionally, the reliability of the start-up burner caused delays, and ultimately the inability to relight the burner on March 16 lead to the decision to end the run.

One of the PCD objectives for the run was to raise the pulse pressure to begin optimizing the pulse parameters. However, when the pulse pressure was raised from 400 to 600 psig (27.6 to 41.4 bar) on March 13 a sharp decrease in pulse flow was observed. At the time HP air was used as the pulse media and it was thought that either entrained water/oil or possibly valve wear was causing the decrease in flow. However, subsequent testing showed that the decrease in flow was due to a design flaw in the valve.

3.2.2 Test Objectives

The objectives for CCT4A were as follows:

- Increase the PCD temperature from 600 to ~1,000°F. (315.5 to ~537.8°C).
- The MWK cyclone had been modified in an attempt to improve particulate capture. Monitoring the quantity as well as the size of the particulate in the PCD was a primary concern.
- Vary the pulse pressure to determine the impact on PCD performance.

3.2.3 Observations/Events

Letters associated with each of the events shown below are located on the associated figures that follow. Refer to the Terms section of this report for help with abbreviations. Description of equipment tag names (e.g., description for FD0210) can be found in either table 2.2-1 or –2.

A. Start of Run–March 9 at 18:55. The main air compressor was started to begin curing out the refractory in the transport reactor and in the PCD. At this time the PI system was not operational.

B. Shut Down To Repair SUB–March 11 at 19:00. After many unsuccessful attempts to light the start-up burner, the main air compressor was shut down and the system depressurized to remove the burner for inspection. A new flame rod was installed and the burner installed. The main air compressor was restated at 22:15.

C. SUB Pilot Lit–March 12 at 00:12. The start-up burner pilot was lit after several attempts and the curing/heatup continued.

D. SUB Main Burner Lit–March 12 at 10:10.

E. Prepared To Feed Sand–March 13 at 10:00. Once refractory cure was complete, the temperature was lowered in the mixing zone prior to feeding sand. At 12:00 conditions were ready to feed sand but there were problems with the control system on the feeders. By 14:30 the problems were resolved, but a leak was discovered on one of the shuttle valves on the feeder FD0210. This was repaired by maintenance.

F. Raised Pulse Pressure–March 13 at 17:00. The pulse pressure was raised from 400 to 600 psig (27.6 to 41.4 bar,g). The PCD pressure at the time was 50 psig (3.4 bar,g). At the high-differential pressure it was noticed that there was an apparent decrease in the mass flow of gas per pulse. Due to the low-PCD differential pressure, the pulse pressure was decreased back to 400 psig (27.6 bar,g) at 22:00.

G. Started Feeding Sand–March 13 at 23:00.

H. Multiple SUB Trips–March 14 at 00:00. The start-up burner tripped multiple times between 00:00 and 12:00.

I. MAC Surged–March 14 at 18:45. The main air compressor flow surged and caused a rapid decrease in system pressure and an increase in face velocity. The surge caused the start-up burner to trip, therefore causing a decrease in temperature. The burner was relit by 20:00.

J. Started Feeding PRB–March 14 at 23:50.

K. MAC Surged–March 15 at 01:37.

L. Started Feeding Bituminous Coal–March 15 at 02:00.

M. FD0220 Blows Spheri Seal–March 15 at 12:00. Coal was being fed into the reactor via FD0210, and FD0220 was continuously feeding sand into the reactor to make up for losses being carried over to the PCD. At 12:00 a spheri valve seal on the lockhopper system blew. At this time the medium pressure nitrogen supplying all of the spheri valves was connected. When the spheri valve seal blew the nitrogen pressure to all valves decreased, causing all of the Clyde systems to trip. By 12:35 the failed seal was isolated and coal feed resumed.

N. FD0210 Switches To Sand Feed–March 16 at 00:40. When FD0220 was taken out-of-service, the bed level in the transport reactor began dropping due to the carryover of particulate into the PCD. At 00:40 the bed level had reached a point where coal feed was terminated to add sand to the reactor. No additional coal was fed during CCT4A.

O. Lit SUB–March 16 at 03:30. With the loss of coal feed and the addition of the sand the temperatures quickly dropped in the transport reactor and the PCD. The pressure was decreased and the start-up burner lit.

P. MAC Surged–March 16 at 11:33. The MAC surged once again at 11:33 and at 12:37. These surges tripped the start-up burner.

Q. End of Run–March 16 at 13:30. Tried multiple times unsuccessfully to relight the start-up burner. It was decided to end the run and inspect the burner.

3.2.4 Run Outcome

Due to the short duration of the run and that there were no filter-related problems, there was not an inspection of the PCD at the end of CCT4A. It was discovered that there was a significant amount of oil in the HP air receiver at grade, and this was drained. It was also discovered that one of the air dryers for the HP air compressor had been out-of-service and this was also corrected prior to the beginning of CCT4B.

Table 3.2.4-1

CCT4A RUN STATISTICS

Start Time:	March 9 at 18:55
End Time:	March 16 at 13:30
Coal Type:	Calumet Alabama Bituminous
Hours on Coal:	24
Sorbent Type:	No Sorbent Fed
TR Bed Material:	Sand
Number of Filter Elements:	91
Filter Element Layout No.:	2 (see Figure 3.2.6)
Filtration Area:	255 ft^2 (20.9 m^2)
Pulse Valve Open Time:	0.3 seconds
Pulse Time Trigger:	30 minutes
Pulse Pressure:	400 – 600 psig (27.6-41.4 bar,g)
Pulse DP Trigger:	100 inWG (248.8 mbar)

Table 3.2.4-2
CCT4A Major Events (Refer to Figures 3.2-1 through –6)

Event	Description	Date at Time
A	Start of Run	March 9 at 18:55
B	Shut Down to Repair SUB	March 11 at 19:00
C	SUB Pilot Lit	March 12 at 00:12
D	SUB Main Burner Lit	March 12 at 10:10
E	Prepared to Feed Sand	March 13 at 10:00
F	Raised Pulse Pressure	March 13 at 17:00
G	Started Feeding Sand	March 13 at 23:00
H	Multiple SUB Trips	March 14 at 00:00
I	MAC Surged	March 14 at 18:45
J	Started Feeding PRB	March 14 at 23:50
K	MAC Surged	March 15 at 01:37
L	Started Feeding Bituminous Coal	March 15 at 02:00
M	FD0220 Blows Spheri Seal	March 15 at 12:00
N	FD0210 Switches to Sand Feed	March 16 at 00:40
O	Lit SUB	March 16 at 03:30
P	MAC Surged	March 16 at 11:33
Q	End of Run	March 16 at 13:30

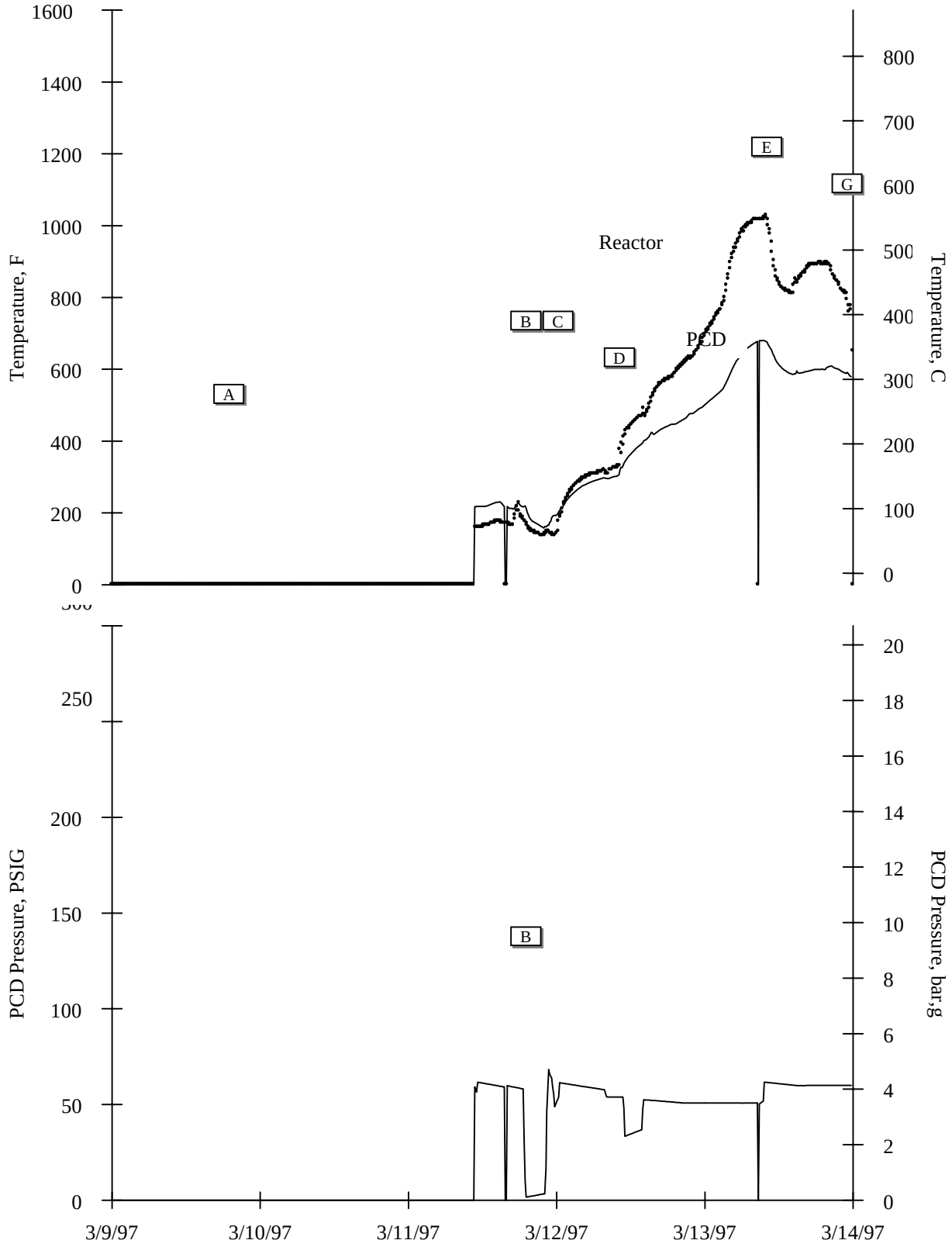


Figure 3.2.4-1 CCT4A Temperature and Pressure for March 9 Through 14

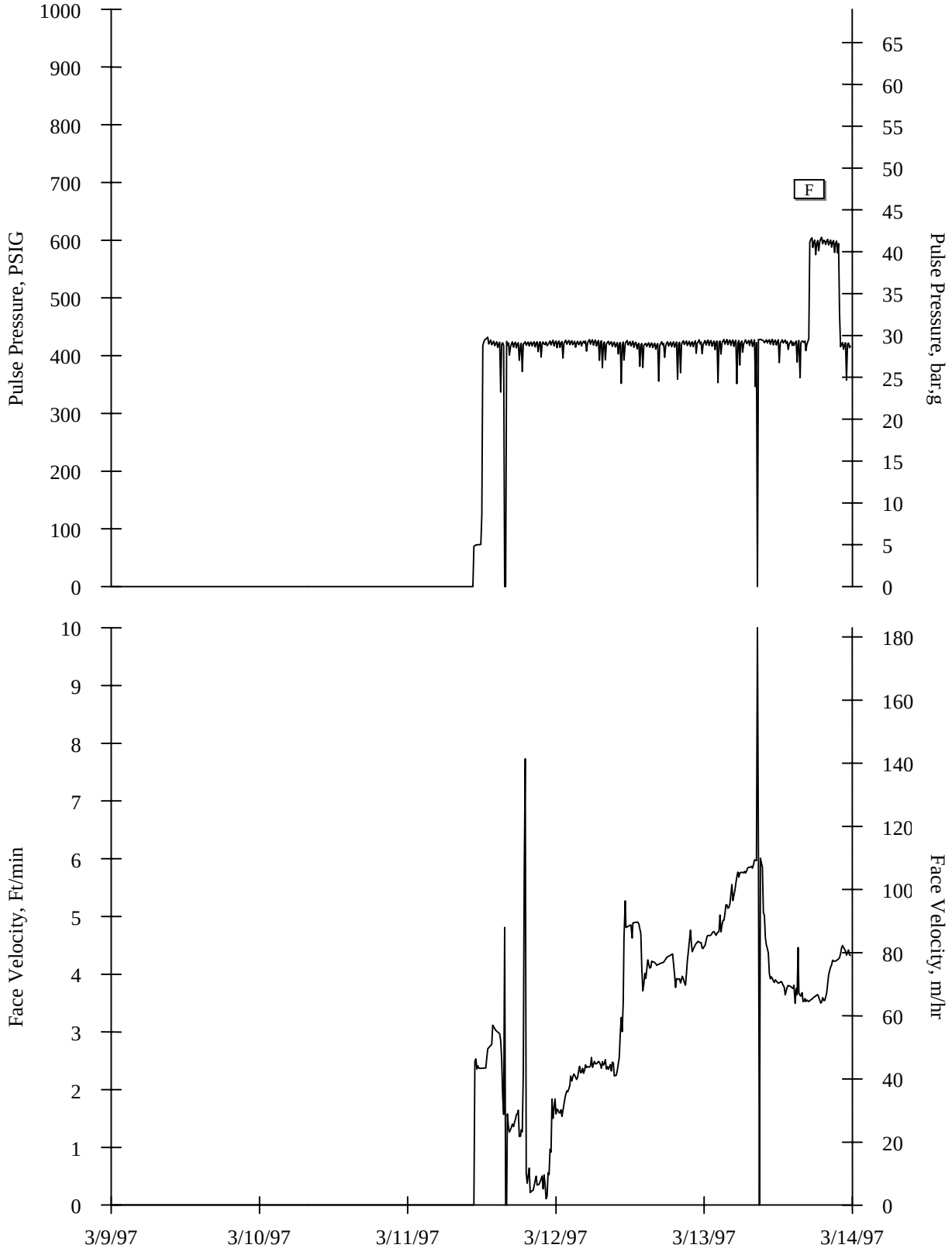


Figure 3.2.4-2 CCT4A Pulse Pressure and Face Velocity for March 9 Through 14

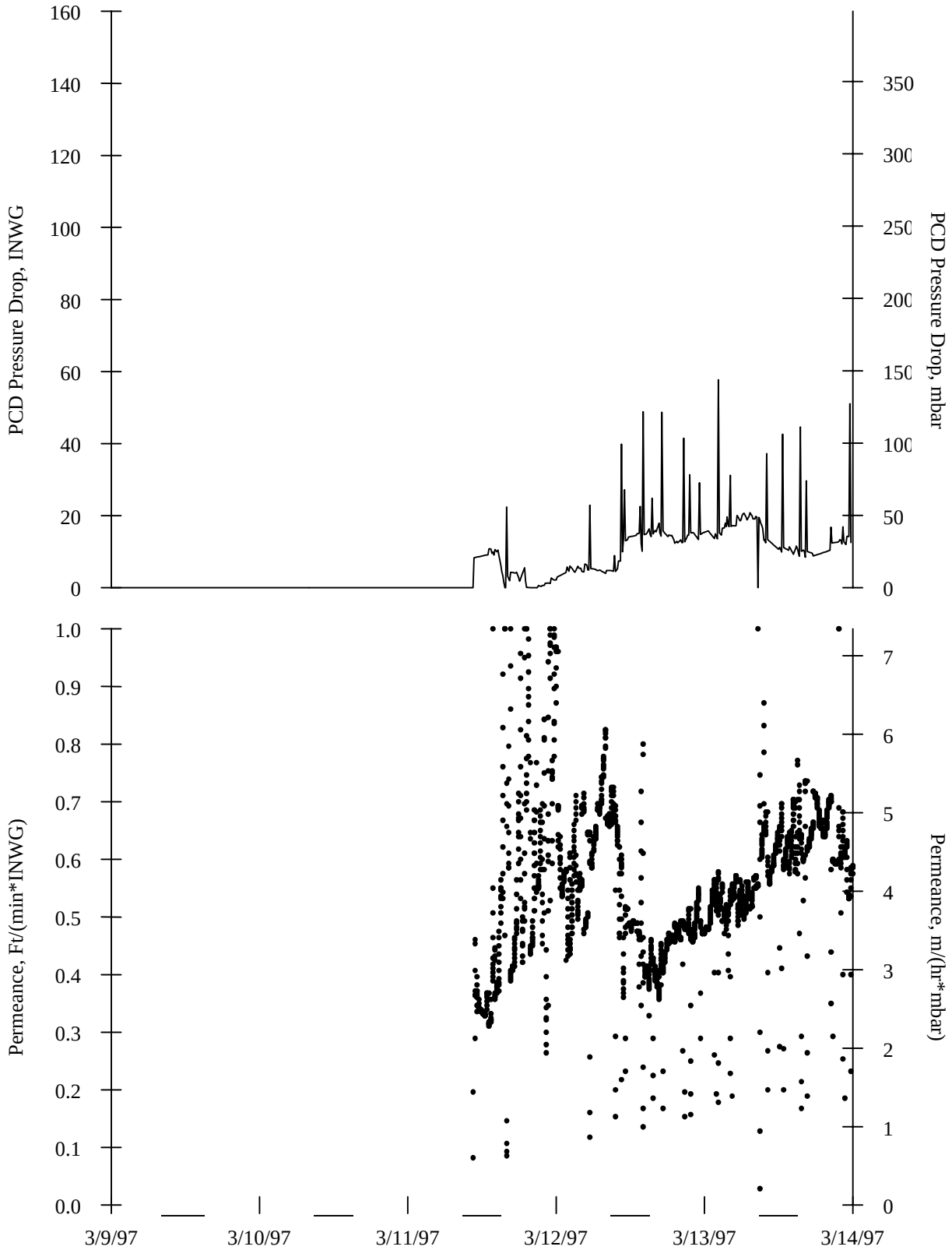


Figure 3.2.4-3 CCT4A Pressure Drop and Permeance for March 9 Through 14

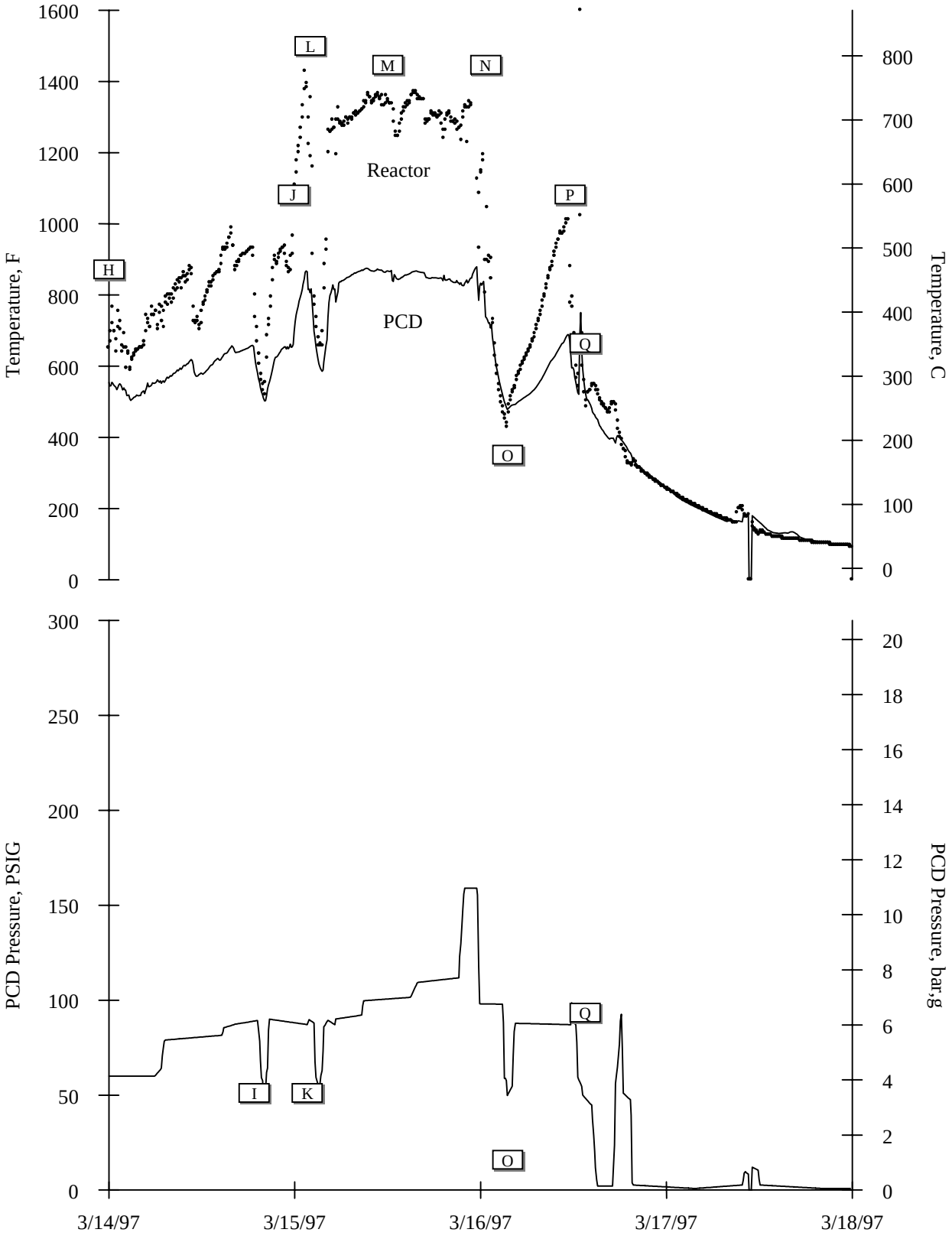


Figure 3.2.4-4 CCT4A Temperature and Pressure for March 14 Through 18

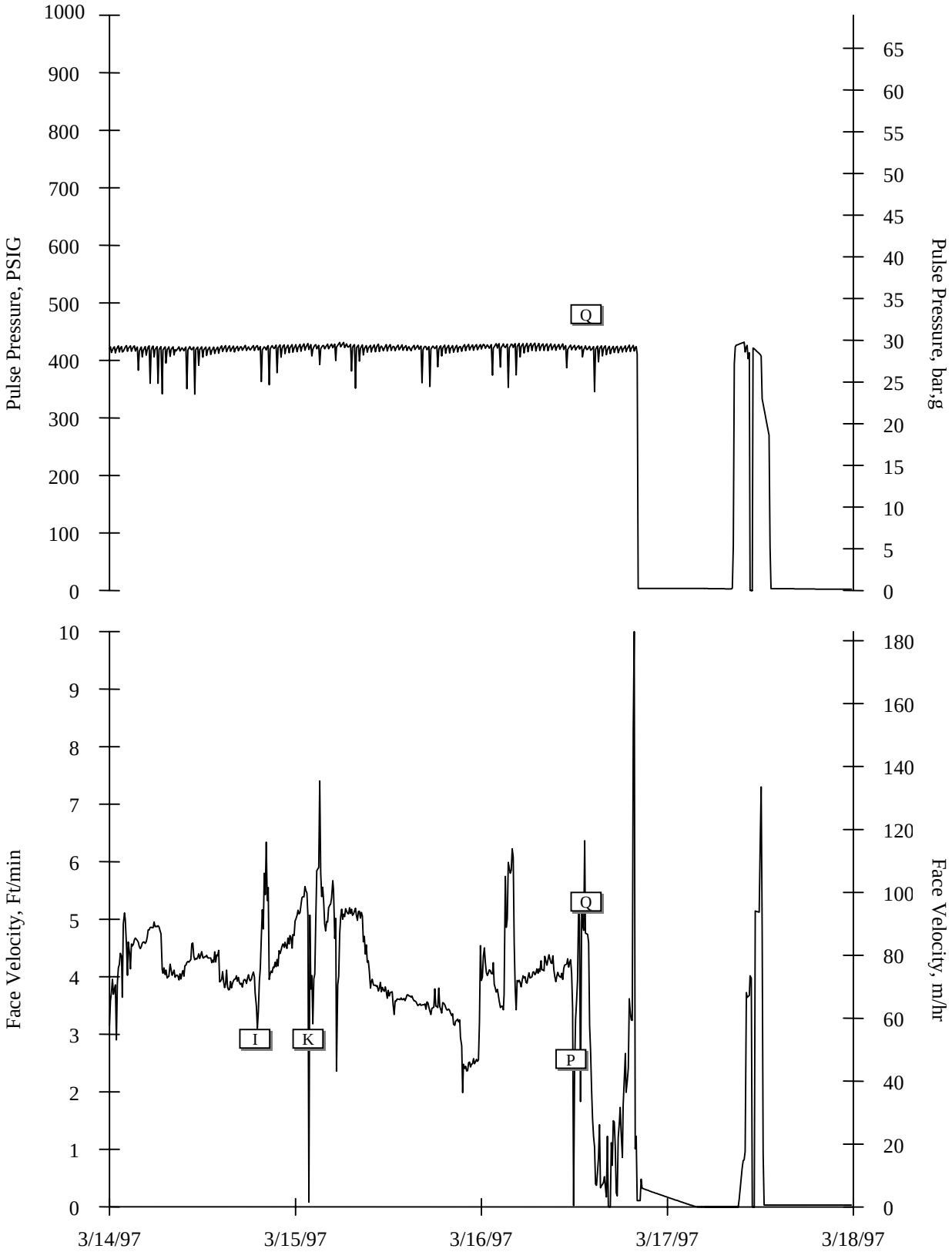


Figure 3.2.4-5 CCT4A Pulse Pressure and Face Velocity for March 14 Through 18

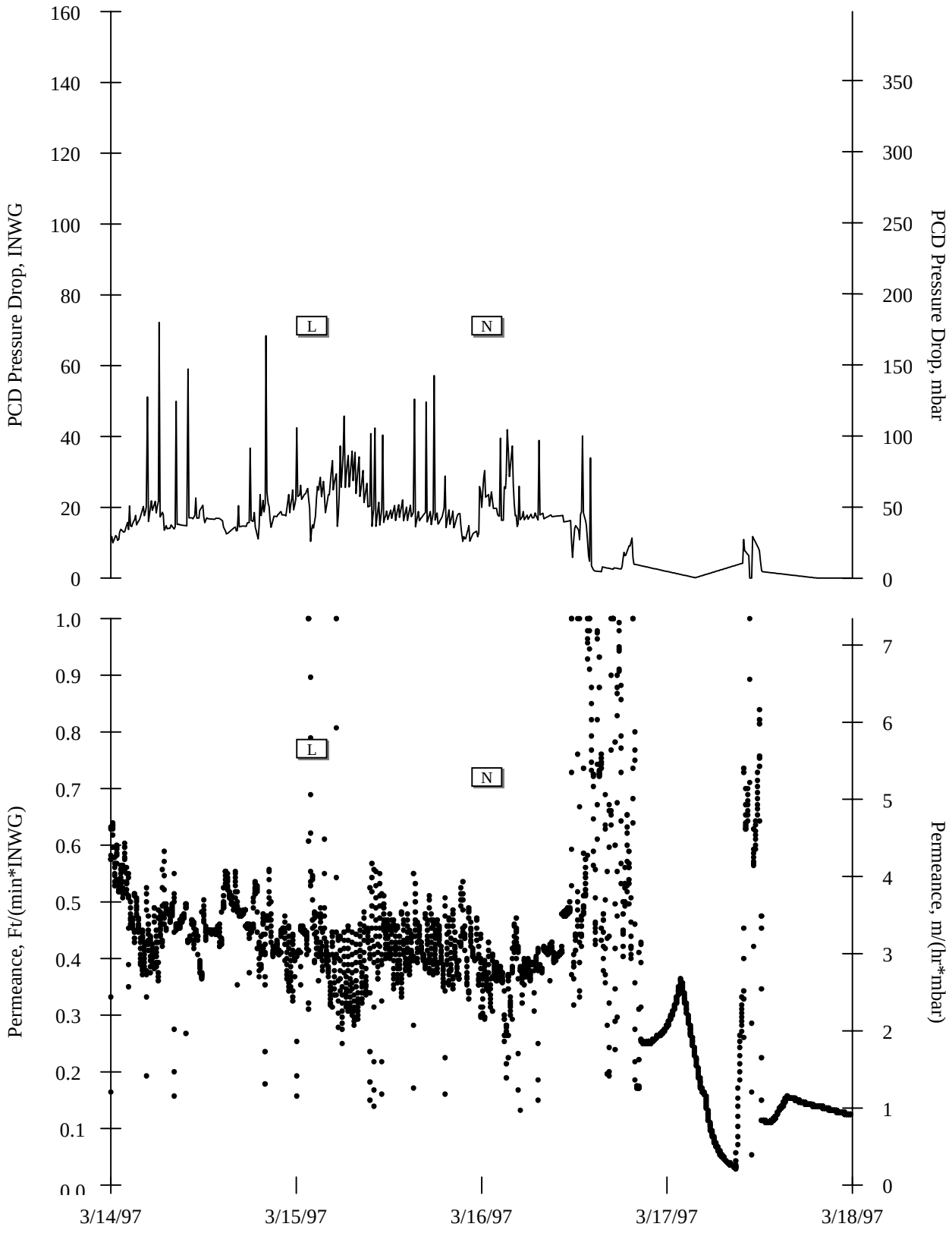


Figure 3.2.4-6 CCT4A Pressure Drop and Permeance for March 14 Through 18

PSDF\1997\3.2

3.3 PCD OPERATION DURING TEST RUN CCT4B

3.3.1 Run Summary

Combustion characterization test CCT4B was started on March 18, 1997, for the purpose of analyzing the transport reactor solids separation problems experienced in previous test runs, specifically those involving the primary cyclone (CY0201). A transport reactor test plan was developed to better understand the carryover problem to the PCD, and to determine if the CY0201 modifications made at the end of 1996 were effective. In previous test runs, surges of solids were carried over to the PCD, which forced the circulation and coal feed in the transport reactor to be slowed or stopped until the fines transporter system (FD0520) could remove the solids. After operating for just over 22 hours on coal, the transport reactor was shut down on March 23, 1997, because of problems with the FD0520 middle spheri valve.

The coal feed did not start until 3 days into this run because of problems with the main air compressor (MAC) and the start-up burner (BR0201). A representative from the MAC manufacturer performed a few tests and tuned the compressor during the first part of the run.

One objective of the CCT4 series test runs was to increase the PCD inlet gas temperature from 600 to 1,200°F (316 to 649°C) by bypassing a portion of the process gas around the primary gas cooler (HX0202). However, the actual inlet temperature for the test run never exceeded 935°F (502°C) because too much of the gas passed through HX0202 and the short coal feed duration.

While on coal, the baseline ΔP was about 20 inWG (50 mbar) and the ΔP rise ranged from 5 inWG (12 mbar) to 10 inWG (25 mbar). The open signal to the back-pulse valve was set at 0.2 and 0.3 seconds during the run. The back-pulse pulse interval was 30 minutes and the back-pulse pressure was set at 400 to 530 psig (27.6 to 36.5 bar,g).

The pulse valves were tested during this run and the data indicated a drop in the mass flow when the back-pulse pressure was increased from 400 to 530 psig (27.6 to 36.5 bar,g). This behavior was the same for all of the pulse valves, which indicated a potential problem with the pulse valves. The pulse valves were tested in runs TC01C through TC01E with a high-speed data acquisition computer. Refer to section 3.27, Pulse Valve Report, for the in-depth pulse valve testing results and analysis.

The filters installed for this test run were installed in September 1996. The filter layout is shown in figure 3.3.1-1 (layout 2). At the conclusion of this test run, the filters in layout 2 had accumulated a total of 203 hours on coal.

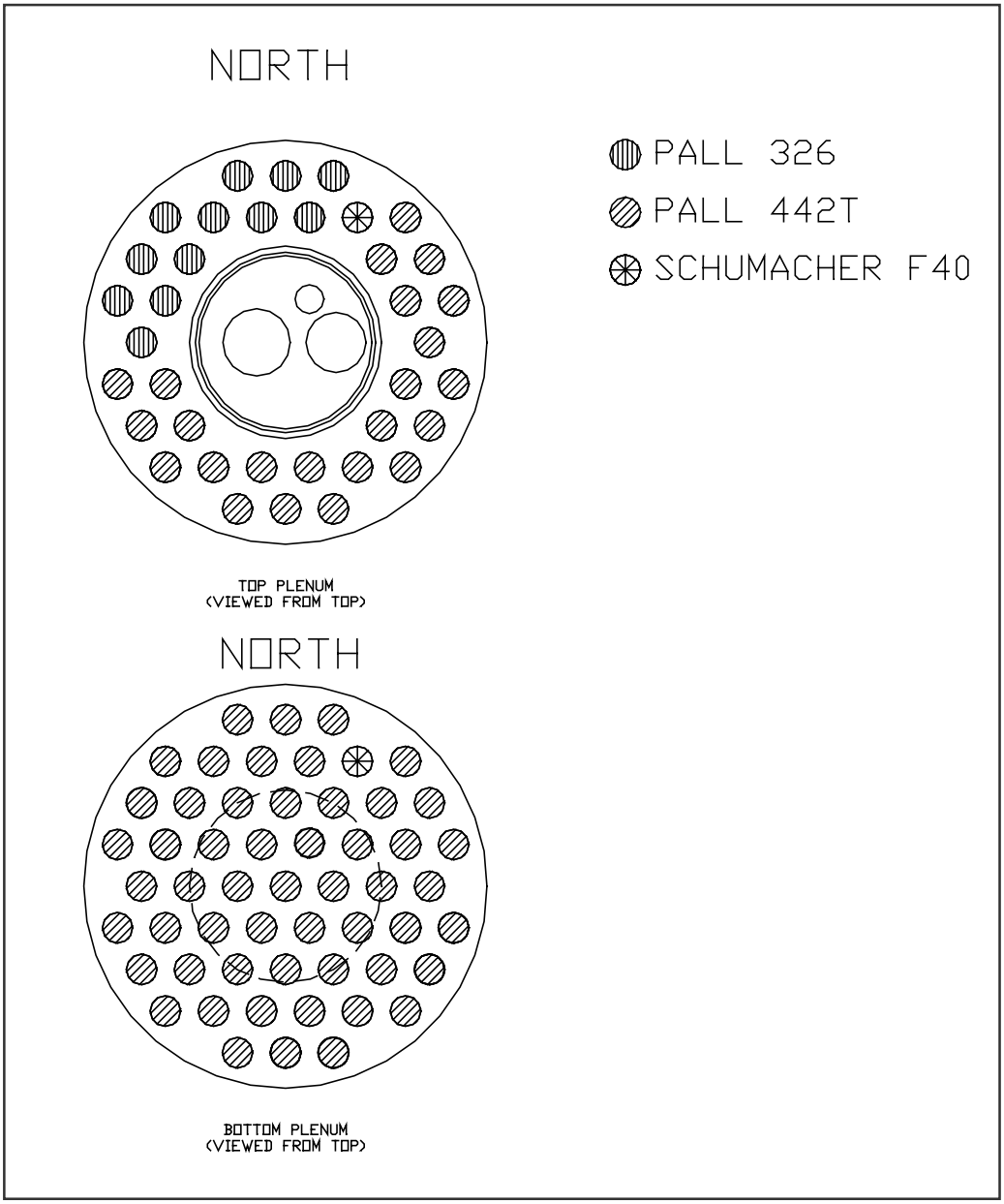


Figure 3.3.1-1 Filter Element Layout for CCT4B (Layout No. 2)

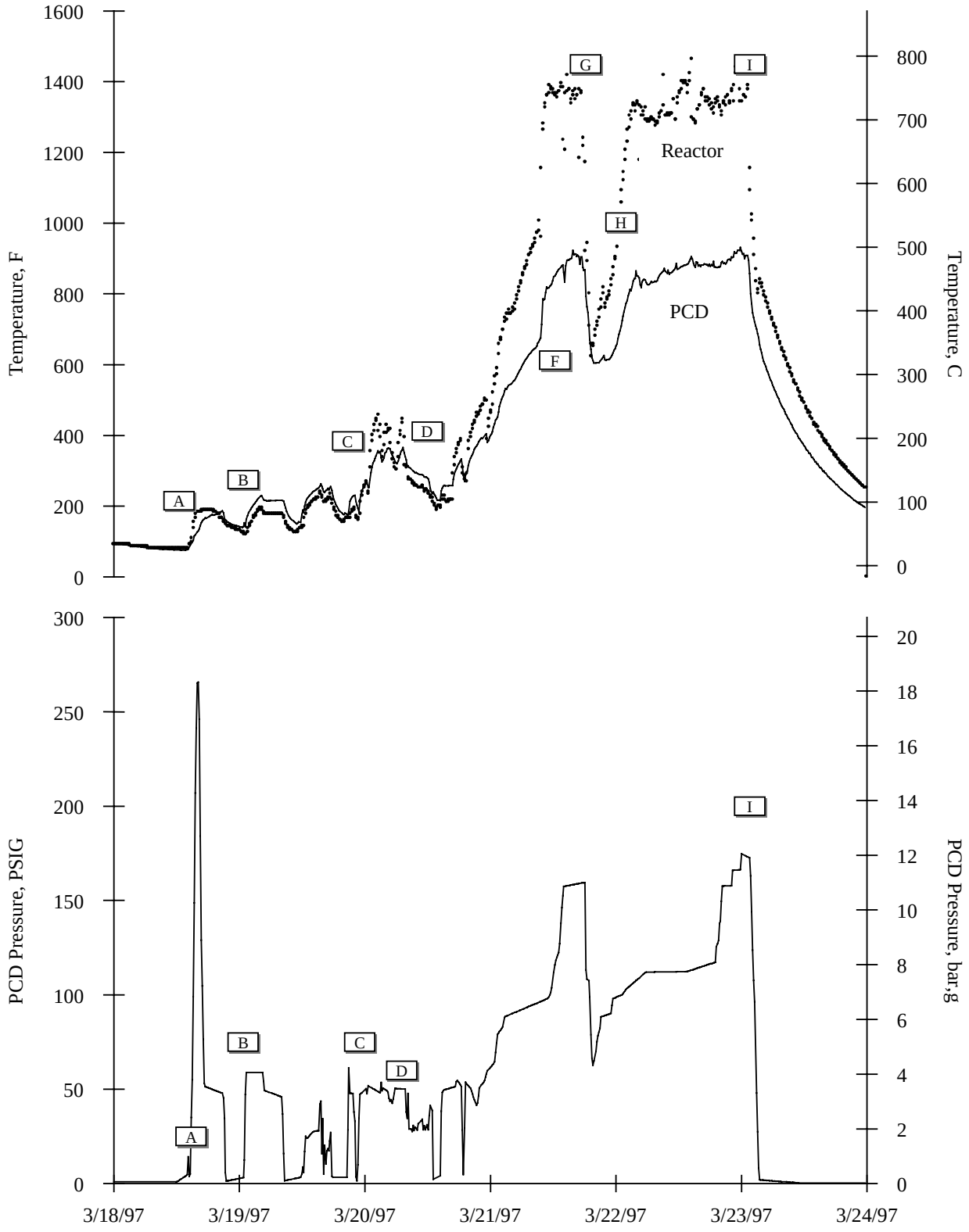


Figure 3.3.1-2 CCT4B Temperature and Pressure for March 18 Through 24, 1997

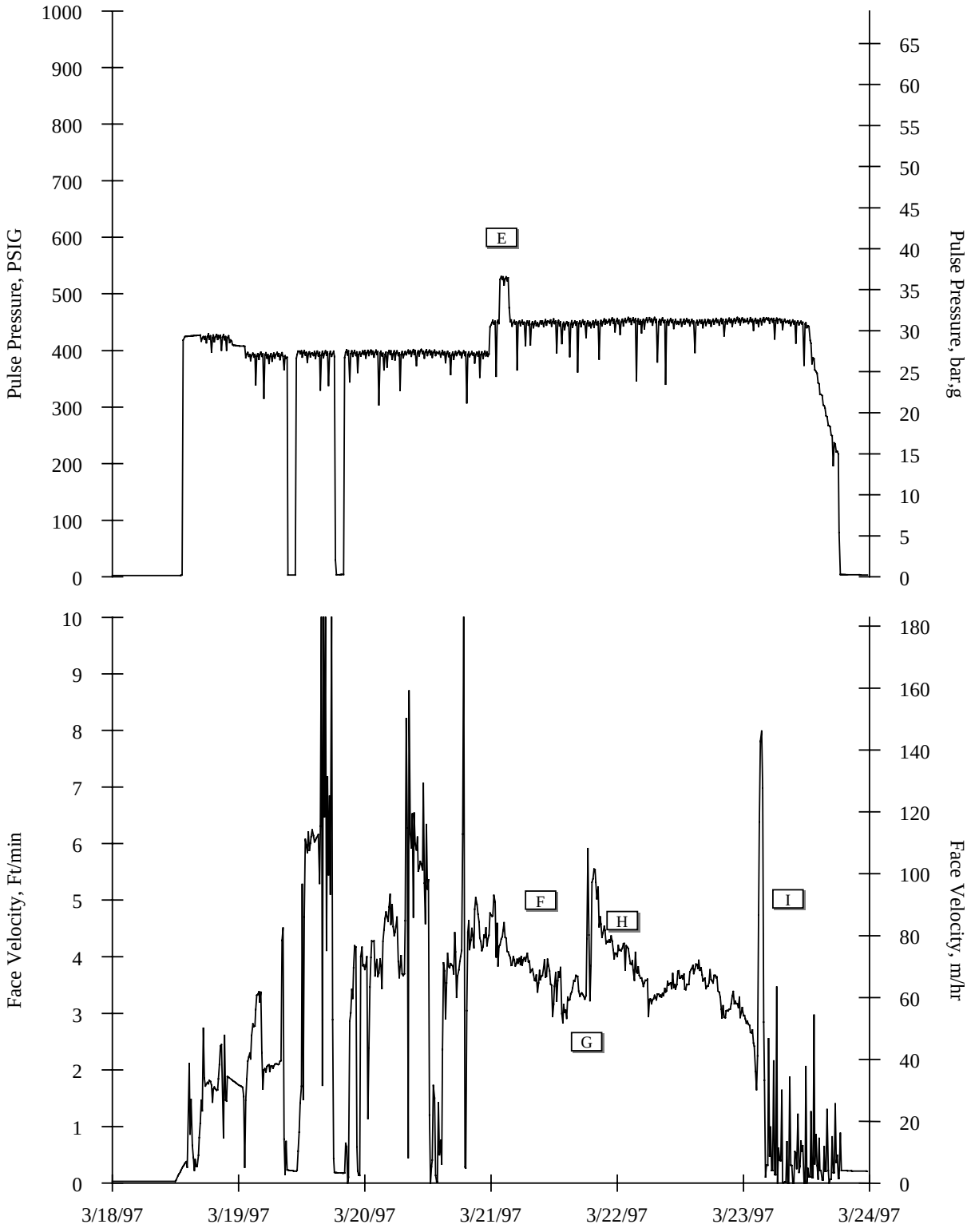


Figure 3.3.1-3 CCT4B Pulse Pressure and Face Velocity for March 18 Through 24, 1997

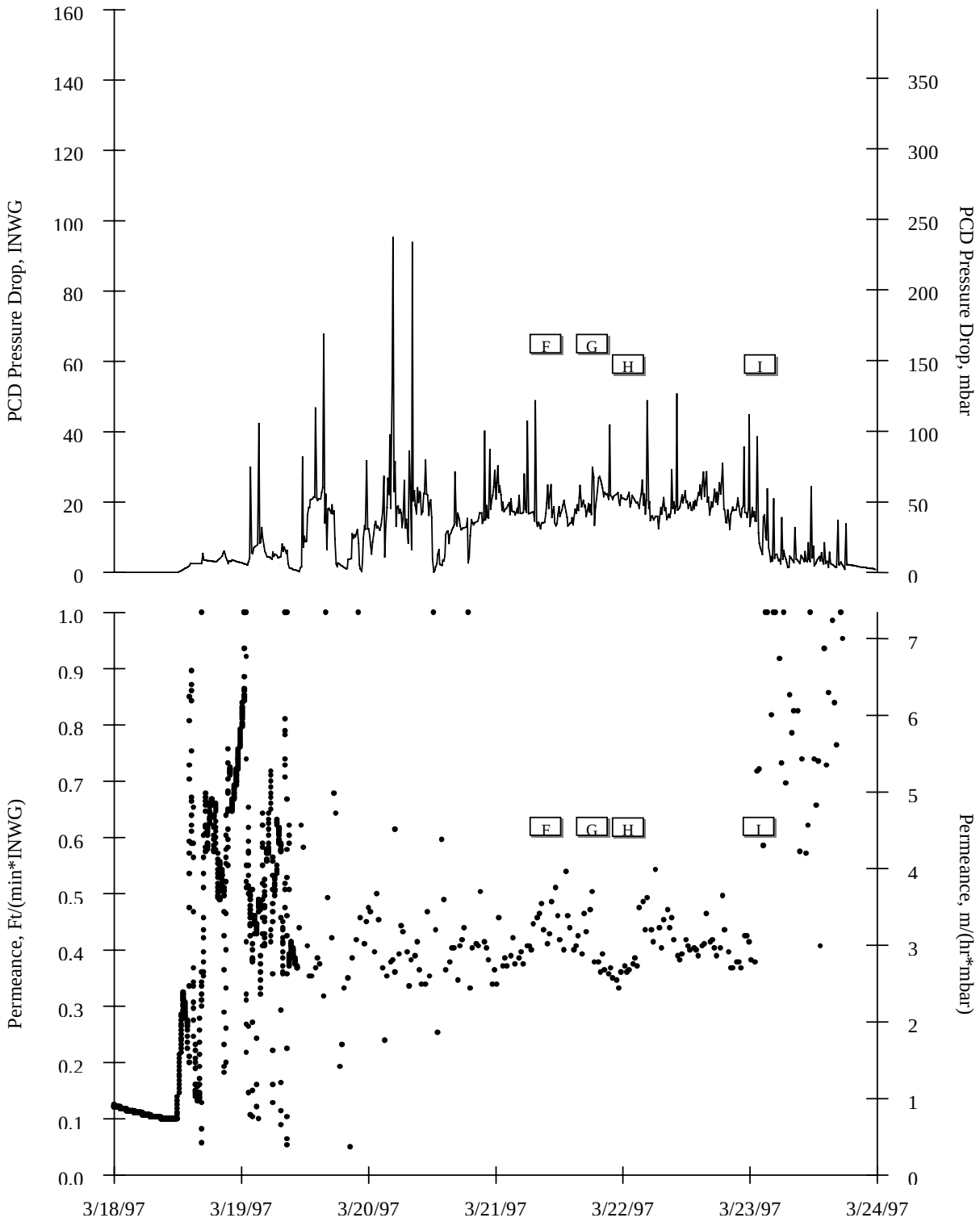


Figure 3.3.1-4 CCT4B PCD Pressure Drop and Permeance for March 18 Through 24, 1997

3.3.2 Test Objectives

The primary test objective for PCD operation was to support transport reactor operation in the analysis of understanding the solid separation problems. Several test objectives for the PCD were scheduled in the event that transport reactor operation was adequately understood to proceed with a period of stable operation. The PCD objectives were as follows:

- Operate at a nominal filter temperature of 1,200°F (649°C).
- Evaluate pulse valve performance when increasing the back-pulse to PCD pressure ratio.
- Take inlet samples with SRI cyclone manifold.
- Confirm SRI particulate loading by collecting all of the ash from the PCD spent fines transport system.
- Estimate the PCD "cut size" by turning off the pulse system to collect a coarse ash sample, and then by back-pulsing the filter elements to collect a fine ash sample. The PCD vessel was believed to have been operating like a cyclone and separating out larger particulate that never reached the filter elements.
- Vary the ash level in the PCD cone to determine the effectiveness of the thermocouples added to the PCD cone in monitoring the ash level.

3.3.3 Observations/Events

A. Test Started – Main Air Compressor (MAC) Started – March 18 at 14:45. No leaks were found in the transport reactor or the PCD during the system pressure test. However, a leak developed after the pressure test in a MAC Victualic coupling and the MAC was shutdown for repair.

B. MAC Restarted – March 19 at 00:42. After the MAC was restarted there were unsuccessful attempts to light the start-up burner. The MAC was shut down. The MAC was being tuned for most of the day by the manufacturer's service representative.

C. Start-up Burner Lit – March 19 at 23:00. After the start-up burner igniter was replaced the start-up burner operated successfully. The MAC began to surge and the start-up burner had to be relit twice into the early hours of March 20.

D. MAC Tuning – March 20 at 07:00. The MAC was shutdown for tuning. The MAC was started back up at 15:00.

E. Back-Pulse Pressure Increased for Testing – March 21 at 02:00. When the back-pulse pressure was raised in CCT4A a drop in the back-pulse mass flow was noticed. Data was collected to analyze the performance problem.

F. Started Coal Feed – March 21 at 09:25.

G. Lost Coal Feed – March 21 at 18:10. The FD0210 middle spheri valve seal failed.

H. Restarted Coal Feed – March 21 at 09:00.

I. Test Ended. Transport Reactor Shutdown – March 23 at 01:33. The decision was made to shut down the transport reactor because of problems with FD0520. The bottom spheri valve was not closing far enough to close the limit switch.

3.3.4 Run Outcome

The transport reactor was shut down because of problems with the FD0520 middle spheri valve. The spheri valve was not closing far enough for the limit switch to close.

The data collected during the back-pulse continued to indicate a drop in the back-pulse flow when the back-pulse pressure was raised above 450 psig (31 bar,g). This phenomenon was studied extensively during runs TC01C through TC01E. The results are covered in section 3.27, Pulse Valve Report.

As planned, the 55-gallon drum collector was tested and used during, CCT4B. The objective of the drum collector was to collect all of the particulate going to the PCD before, during, and after SRI collected an inlet sample with the inlet sampling system. The results of this testing from the drum sampler are discussed in section 3.7, CCT4 Ash Characteristics and PCD Performance.

The operation of the TR was not stable enough to allow a purposeful increase in the PCD cone ash level when slowing the screw cooler, FD0502. The objective was to raise the ash in the PCD cone, observe the temperature trends in the PCD hopper, and determine the effectiveness of the new thermocouples in monitoring the ash level. The objective was met, however, only because of the unstable operation of the transport reactor and the numerous FD0520 trips. The new thermocouples located in the PCD cone were reliable in detecting accumulated ash.

Operating problems with the transport reactor prevented the pulse system from being turned off, as planned, to collect samples from FD0520 and determine the PCD "cut size."

Table 3.3.4-1

CCT4B Run Statistics

Start Time:	3/18/97 14:45
End Time:	3/23/97 01:33
Coal Type:	Calumet Alabama Bituminous
Hours On Coal:	22
Sorbent Type:	Plum Run Dolomite
Number of Filter Elements:	91
Filter Element Layout No.:	2 (Figure 3.3.1-4)
Filtration Area:	255 ft^2 (23.7 m^2)
Pulse Valve Open Time:	0.2 to 0.3 seconds
Pulse Time Trigger:	30 minutes
Pulse Pressure:	400 to 530 psig (27.6- 36.5 bar,g)
Pulse DP Trigger:	100 inWG (249 mbar)

Table 3.3.4-2

CCT4B Major Events (Refer to Figures 3.3.1-2 Through 3.3.1-4)

Event	Description	Date at Time
A	Test Started	3/18 at 14:45
B	MAC Restarted	3/19 at 00:42
C	Start-up Burner Lit	3/19 at 23:00
D	Sand Feed to TR Started	3/20 at 07:00
E	Back-pulse Pressure Increased for Testing	3/21 at 02:00
F	Started Coal Feed	3/21 at 09:25
G	Lost Coal Feed	3/21 at 18:10
H	Restarted Coal Feed	3/22 at 00:47
I	Test Ended. Transport Reactor Shutdown	3/23 at 01:33

3.4 PCD OPERATION DURING TEST RUN CCT4C

3.4.1 Run Summary

Combustion characterization test CCT4C was started late on April 5, 1997, for the purpose of analyzing the solid separation problems of the transport reactor (RX0201), specifically those involving the primary cyclone (CY0201). Problems with excessive carryover to the PCD from RX0201 continued to occur in CCT4A and CCT4B, so a formal test campaign was developed as a mechanism for understanding this problem. This test campaign was implemented as CCT4C.

During the normal course of MWK start-up activities, it is necessary to feed sand to RX0201 to increase the reactor bed level and begin solid circulation prior to coal feed. During this sand addition phase of the start-up activities for CCT4C, the discharge piping of the spent fines transport system (FD0520) became plugged with what was soon discovered to be pieces of filter elements. It was then decided to end the test in order to inspect the PCD for broken filter elements. Upon inspection, several filter elements were found to be broken and many others significantly cracked. Subsequent data analysis suggested that during feed of sand, coal was inadvertently fed to the reactor and carried over to the PCD where it ignited and caused a 170°-temperature increase (77°C) in the PCD outlet temperature over a period of 13 minutes. The extreme thermal stress of the combustion event, which manifested itself in the sharp rate of increase of the PCD outlet temperature, was deemed the cause of the severe damage to the filter elements in the PCD.

3.4.2 Test Objectives

The primary test objective for PCD operation was to support reactor operation in the analysis of the solid separation problems. Several objectives for PCD operation were scheduled in the event that reactor operation was adequately understood to proceed with a period of stable reactor operation after the solid separation tests. These PCD objectives were outlined prior to the test and are included below:

- Pulse clean, using high-pressure nitrogen. The objective was to see if using high-pressure nitrogen for back-pulsing would improve the performance of the back-pulse system. During runs CCT4A and CCT4B the back-pulse flow dropped off whenever the back-pulse pressure was increased above 450 psig (31.0 bar). Demonstrating the high-pressure nitrogen system operation prior to gasification was also part of the objective. If any problems had been experienced during this run with the high-pressure nitrogen system the Norwalk compressor would have been used to provide high-pressure air for back-pulsing. If required (or desired), nitrogen could be fed to the Norwalk.

- Evaluate MWK cyclone modifications and transport reactor operation. This was an objective throughout the test run. It involved SRI taking inlet and outlet samples under varying reactor conditions.

- Evaluate pulse valve performance. The back-pulse system experienced flow problems during CCT4A and CCT4B, and the pulse valves were suspected to be the problem. Monitoring the valve performance using a high-speed data acquisition system (if available in time) was planned.

- Take inlet and outlet samples under steady state conditions.

- Take PCD inlet sample with cyclone manifold. SRI had modified a stainless steel, multistage cyclone assembly for testing on the PCD inlet during the run if the PCD temperature was below 1,200°F (649°C).

- Confirm SRI particulate loading. It was necessary to confirm the particulate loading determined by SRI. This would be done by using the drum sampler to collect all of the ash carried over to the PCD for a period of time before, during, and after SRI sampling.

- Estimate "cut size" of PCD. This was to be done to estimate what size particulate was making it to the filter elements. It would be accomplished by turning off the back-pulse system (if conditions permitted) for 1 or 2 hours and collecting the sample from FD0520. The filter elements would then be pulse cleaned and the sample collected in a separate drum.

- Vary the ash level in the PCD cone. Two new thermocouples were added to the cone to help in monitoring ash level. At the end of the test the speed of the fine ash screw cooler (FD0502) would be decreased to see if a level could be built (controllably) and maintained in the PCD cone. The effectiveness of the new thermocouples for measuring ash level could be determined in this manner.

3.4.3 Observations/Events

A. Test Started – April 5 at 23:50. The main air compressor (CO0201) was started late on April 5 to begin CCT4C. The pressure test had been performed on April 4.

B. Start-up burner pilot lit – April 6 at 22:00.

C. Start-up burner main lit – April 7 at 04:00.

D. Sand feed to RX0201 started – April 7 at 09:25. Approximately 3,200 lb (1,451 kg) of solids (sand with a suspected, unknown amount of coal) were fed into the reactor between 09:25 and 10:00.

E. Start of temperature transient in PCD – April 7 at 09:48. Several temperature indications in the PCD showed considerable increases starting at 09:48. These increases were in contrast with the behavior of the PCD inlet temperature, which was decreasing due to the decrease in RX0201 temperature resulting from addition of cold solids (sand). Indications in the PCD showed four definite temperature rises over the course of the event, implying that there were four separate combustion events which contributed to the overall temperature transient as shown in figure 3.4.4-1.

F. Peak of PCD temperature transient – April 7 at 10:01. The PCD outlet temperature increased from about 400°F (204°C) to about 570°F (299°C) in approximately 13 minutes, which translates into a rate of increase of approximately 780°F/hr (420°C/hr).

G. Spent fines transport system discharge plugged – April 7 at 10:09. The FD0520 system conveying pressure increased normally, indicating it was conveying solids from its discharge vessel; but the pressure in the vessel remained elevated, indicating that the discharge piping was plugged. Circulation of solids in the reactor was stopped so that the cause of the blockage could be ascertained. Upon disconnection of the FD0520 discharge piping and inspection, ceramic pieces of filter elements were found to be the cause of the blockage. The decision was then made to shut down the MWK system in order to inspect the PCD for suspected filter breakage.

H. Test ended – April 7 at 14:00. After shutting down the start-up burner (CO0201) was run for a while to cool the system. CO0201 was then shut down, signifying the end of the test run.

3.4.4 Run Outcome

The inspection of the PCD is detailed in section 3.5 of this report, but in summary, all of the filter elements were severely damaged due to thermal stress. During discussions of the events of CCT4C among Southern Company and MWK personnel, the conclusion was reached that the damage to the filter elements was ultimately caused by the inadvertent feed of coal into the system at temperatures below which the coal would combust in the reactor. The coal, having not burned in the reactor, was carried over to the PCD and somehow combusted in the PCD, causing extreme thermal stress to the elements. The inadvertent coal feed was attributed to the interchangeable use of the coal feeder as a RX0201 bed material (sand) make-up feeder and a coal feeder. It was then decided that whichever feeder was being used as the coal feeder for a particular test run would be used only to feed coal for that run and would be thoroughly inspected prior to its use in subsequent runs for feeding a material other than coal.

In the aftermath of the temperature transient in the PCD and the resulting severe damage to the filter elements, several solid samples were analyzed to try to better understand the mechanism which caused the transient. Loss on ignition (LOI) tests were performed on samples from the RX0201 bed, the PCD solids outlet cone, and the top plenum filter elements. The results are shown in table 3.4.4-1.

The sample location HX0203 in RX0201 indicates that the sample was taken from the combustion heat exchanger. The sample taken from the MWK ash silo consisted exclusively of solids from the PCD since the FD0520 system was the only system feeding the silo during the run. The results of these tests clearly show that there was considerable combustible material in the PCD, further supporting the conclusion that combustion occurred in the PCD. The high LOI coupled with the measured d_{50} of the solids from the top plenum, which was approximately 4 μm, combined to produce a situation highly suitable for combustion (excluding temperature), one with a relatively large amount of combustible material and large surface area. In contrast, the d_{50} of the reactor solids was measured at approximately 300 μm, and the LOI was low, as shown in table 3.4.4-1.

Table 3.4.4-1

Loss on Ignition Tests for CCT4C Solid Samples

Sample Location	Sample Date	LOI (wt %)
RX0201 (noz A31)	April 10	1.74
RX0201 (HX0203)	April 11	4.21
RX0201 (noz H4)	April 15	2.96*
RX0201 (HX0203)	April 15	0.412*
RX0201 (HX0203)	April 15	0.302*
PCD Cone	April 9	9.68
Top Plenum	April 10	5.03
MWK Ash Silo	April 16	19.6*

* Average of two LOI tests.

Table 3.4.4-2

CCT4C Run Statistics

Start time:	April 5 at 23:50
End time:	April 7 at 14:00
Coal type:	No deliberate coal feed
Hours on coal:	N/A
Sorbent type:	No sorbent feed
Number of filter elements:	91
Filter element layout number:	2 (see figure 3.4.4-4)
Filtration area:	255 ft^2 (23.7 m^2)
Pulse valve open time:	0003 seconds
Pulse time trigger:	30 minutes
Pulse pressure:	450 to 500 psig (31.0-34.5 bar,g)
Pulse DP trigger:	100 inWG (249 mbar,g)

Table 3.4.4-3
CCT4C Major Events (Refer to Figures 3.4.4-1 through -3)

Event	Description	Date at Time
A	Test started	April 5 at 23:50
B	Start-up burner pilot lit	April 6 at 22:00
C	Start-up burner main lit	April 7 at 04:00
D	Sand feed to RX0201 started	April 7 at 09:25
E	Start of temperature transient in PCD	April 7 at 09:48
F	Peak of PCD temperature transient	April 7 at 10:01
G	Spent fines transport system discharge plugged	April 7 at 10:09
H	Test ended	April 7 at 14:00

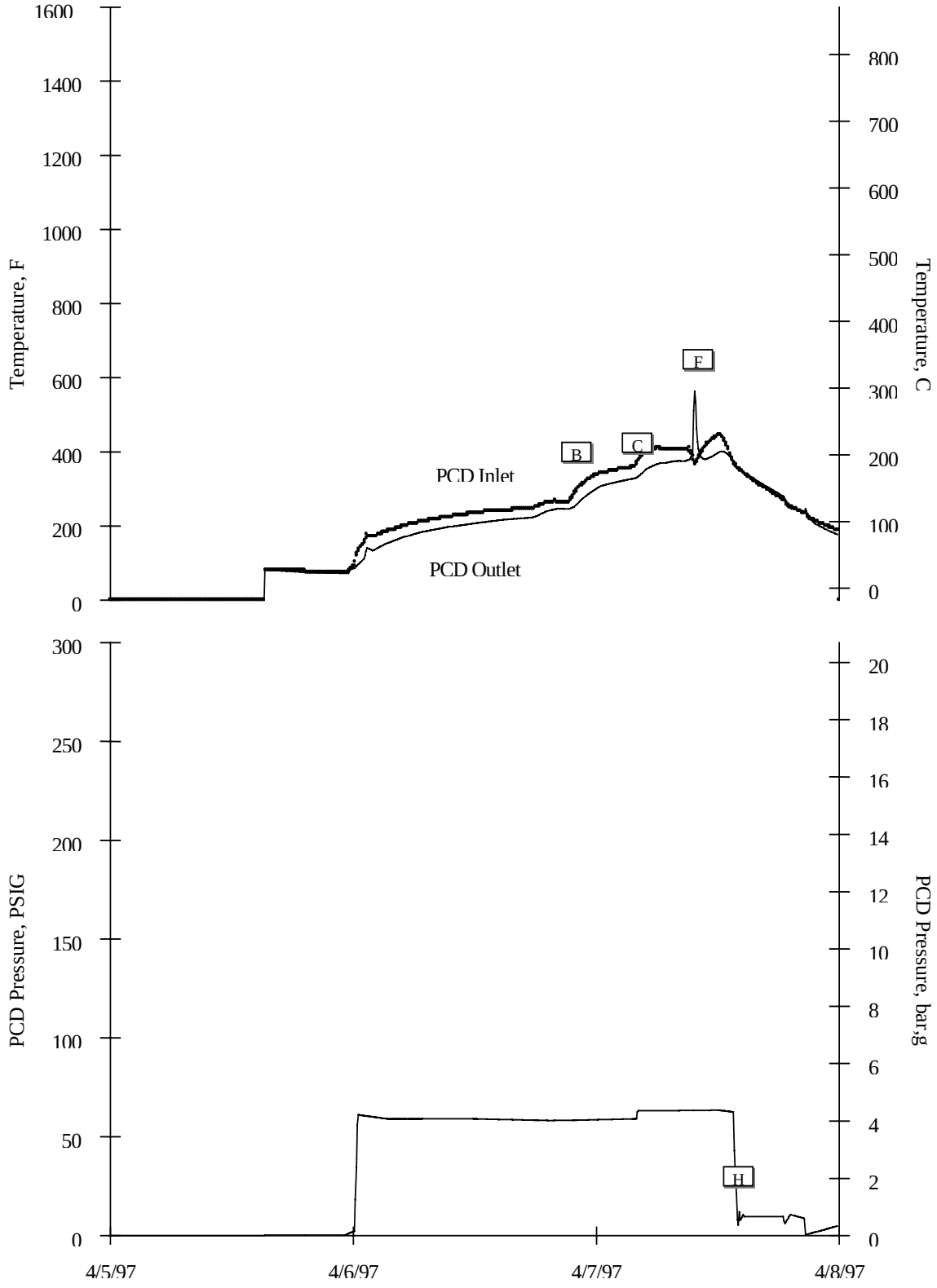


Figure 3.4.4-1 CCT4C Temperature and Pressure for April 5 Through 7

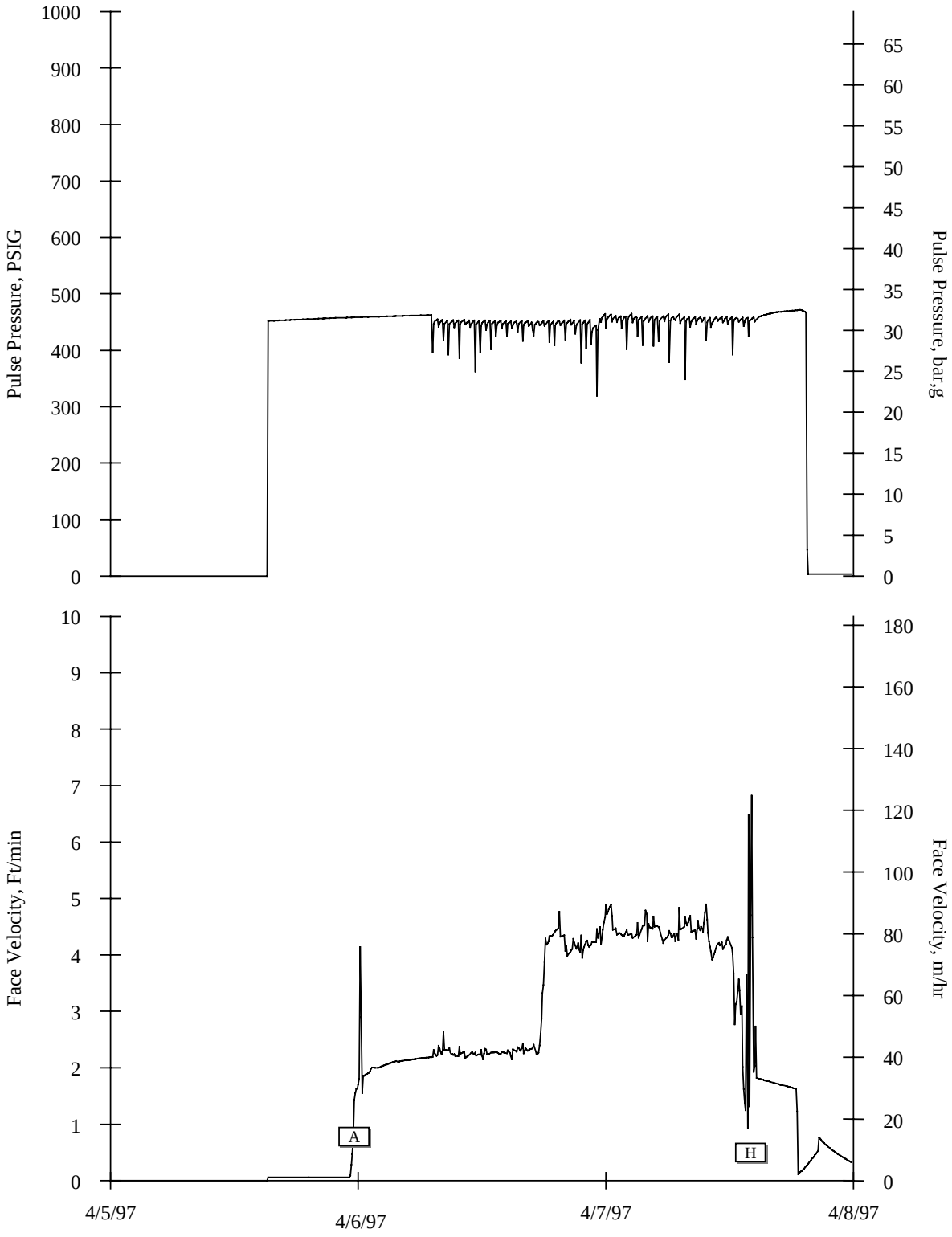


Figure 3.4.4-2 CCT4C Pulse Pressure and Face Velocity for April 5 Through 7

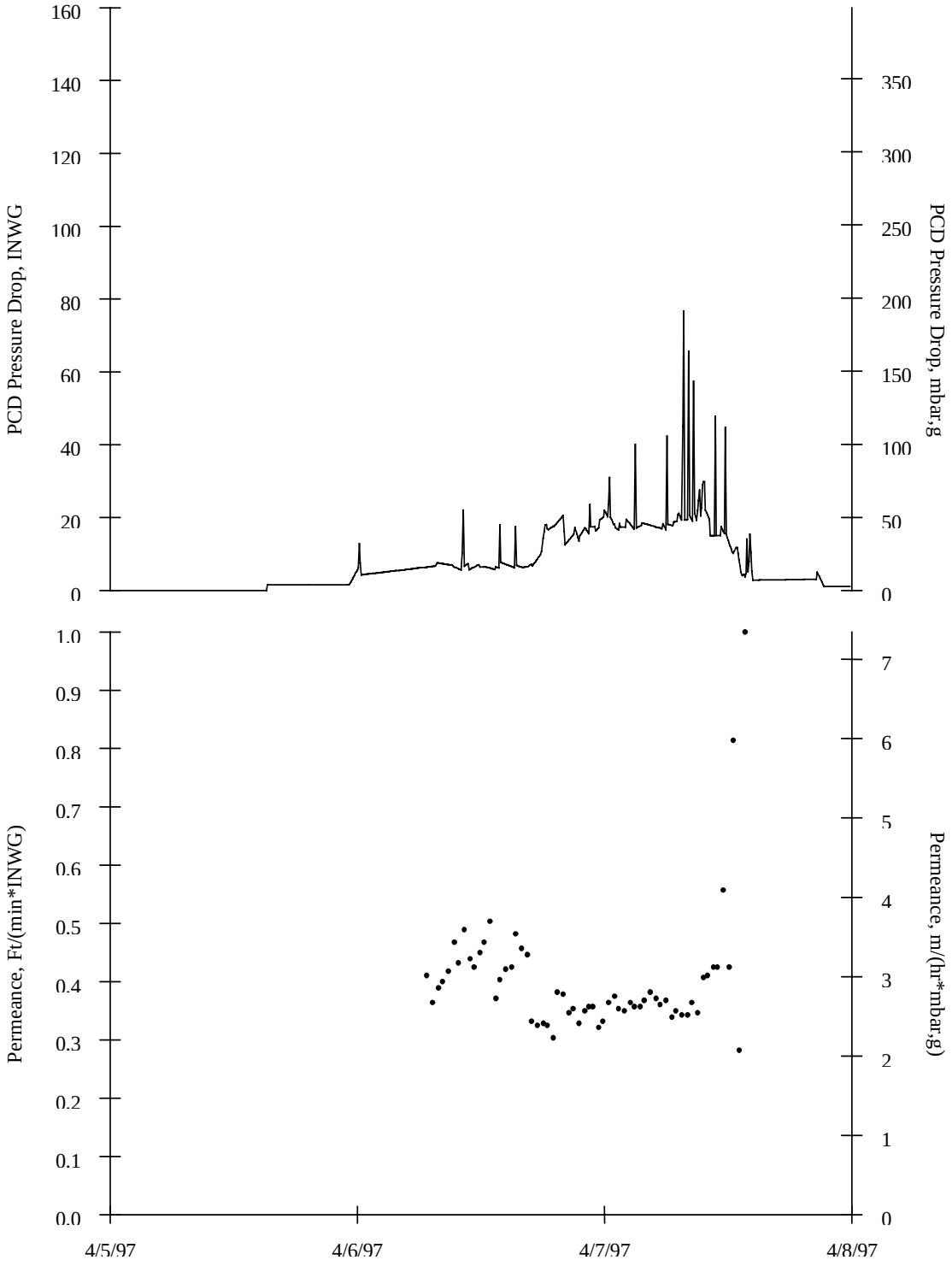


Figure 3.4.4-3 CCT4C Pressure Drop and Permeance for April 5 Through 7

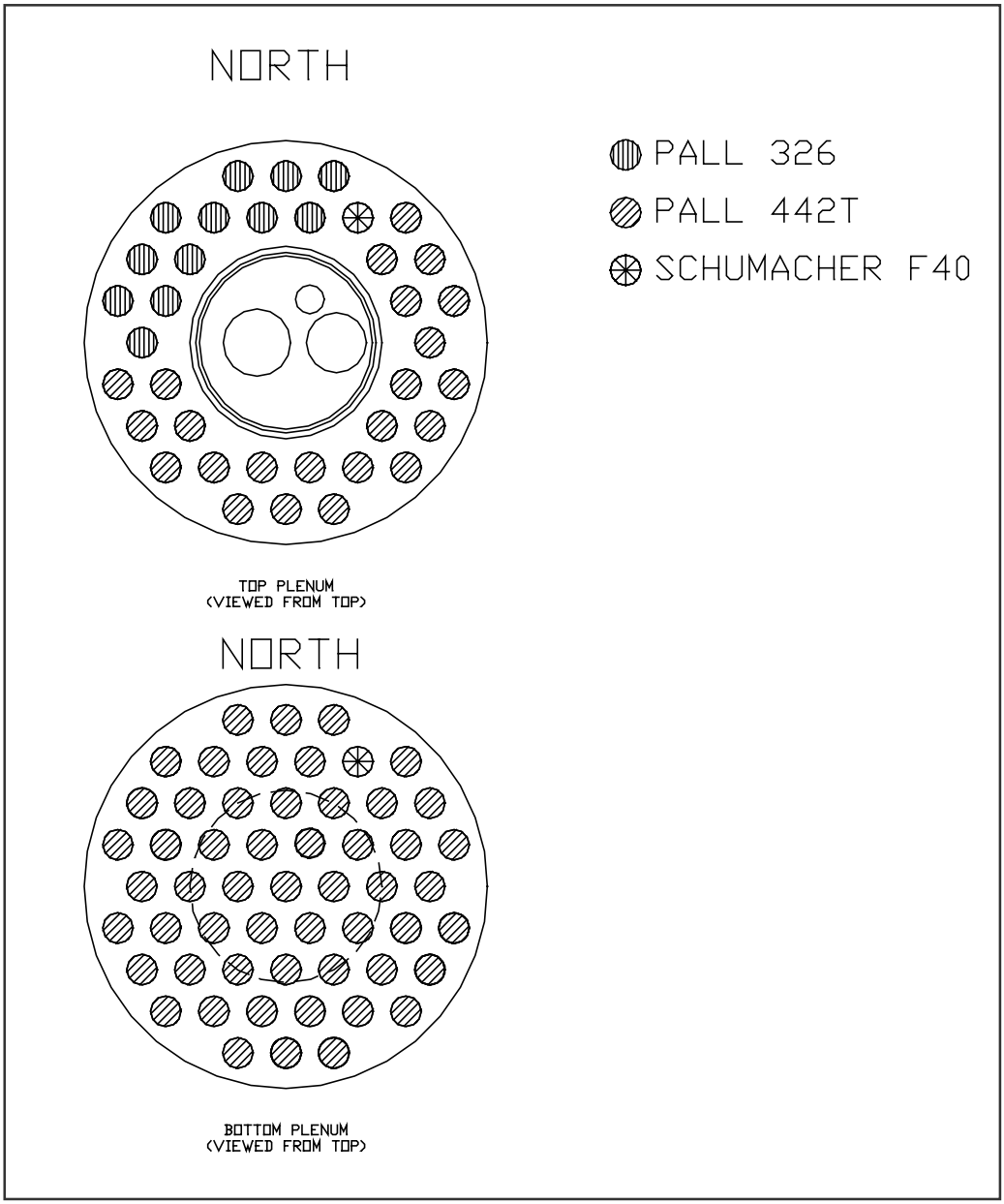


Figure 3.4.4-4 Filter Element Layout for CCT4C (Layout No. 2)

3.5 PCD INSPECTION CCT4C

3.5.1 PCD Inspection

Inspection of the PCD was conducted April 8, 1997, and began with an inspection of the bottom plenum of filter elements through the lower vessel man-way. Upon initial inspection, no elements in the bottom plenum appeared to be damaged. It was assumed, therefore, that the broken pieces resulted from element failure in the top plenum and that the run may have been able to continue if the damage was minimal. Several attempts were made to see the elements in the top plenum from the bottom man-way door, but only those on the outside edge were visible and none appeared broken. It was then decided that the vessel would be fully entered through the bottom man-way door to completely inspect the outer ring of filter elements. A borescope was also prepared for a more extensive inspection of the top plenum.

As the entry through the bottom man-way and the borescope inspection of the top plenum were being prepared, three elements in the bottom plenum seemed to spontaneously break and the broken fragments fell into the solids cone. It was then decided that the vessel entry, and any future entry into the vessel under the cluster with installed filter elements, would be unsafe and would not be implemented. The borescope inspection proceeded, and it was discovered that three elements in the top plenum were broken off at varying points along their lengths. It is not known exactly when these elements broke. It is probable that at least one broke during the run, given the filter element fragments found in the spent fines transport system discharge piping. There is evidence that at least one of the elements spontaneously broke as the vessel entry was being prepared and that the broken fragments fell to the bottom plenum and caused the observed breakage of the three elements on the bottom plenum.

Due to the breakage of filter elements in the bottom plenum during the inspection it was decided that the structural integrity of the remaining elements was in question and that the entire cluster of elements had to be removed for inspection.

3.5.2 Cluster Inspection

Removal of the internals took place on April 9, 1997. During removal of the cluster (see figure 3.5.2-1) several more filter elements broke and fell to the solids outlet cone of the PCD. Inspection of the cluster of filter elements revealed many cracks, mostly circumferential (see figure 3.5.2-2) but some longitudinal, over the surface of the elements. At several of the places in the filter elements where pieces had broken off it was evident from a dark discoloration on one side of the broken edge that there had initially been a crack and that ash had penetrated into the crack and may have ultimately caused the element to break. Whatever the failure mechanism, it was evident that the elements were first cracked by thermal stress and then broke due to the structural weakness caused by the cracks. Figure 3.5.2-3 shows examples of the types of fractures that occurred as a result of the thermal event. Additional observations included a sort of dark gray spotting phenomenon on the surface of the elements and the almost black appearance of the ash on the elements, suggesting the presence of combustible material and/or a combustion occurrence. Of the elements in this layout, the Pall 326 elements seemed to have the least cracks and appeared to be the most resistant to thermal shock.

After inspection, it was decided that the entire cluster of filter elements would be replaced. The remainder of April 9 was spent removing the filter elements from filter element layout 2 and preparing to install new elements.

Figure 3.5.2-1 CCT4C Inspection – Initial Cluster Removal

Figure 3.5.2-2 CCT4C Inspection – Filter Element Cracking

Figure 3.5.2-3 CCT4C Inspection – Top Plenum View

3.5.3 Filter Element Layout No. 3

Installation of filter elements for filter element layout no. 3 occurred April 10 and 11. As in filter element layout 2, all new elements were installed. However, this time all the elements were directly from the manufacturers as opposed to some being unused elements from the Tidd project as in layout 2. The exception to this is that one element was supplied by Dr. Roger Chen of West Virginia University as part of his nondestructive element testing campaign. Of the 91 elements (36 in the top plenum and 55 in the bottom plenum), 61 were Pall 442T elements (15 in the top and 46 in the bottom). There were also 10 Pall 326 elements (all in the top plenum) and 19 Coors P-100A elements (10 in the top and 9 in the bottom). The element supplied by Dr. Chen was a Schumacher F40 element and was located in the top plenum.

3.6 PCD OPERATION DURING TEST RUN CCT4D

3.6.1 Run Summary

After the fire in the particulate control device (PCD) that occurred on April 7, new filter elements were installed in the PCD prior to beginning combustion characterization test CCT4D. For the first time at the PSDF, filter elements from Coors Ceramics Company would be tested. After the short runs in CCT4A-C, CCT4D would combust coal for 173 hours — the longest run to date. However, as evidenced by the temperature plots shown in figures 3.6.1-4 and 3.6.1-7, the coal feed was not continuous. Pluggages in the coal feeder and transport reactor instabilities caused loss of coal feed and loss of temperature on several occasions.

Although there were a few PCD objectives for this run segment, the primary purpose of the run was to let the transport reactor engineers continue experimenting with the system to improve the performance of the primary cyclone. The results of their efforts were beginning to be evidenced in the lower permeance values for CCT4D in comparison to CCT4A-C. By the end of CCT4D the system permeance was approximately 0.3 ft/(min * inWG) (2.2 m/(hr*mbar)), while at the end of CCT4B the permeance was about 0.4 ft (min * inWG) (2.9 m/(hr*mbar)), a 25-percent decrease. This can mostly be attributed to the ongoing decrease in median particle size. The face velocity for both runs was comparable around 4 ft/min (20.3 mm/s), but the baseline pressure drop was slightly higher than in previous runs. The PCD temperature remained at 1,000°F (537°C) for this run.

The major PCD objectives included verification of Southern Research Institute's (SRI) mass train particulate loadings and continuing to investigate the flow phenomena associated with the pulse valves. For this run the pulse media was nitrogen. The main reason for changing to nitrogen was to eliminate entrained water vapor as a possible problem and to prepare for gasification runs. The nitrogen used for pulsing is generated by on-site vaporization of liquid nitrogen, so the possibility of water vapor in the gas is remote. In addition, all four valves (primary and back-up) were actuated. Throughout the testing to date the primary valves alone had been used. Testing the back-up valves allowed the elimination of mechanical wear as a possible problem. By the end of CCT4D it was apparent that there was a problem associated with the valves and/or piping. Quantifying the phenomena would occur in CCT5A.

Table 3.6.1-1

CCT4D Run Statistics

Start Time:	April 19–19:30
End Time:	May 3–01:05
Coal Type:	Calumet Alabama Bituminous
Hours On Coal:	173
Sorbent Type:	Plum Run Dolomite
TR Bed Material	Sand
Number of Filter Elements:	91
Filter Element Layout No.:	3 (Figure 3.6.1-10)
Filtration Area:	255 ft^2 (23.7 m^2)
Pulse Valve Open Time:	0.3 seconds
Pulse Time Trigger:	30 minutes
Pulse Pressure:	450-500 psig (31-34.5 bar,g)
Pulse ΔP Trigger:	100 inWG (248.8 mbar,g)

Table 3.6.1-2

CCT4D Major Events (Refer to Figures 3.6.1-1 through -9)

Event	Description	Date at Time
A	Tuning of MAC	April 16-17
B	MAC Started; Run Begins	April 19 at 19:30
C	Pressure Test of Reactor System	April 21 at 08:35
D	PCD Preheat Started	April 21 at 12:15
E	Sub Lit	April 21 at 13:38
F	Started Feeding bituminous Coal	April 22 at 19:45
G	Increased Pulse Pressure	April 23 at 19:00
H	Coal Feed Lost	April 25 at 07:10
I	Coal Feed Resumed	April 26 at 18:33
J	Coal Feed Lost	April 28 at 03:30
K	Coal Feed Resumed	April 29 at 04:00
L	Coal Feed Lost	April 29 at 14:10
M	Coal Feed Resumed	April 30 at 01:10
N	Coal Feed Lost	April 30 at 14:15
O	Coal Feed Resumed	May 1 at 04:00
P	Test Run Ends	May 3 at 01:05

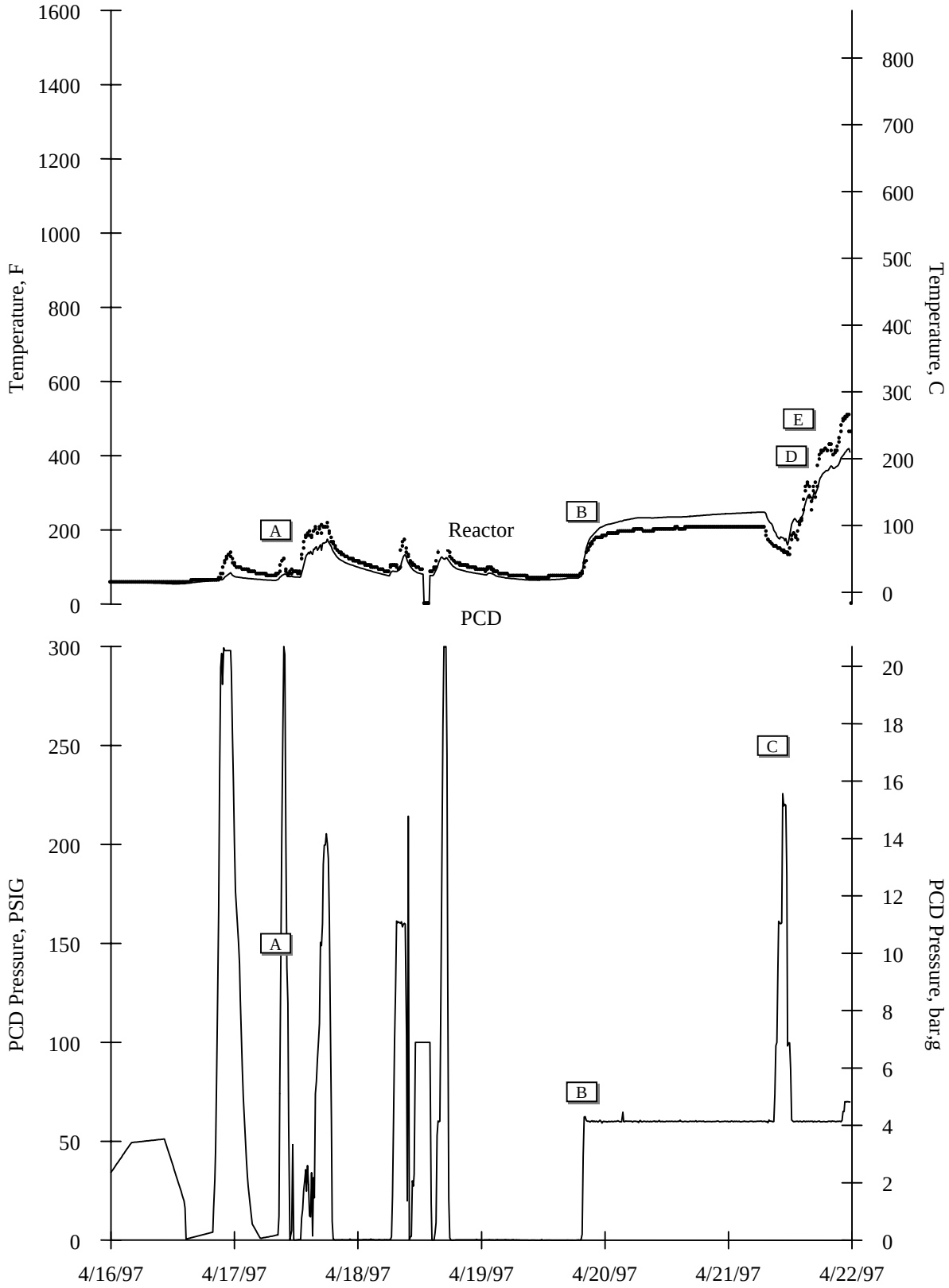


Figure 3.6.1-1 CCT4D Temperature and Pressure for April 16 to 22

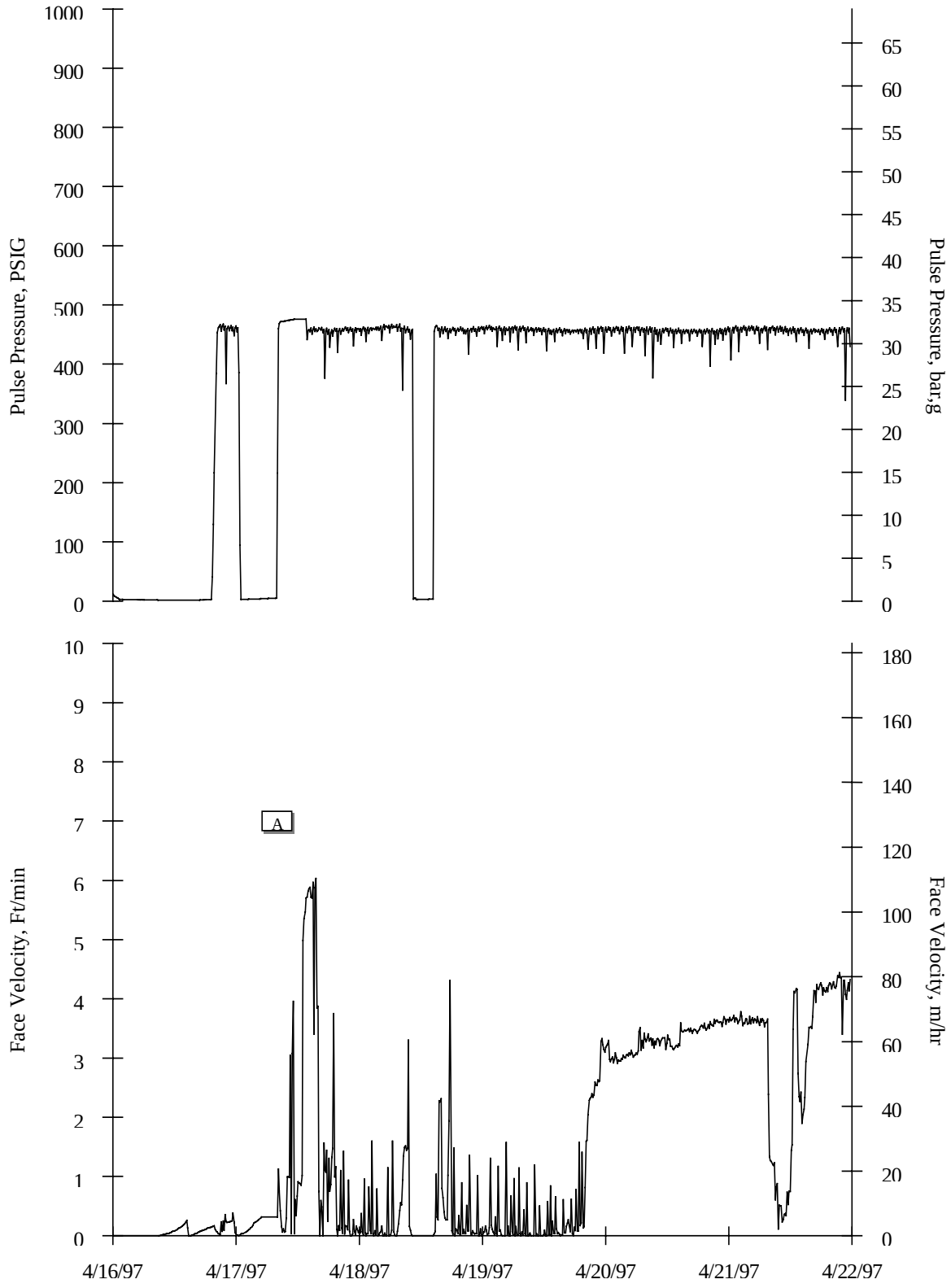


Figure 3.6.1-2 CCT4D Pulse Pressure and Face Velocity for April 16 to 22

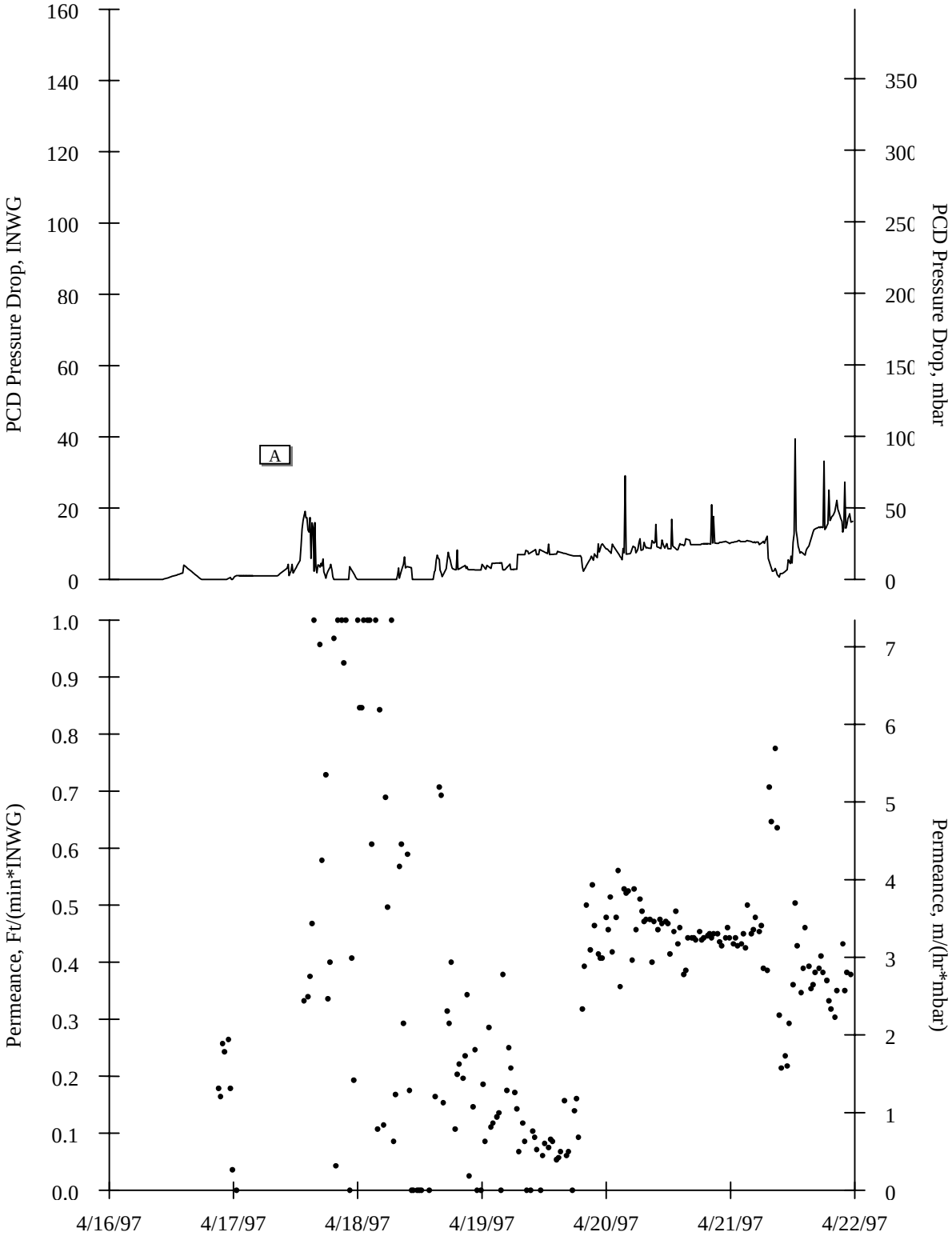


Figure 3.6.1-3 CCT4D Pressure Drop and Permeance for April 16 to 22

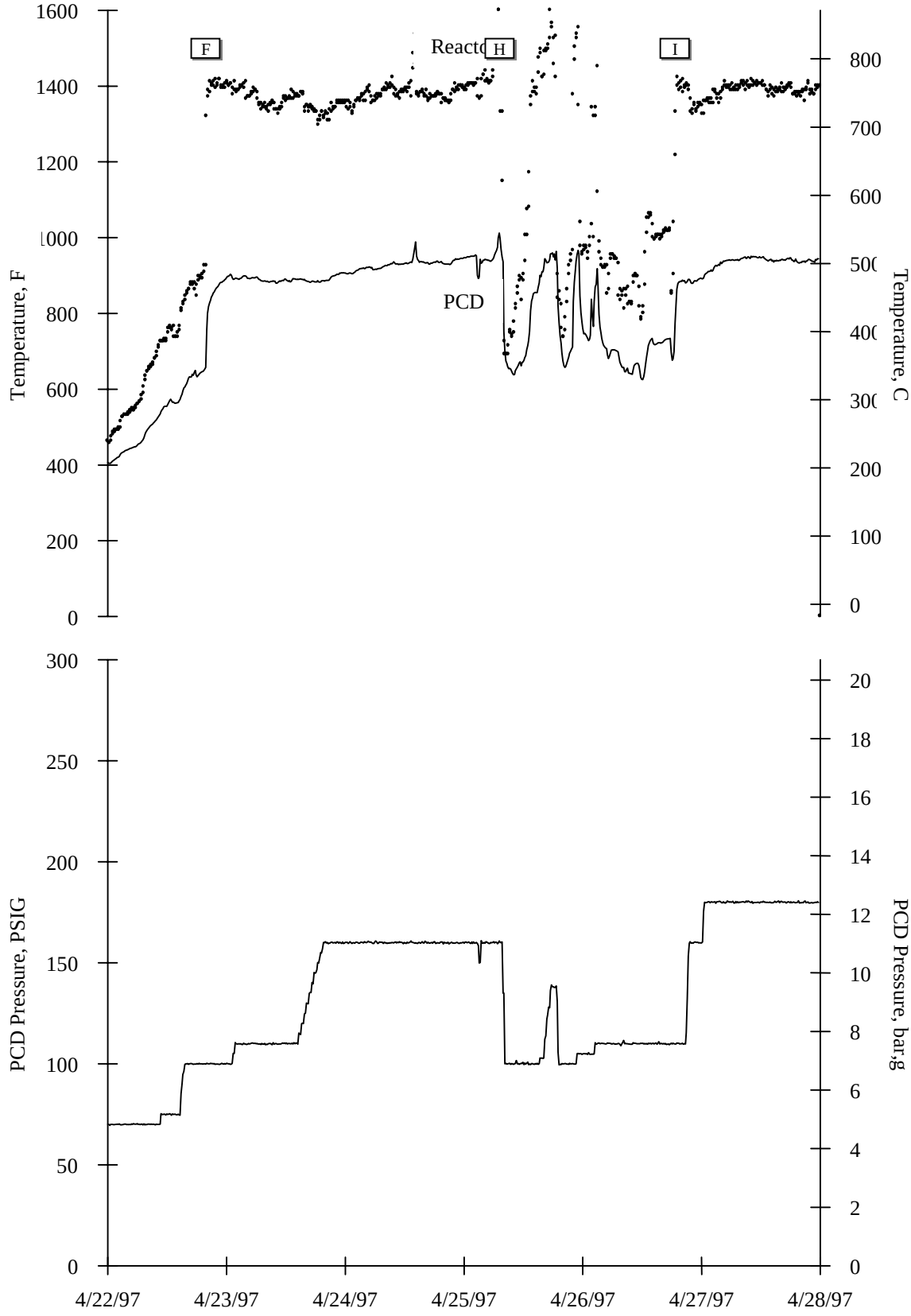


Figure 3.6.1-4 CCT4D Temperature and Pressure for April 22 to 28

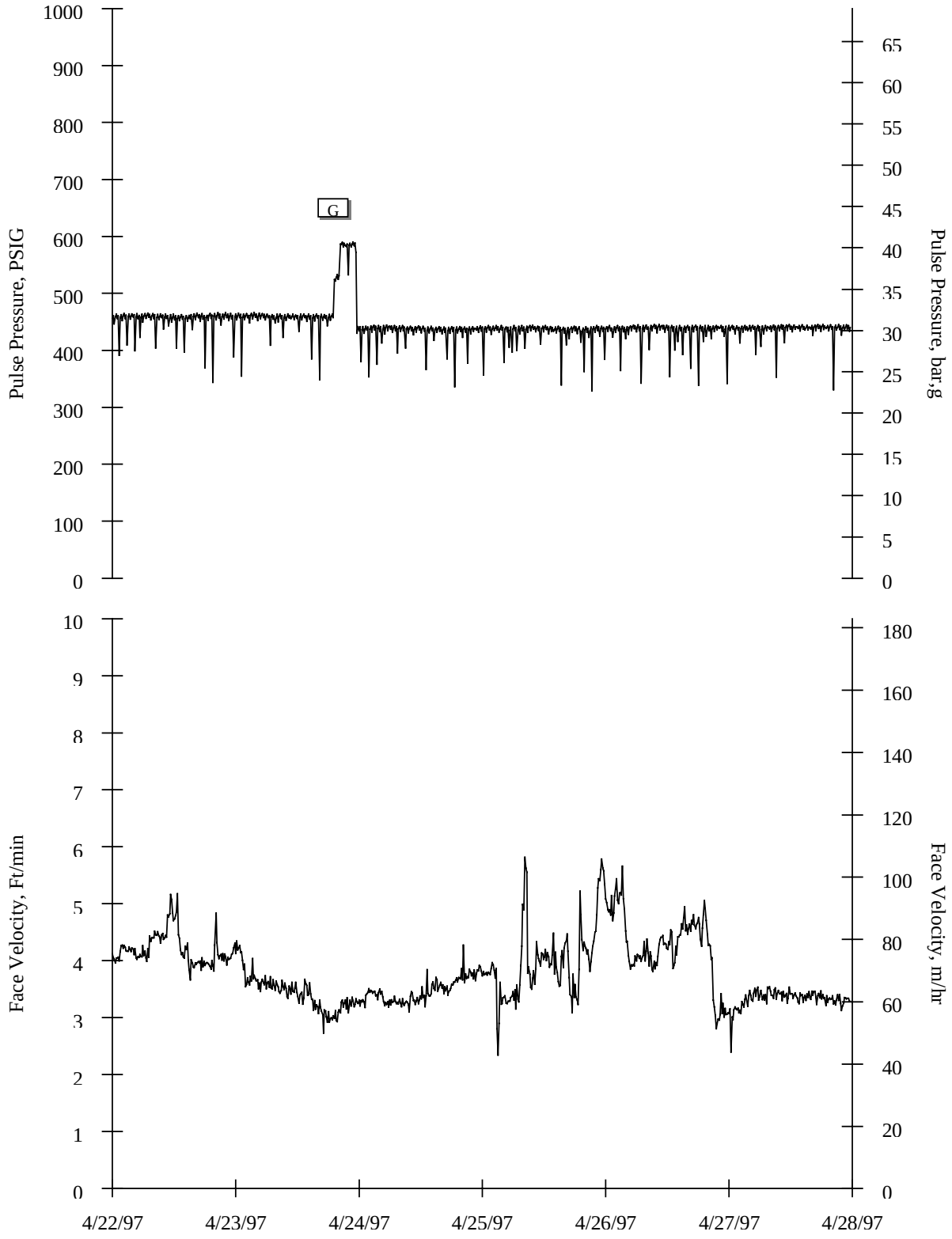


Figure 3.6.1-5 CCT4D Pulse Pressure and Face Velocity for April 22 to 28

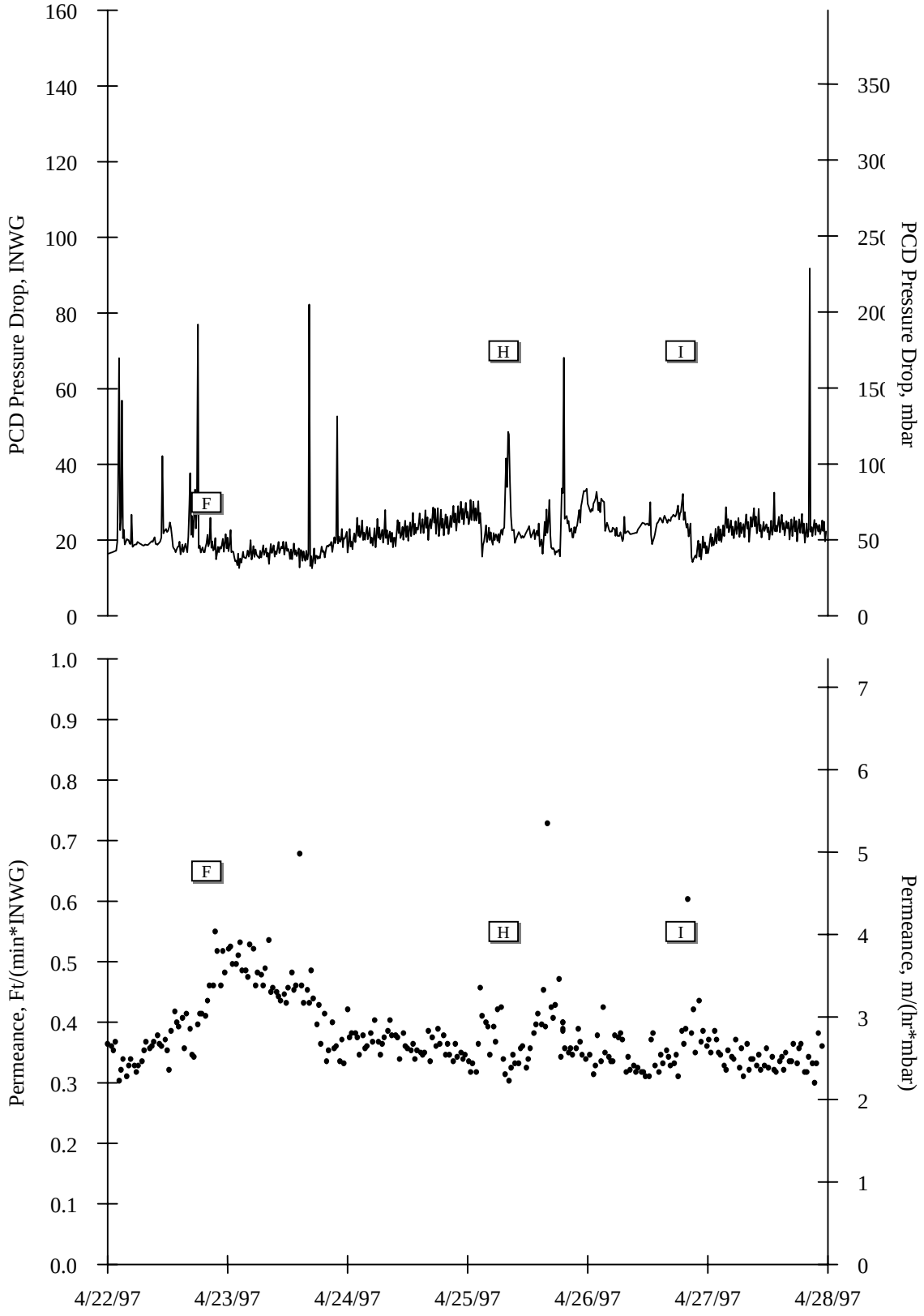


Figure 3.6.1-6 CCT4D Pressure Drop and Permeance for April 22 to 28

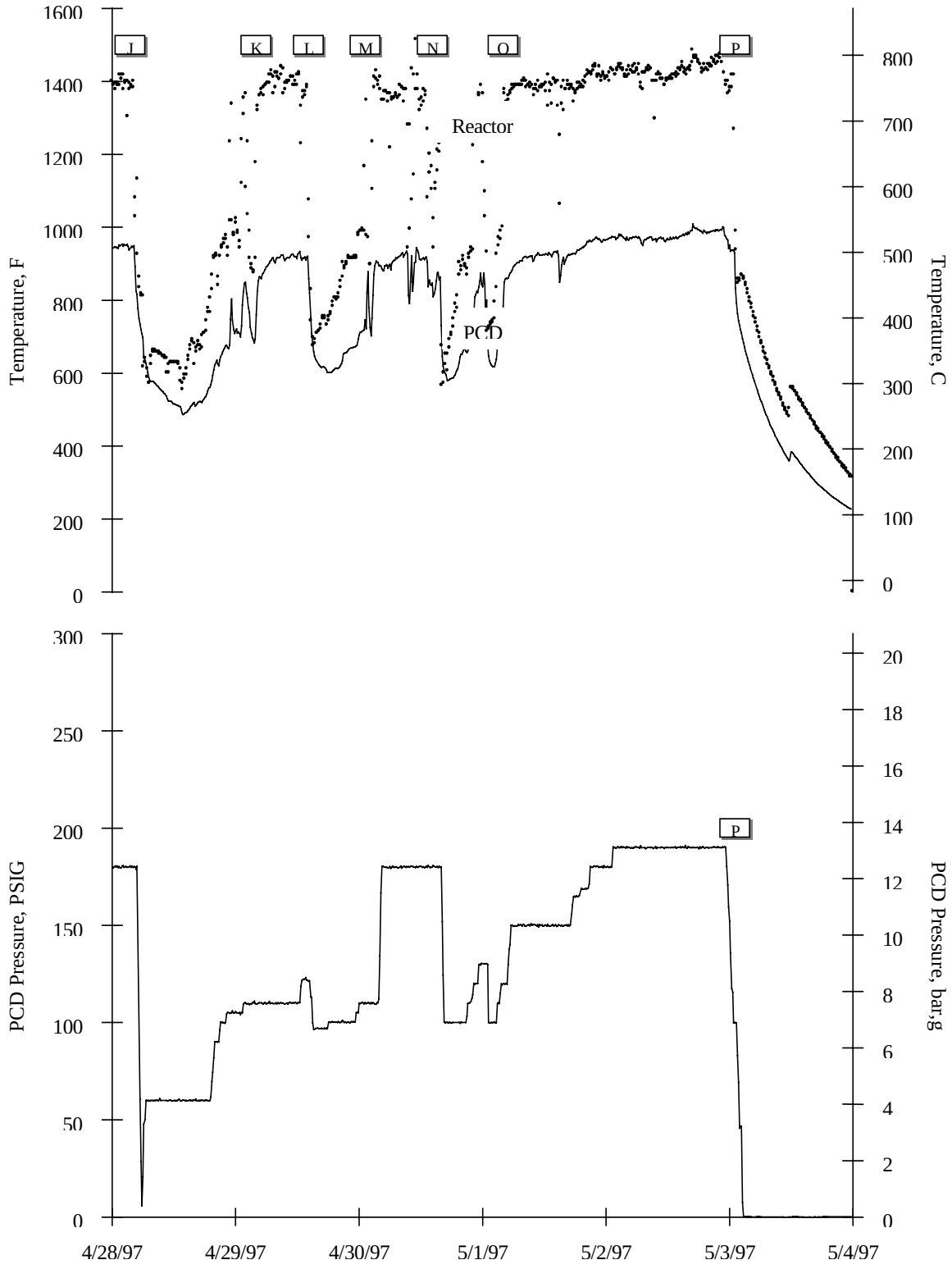


Figure 3.6.1-7 CCT4D Temperature and Pressure for April 28 to May 4

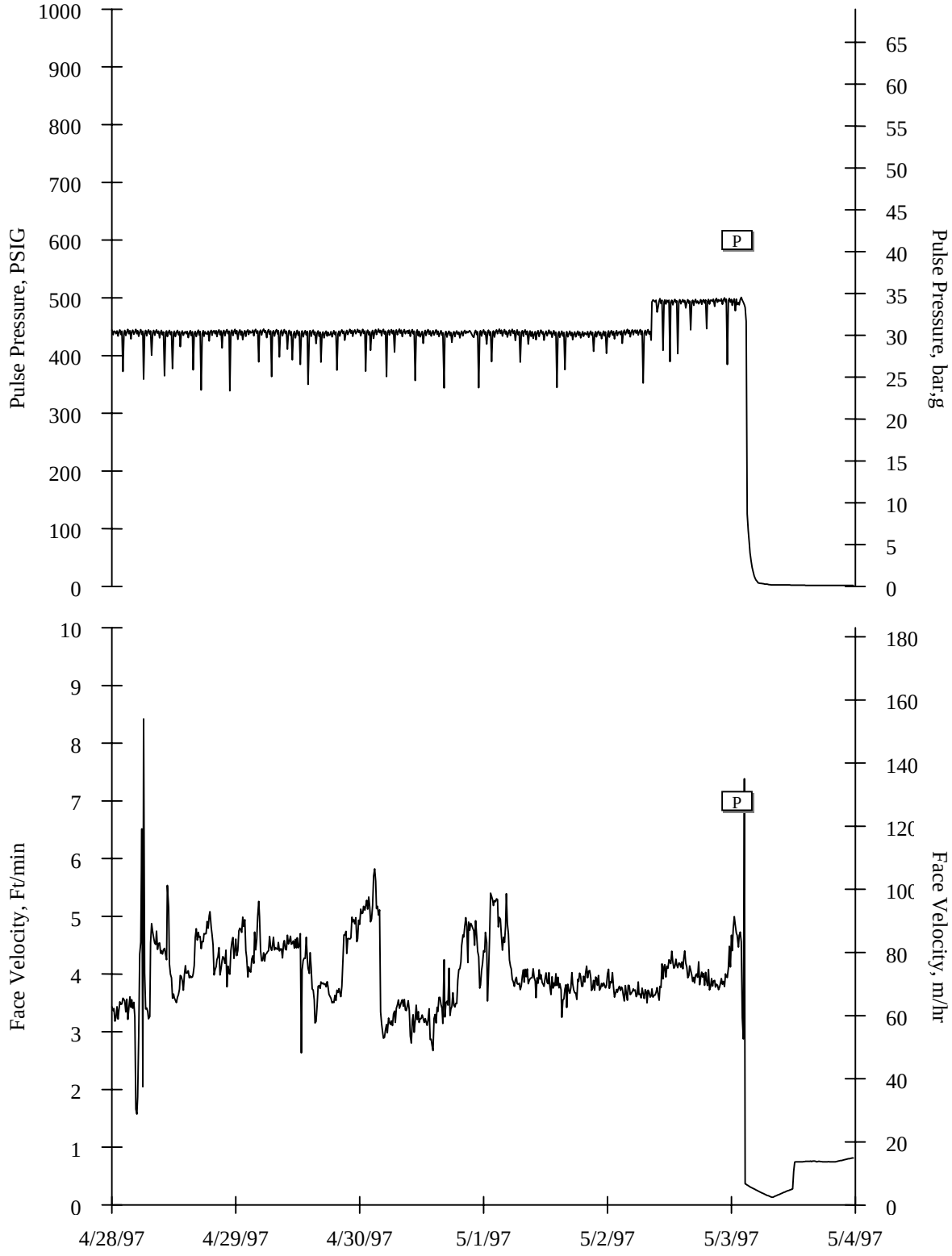


Figure 3.6.1-8 CCT4D Pulse Pressure and Face Velocity for April 28 to May 4

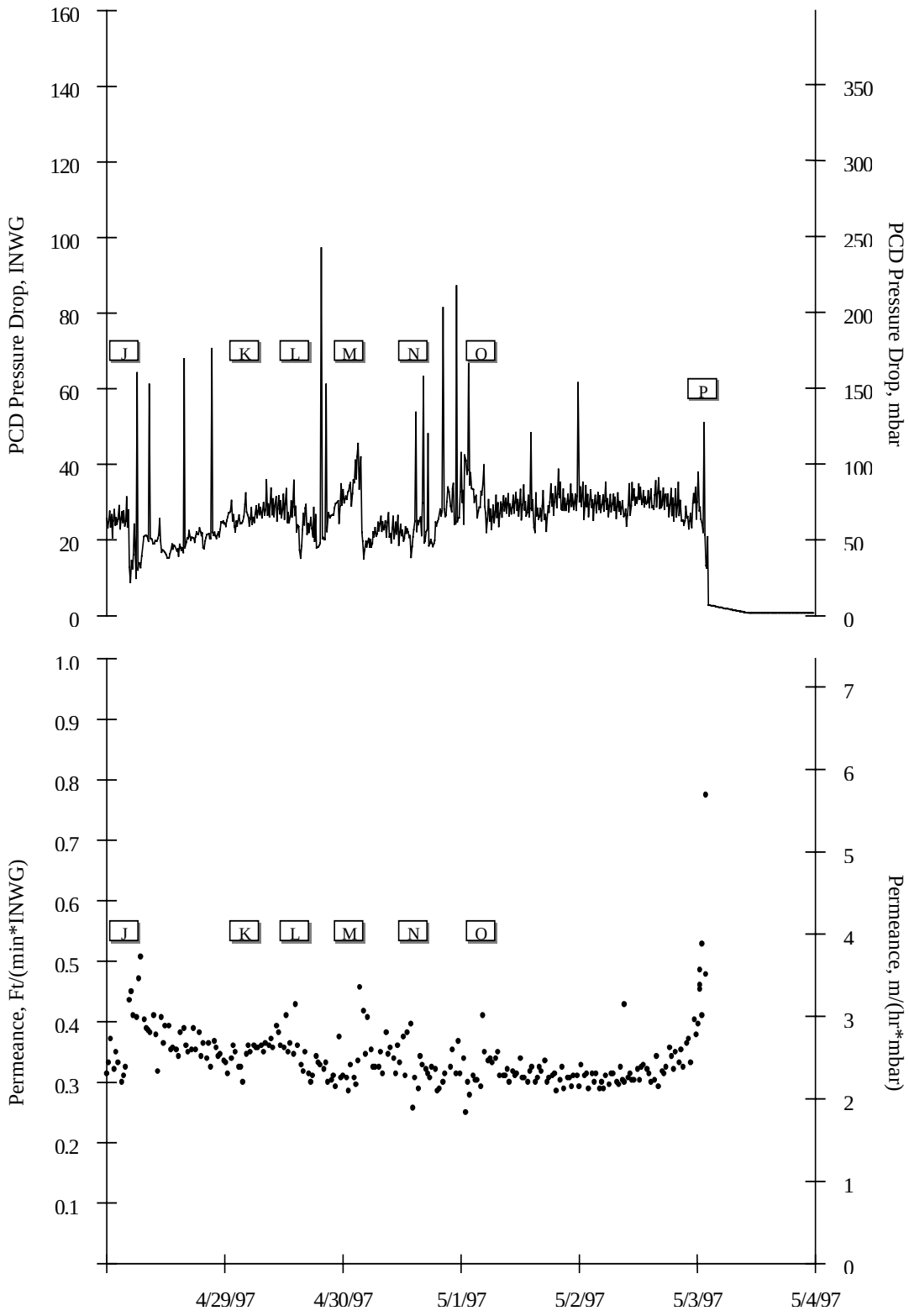


Figure 3.6.1-9 CCT4D Pressure Drop and Permeance for April 28 to May 4

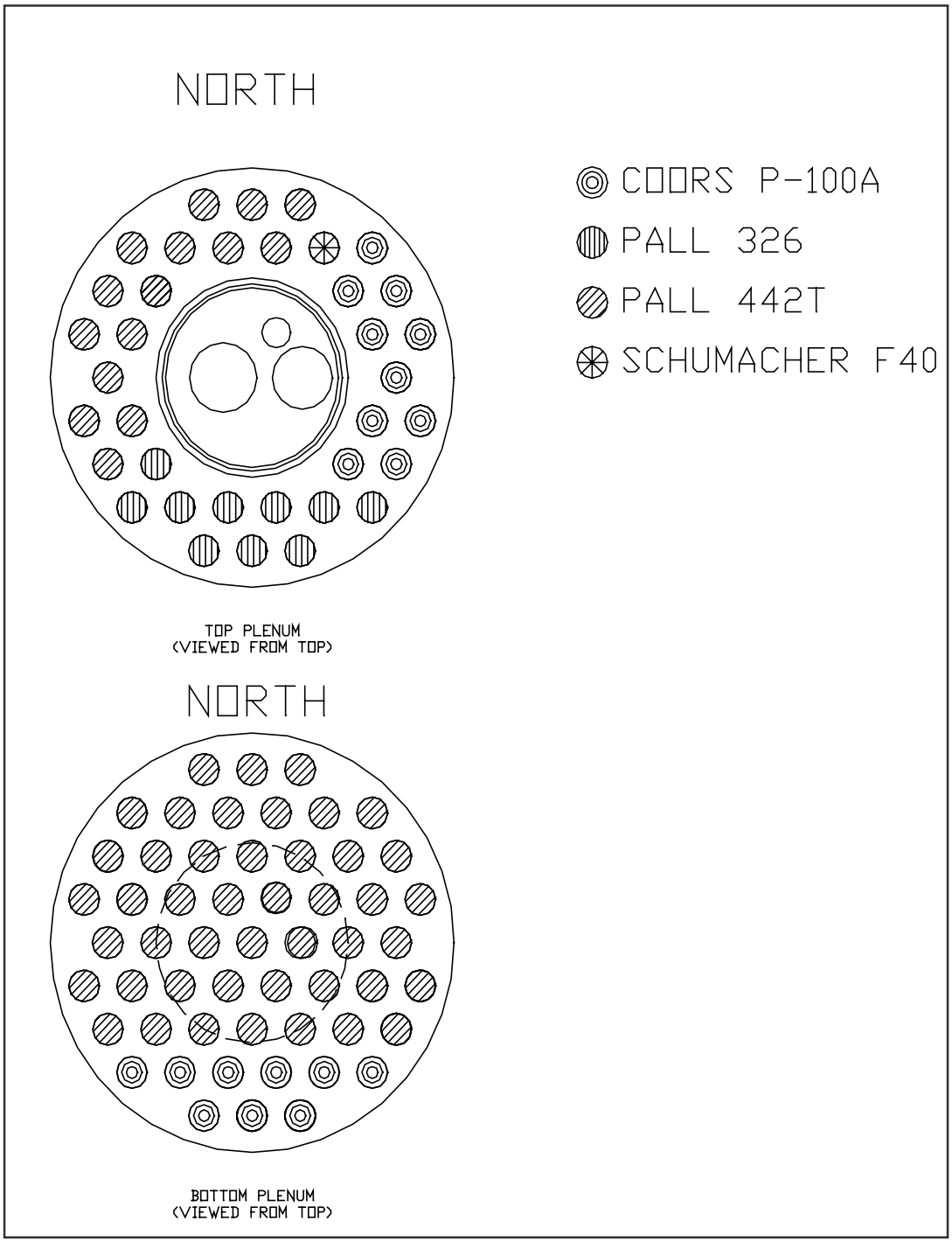


Figure 3.6.1-10 Filter Element Layout for CCT4D (Layout No. 3)

3.6.2 Test Objectives

The PCD objectives for CCT4D were to:

- Continue to support transport reactor engineers during cyclone testing by taking samples, monitoring level in PCD cone, etc.
- Verify SRI loadings.
- Eliminate entrained water and valve wear as the source of pulse valve flow phenomena.

3.6.3 Observation/Events

A. Tuning of MAC–April 16-17. Due to the problems encountered in earlier test runs a field service engineer was on site for 2 days to tune the main air compressor (MAC).

B. MAC Started; Run Begins–April 19 at 19:30.

C. Pressure Test of Transport Reactor/PCD–April 21 at 08:35.

D. PCD Preheat Started–April 21 at 12:15. The sulfator start-up burner was used to heat the PCD to 200ºF (93.3ºC) (CH-CC).

E. Start-up Burner Lit–April 21 at 13:38. The start-up burner pilot was lit at 13:38. The main burner was lit about 1 hour later at 14:43.

F. Started Feeding Bituminous Coal–April 22 at 19:45. Prior to feeding bituminous coal a pluggage of wet sand/ash was found in the discharge line of the spent fines transport system (FD0520). This pluggage was blown out using HP air.

   Once the reactor was up to ~1,000ºF (537.8ºC) bituminous coal was fed into the reactor.

G. Raised Pulse Pressure–April 23 at 19:00. As a part of the ongoing investigation to determine why the pulse valve flow decreased at high-value ΔP, the pulse media had changed from HP air to HP nitrogen.

   There were two reasons for the changeover.

   1. The nitrogen gas used is produced by vaporizing liquid nitrogen. Therefore, trace water vapor was eliminated as a potential source of the problem.

   2. The HP air compressor has no auto-unloading capability. Typical operation requires the starting and stopping of the compressor several times a day, which is less than ideal for the equipment. The nitrogen compressors do have the capability to auto unload.

   3. Gasification – In addition to changing the pulse media, both the primary and secondary valves were actuated. The purpose for the test was to see if the primary valves had been subjected to premature wear. However, all four valves showed the same response. The mass flow per pulse did actually decrease with increasing valve ΔP.

H. Coal Feed Lost–April 25 at 03:30. The coal feeder tripped and the start-up burner had to be relit; there were some instabilities in the transport reactor and problems with the coal feeder, which prevented continuous coal firing for about 36 hours.

I. Coal Feed Resumed–April 26 at 18:33.

J. Coal Feed Lost–April 28 at 03:30. The coal feeder (FD0210) tripped and could not be restarted. Maintenance found construction debris, several pieces of the lockhopper internal epoxy coating in the discharge, as well as finding that the coal had bridged. The feeder was cleaned and put back in service.

K. Coal Feed Resumed–April 29 at 04:00.

L. Coal Feed Lost–April 29 at 14:00. Again, the coal feed line was plugged by pieces of epoxy coating. The feeder was cleaned and placed back in service.

M. Coal Feed Resumed–April 30 at 01:10.

N. Coal Feed Lost–April 30 at 14:15. The coal feeder was tripped because of an irregular temperature profile; the start-up burner was relit until coal feed was reestablished.

O. Coal Feed Resumed–May 1 at 04:00.

P. Test Run Ends–May 3 at 01:05. With the test run objectives fulfilled, the run ended.

3.6.4 Run Outcome

There were very few problems during CCT4D associated with the PCD and with the spent fines transport system. Some pluggage of the spent fines transport system discharge occurred, but this was readily cleaned on line. Prior to CCT5A the filter elements were visually inspected through the lower manway door. All elements were found to be intact: there was no evidence of ash bridging: and the residual cake appeared relatively thin and uniform.

Based on the results of the pulse valve testing in CCT4D, it was decided to begin quantifying the magnitude of the problem in CCT5A. A high-speed recorder, in conjunction with the plant information (PI) system, would be used to generate curves of pulse pressure versus mass flow per pulse.

3.7 CCT4 ASH CHARACTERISTICS AND PCD PERFORMANCE

During CCT4, in situ samples of the particulate mass entering and exiting the PCD were collected, and the particle-size distribution entering the PCD was measured both in situ with a cascade cyclone assembly and using laboratory techniques. The mass concentration measured in situ at the PCD inlet was compared to the total mass discharged from the PCD hopper. At the end of CCT4C, samples of the filter dustcake were removed from the candles. The physical characteristics (particle-size distribution, porosity, chemistry, and permeability) of selected in situ samples and a dustcake sample were determined.

3.7.1 PCD Inlet Particle Concentrations

Although the initial shakedown of the in situ sampling system located at the PCD inlet had been completed during previous operation, CCT4 was the first test program where routine data were collected. Despite some initial problems discussed below, the system operated flawlessly. Table 3.7.1-1 summarizes the results of the sampling runs performed at the PCD inlet. The particulate loadings given in the table suggest that the carryover of solids varied considerably throughout CCT4 and exceeded design levels during most of the sampling runs. With the exception of one sampling run, all runs were done during coal firing. The third mass sampling run (CCT4IMT-4) was conducted while the transport reactor was fired with propane, and only bed material was carried over to the PCD.

During the first portion of CCT4, an incorrect value was used for the calibration constant of the sample orifice. This caused the sample flow rates to be lower than expected by about 35 percent. Although the correct value was used when the mass concentrations were calculated, one effect of collecting the sample at the reduced sample rate is more persistent. Table 3.7.1-1 indicates the value of isokinetic agreement for each sampling run. This value describes how closely the gas velocity entering the sample nozzle matches the gas velocity in the process duct. Acceptable isokinetic agreement is generally taken as 90 to 110 percent. For velocity matches outside that range, the flow streamlines entering the sample nozzle must curve excessively (either into or away from the nozzle) resulting in a sample that is biased in the numbers of large particles collected. Small particles (<5 μm) will follow the streamlines, but larger particles will separate from the streamlines because of their higher momentum. Thus, when the nozzle velocity is less than duct velocity, as it was here, an unrepresentative number of large particles will be collected in the sample resulting in an incorrect high-mass loading indication. For the first five sample runs, the isokinetic agreement ranged from 64.4 to 71.1 percent. To correct for the effects of anisokinetic sampling, we used a technique described by Belyaev and Levin[1]. Since the mass concentration error that results is dependent on the size distribution of particles (more large particles equal greater error) the size distribution of all samples was measured with the Microtrac size analyzer and the correction applied to each size interval.

The overall mass concentration correction factors for the first five runs ranged from 0.67 to 0.87. When the orifice calibration problem was corrected, incorrect values that were returned by

[1] S. P. Belyaev and L. M. Levin. Techniques for Collection of Representative Aerosol Samples. Aerosol Science, 1974, Vol. 5, pp 325 to 338.

the process information system (PI) caused the sixth run to have a high-isokinetic agreement. The mass concentration for this sample was also corrected. All of these problems have been addressed to prevent future errors in the data.

Table 3.7.1-1

Sampling Parameters and Results of Sampling Runs at PCD Inlet

Sampling Parameters							
Run No. CCT4IMT	2	3	4	5	6	7	8
Date	3/15/97	3/22/97	4/22/97	4/23/97	4/24/97	5/1/97	5/2/97
Start time	1353	1103	1413	1059	1115	1030	1030
Duration, min	15	31	15	15	15	27.27	31.13
Process Parameters							
Fuel	Coal	Coal	Propane	Coal	Coal	Coal	Coal
Pressure, psig (bar)	101 (7.0)	111 (7.7)	75 (5.2)	110 (7.6)	159 (11)	149 (10)	189 (13)
Temperature, °F (°C)	854 (457)	859 (459)	567 (297)	886 (474)	930 (499)	928 (498)	971 (522)
Oxygen (%)	14.1	12.4	13.5	9.5	9.5	10.9	10.6
Carbon dioxide (%)	4.3	3.6	2.5	6.5	6.2	6.1	5.8
Water vapor (%)	1.6	3.1	1.9	2.2	2.0	2.0	2.0
Gas velocity, ft/sec (m/s)	20.3 (6.2)	20.1 (6.1)	23.1 (7.0)	19.0 (5.8)	18.2 (5.5)	21.6 (6.6)	22.5 (6.9)
Sampling Results							
Isokinetic agreement (%)	67.3	71.1	67.4	67.7	64.4	112.1	105.4
Loading, ppmw[1]	18,800	95,700	53,500	39,900	28,300	19,800	18,500

Notes: (1) Mass loading corrected for isokinetic error.

3.7.2 Comparison of In Situ Measurements With PCD Ash Discharge Rates

Table 3.7.2-1 compares the in situ measurements of particulate loading to estimates of particulate loading based on the rate of ash discharge from the PCD hopper. The estimates were obtained by collecting the discharged ash in a 55-gallon (200-L) drum and weighing the amount of ash collected in a known time period (nominally 30 minutes). This procedure was repeated for three different sampling runs as indicated in the table. To allow a direct comparison of the two values, the in situ sampling intervals were coordinated with the hopper dump cycles.

In the case of the first comparison, the in situ value was quite high (95,700 ppmw) as a result of a slug of solids that was carried out of the transport reactor at the end of the sampling run. The particulate loading estimated from the drum catch did not reflect this large carryover of solids, because of the time lag between the arrival of the solids to the PCD and the discharge of the solids from the ash removal system. Based on the amount of ash removed from the PCD hopper over the next 30 minutes after the test, the estimated particulate loading was 77,800 ppmw, which is considerably closer to the in situ value. In the case of the other two comparisons, the particulate loadings estimated from the drum catches were reasonably close to the in situ values (17,900 versus 19,800 ppmw and 17,700 versus 18,500 ppmw). Better agreement may have been achieved in these last two cases because the rate of solids carryover from the transport reactor was relatively constant during these tests. The particulate loading calculated from the rate of ash discharge was still 4 to 10 percent lower than the particulate loading determined from the in situ measurement, possibly because of retention of ash on the PCD candles and in the PCD hopper and ash removal system. However, this is considered quite good agreement for a comparison of this type.

Table 3.7.2-1

Comparison of Particulate Loadings Obtained from In Situ Measurements With Particulate Loadings Estimated From Rate of Ash Discharge

Run No.	**Date**	**Time**	**In Situ Measurement (ppmw)**	**Estimate from Ash Discharge (ppmw)**
CCT4IMT-3	3/22/97	11:01 to 11:34	95,700	42,200
CCT4IMT-7	5/1/97	10:29 to 10:57	19,800	17,900
CCT4IMT-8	5/2/97	10:30 to 11:01	18,500	17,700

3.7.3 In Situ Measurements of PCD Inlet Particle-Size Distribution

The first in situ measurements of particle-size distribution using the cascade cyclone system were made at the PCD inlet during CCT4. A total of three runs were made, although the first run was made during a period when transport reactor circulation rate was very low and insufficient sample was collected to be meaningful. For the other two runs (CCT4ICYC-2 and –3) the particulate catches from the individual cyclones were weighed separately to determine the particle-size distributions. Figure 3.7.3-1 shows the particle-size distributions obtained from the two runs on the basis of differential mass concentration smaller than the stated particle size. Figures 3.7.3-2 and -3 show the same two particle-size distributions on the basis of cumulative mass percentage smaller than the stated size and differential mass versus particle size. The cumulative mass percentage is calculated by dividing the cumulative mass concentration by the total mass concentration. The differential mass distribution is determined by splitting the particle-size range into a series of narrow size intervals and plotting the mass in each interval at the geometric mean particle size for that interval. This type of distribution provides a direct indication of the mass concentration associated with a given particle size.

Because of its aerodynamic sizing characteristics, the five-stage cyclone assembly provides particle-size data over a range of about 0.5 to about 10 μm. The cyclone assembly has been shown to provide reliable particle size information over this range of particle sizes. However, to provide an estimate for the complete size distribution, the data are extrapolated from the largest cutpoint of 10 μm to the maximum probable particle size (1,000 μm). The extrapolation uses a smooth fit to infinite slope at the maximum particle size in log-probability space (figure 3.7.3-2) where a straight line represents a log normal distribution. Therefore, the extrapolation assumes that the mass larger than 10 μm is, more or less, evenly distributed over the range of 10 to 1,000 μm. For small exapolations, say to 20 or 30 μm, this should not introduce large errors. However, with very coarse size distributions as seen during CCT4, the cyclone data should be used cautiously when extrapolating beyond 40 or 50 μm. This may become less of an issue as carryover of bed material is reduced and the size distribution becomes finer. Despite this limitation, the results obtained for the smaller particles are valid and can be used to draw conclusions concerning the distribution of particulate mass. For example, referring to figure 3.7.3-3, the two particle-size distributions appear to be essentially identical up to a particle size of about 3 μm. Above 3 μm, the distributions diverge, with the distribution measured on May 1 obviously containing more particulate mass than the distribution measured on April 29. The difference increases as the particle size increases above 3 μm. At 10 μm, the difference amounts to a factor of four in the mass concentration, and the difference appears to be increasing beyond 10 μm. This result suggests that the increased particulate loading measured on May 1 (21,600 ppmw versus 6,700 ppmw on April 29) is attributable to the carryover of relatively large particles (probably bed material).

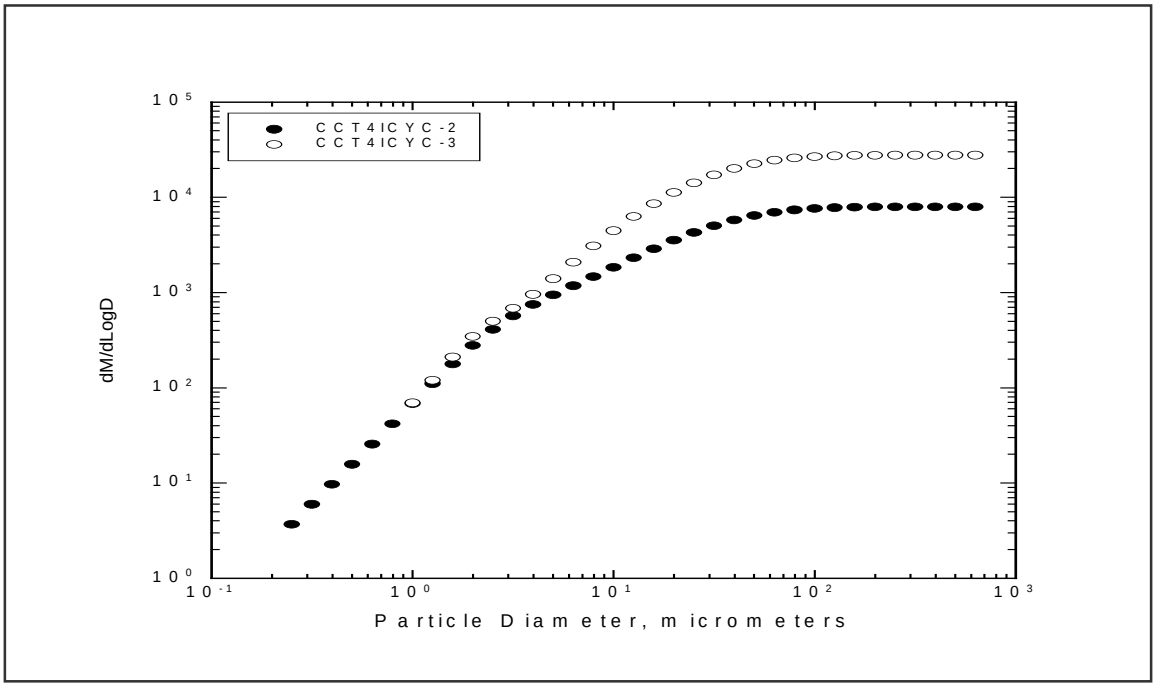


Figure 3.7.3-1 Differential Mass Distributions Obtained From Cascade Cyclone Runs

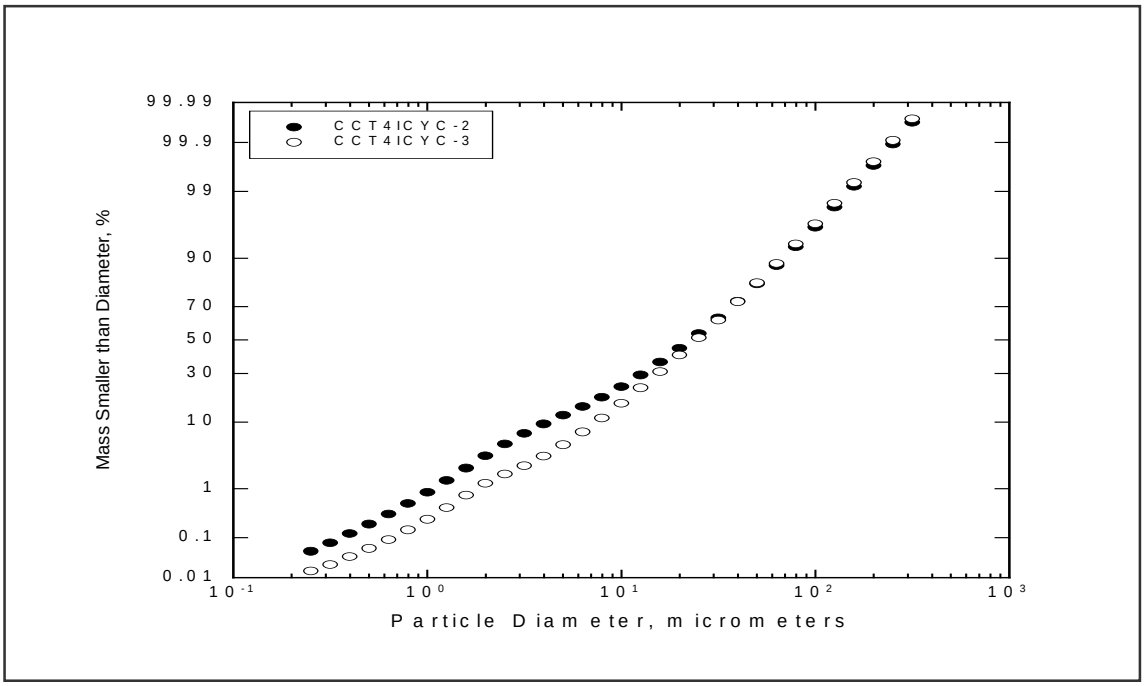


Figure 3.7.3-2 Cumulative Percent Distributions Obtained From Cascade Cyclone Runs

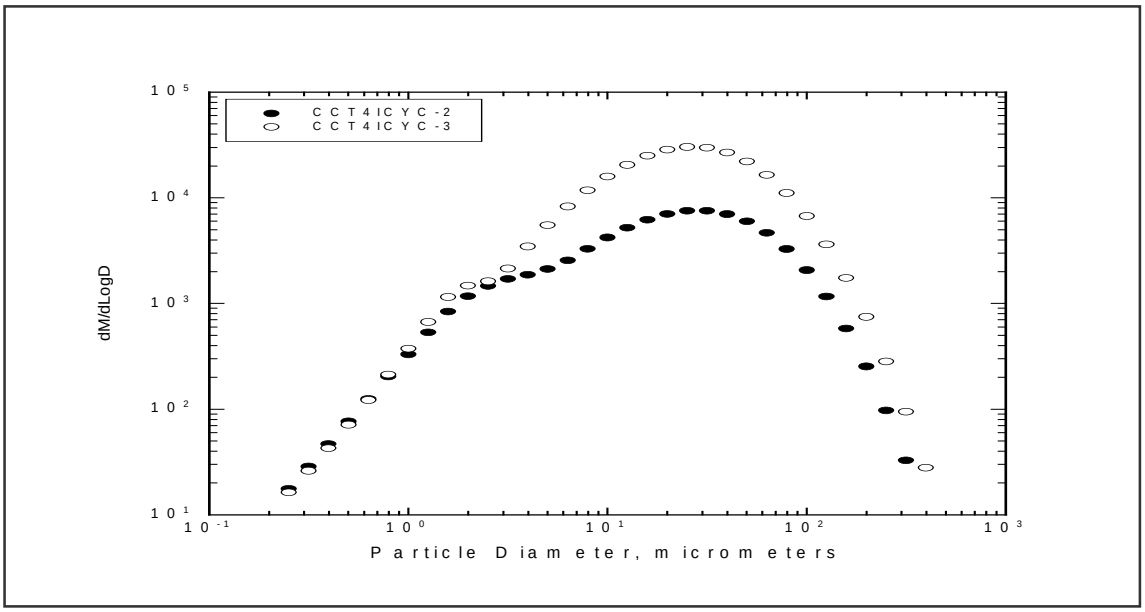


Figure 3.7.3-3 Differential Mass Distributions Obtained From Cascade Cyclone Runs

3.7.4 Laboratory Analysis of Cascade Cyclone Catches

For comparison of the two techniques, the catches from the four individual cyclones were run through the Microtrac X-100 particle-size analyzer. Figures 3.7.4-1 and -2 show particle-size distributions for the two cyclone runs. Particle-size distributions could not be obtained for the backup filter catches, because the ash collected on the filter cannot be completely separated from the filter material and recovered for analysis. The distributions are shown on the basis of the percentage of the cumulative mass smaller than the corresponding particle size. The open symbols on the graph show the Microtrac size distributions, while the solid symbols indicate the geometric mean diameter (GMD) calculated from the cyclone cutpoint (D_{50}) and the cutpoint of the next larger stage. In the case of the first cyclone, the cutpoint of the next larger stage is taken as the maximum particle size detected by the Microtrac analyzer (419 μm for CCT41CYC-2 and 704 μm for CCT4ICYC-3). Referring to figure 3.7.4-1, the Microtrac results for the first three cyclone stages confirm the geometric mean particle sizes based on the aerodynamic sizing characteristics of the cyclones. The Microtrac result for the last cyclone stage indicates a larger mean size than calculated from the aerodynamic sizing characteristics. Referring to figure 3.7.4-2, the Microtrac results for the second set of cyclone catches consistently indicate larger mean sizes than those calculated from the cyclone's aerodynamic sizing characteristics. This result is not surprising considering how difficult it is to redisperse fine particles. The ultrasonic dispersion used prior to the Microtrac analysis is apparently insufficient to break apart the agglomerates formed from the fine particles in the cyclone catches. Because of these agglomeration effects, laboratory analyses of bulk samples almost always indicate coarser size distributions than do in situ particle-size measurements.

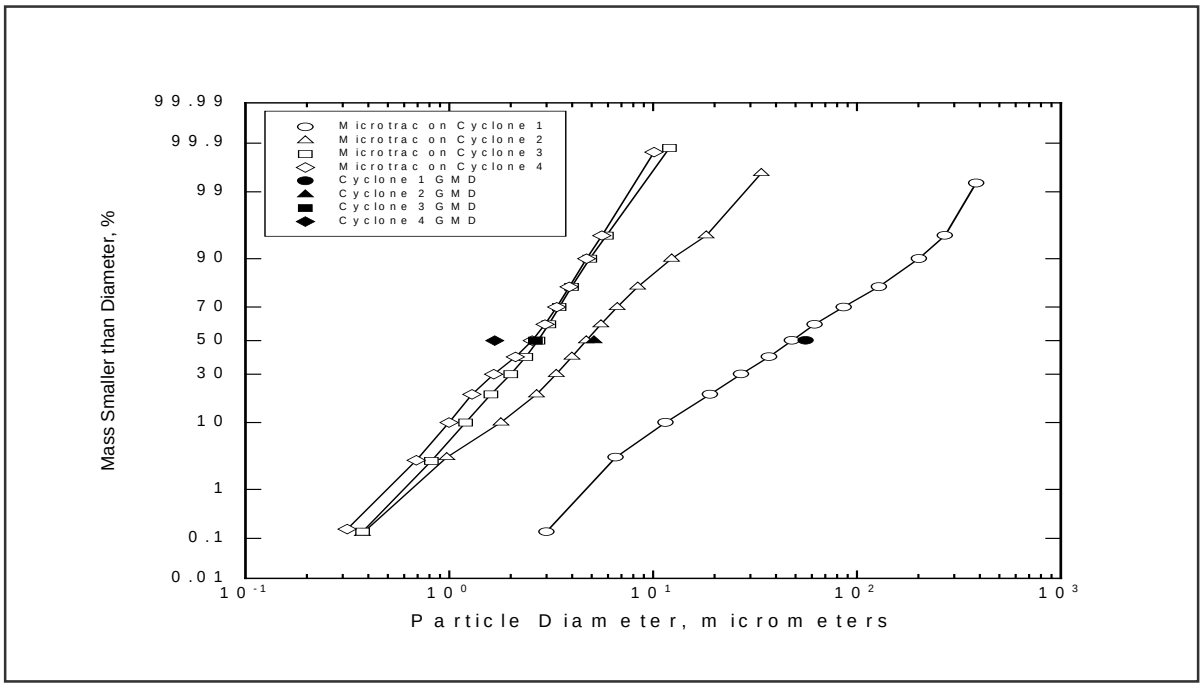


Figure 3.7.4-1 Microtrac Particle-Size Analysis of Cyclone Catches From CCT4ICYC-2

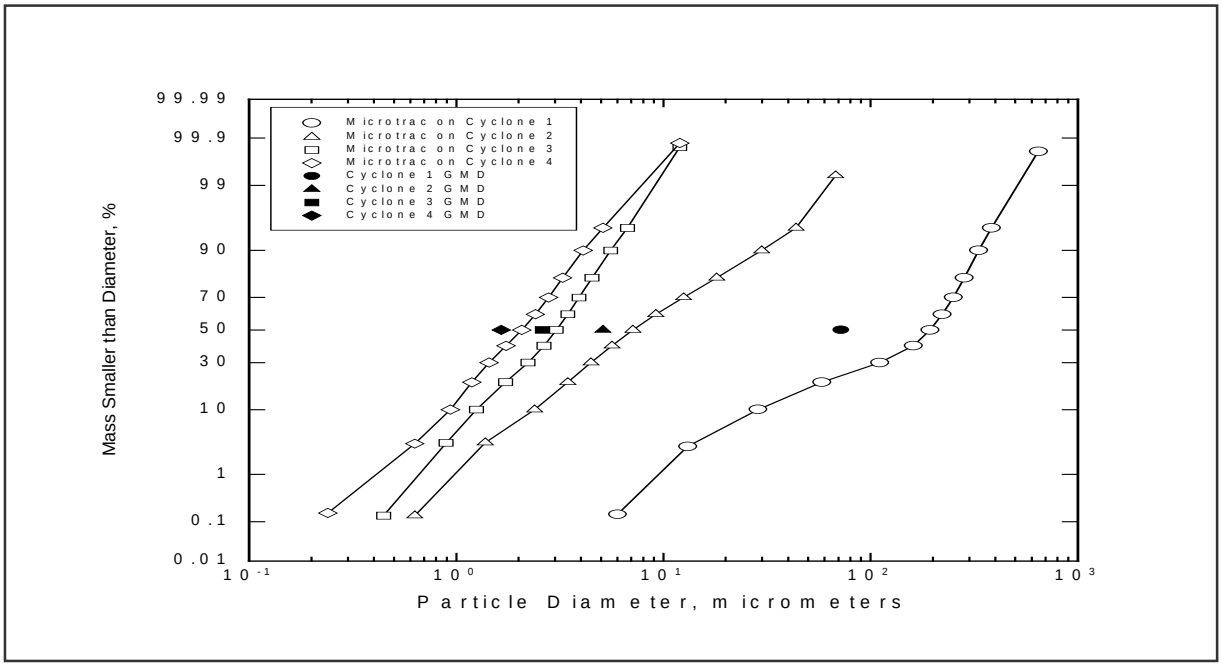


Figure 3.7.4-2 Microtrac Particle-Size Analysis of Cyclone Catches From CCT4ICYC-3

3.7.5 Comparison of Cyclone and Hopper Size Distributions

Figure 3.7.5-1 shows a comparison of the size distributions measured with the cascade cyclone assembly with those measured by sieve and Microtrac analyses of hopper samples taken on the same day. As shown in the figure, all of the particle-size distributions are in reasonable agreement at particle sizes below about 3 μm. The cyclone and hopper results obtained on April 29 are also in reasonable agreement with each other at particle sizes up to about 40 μm, but the two distributions diverge as the particle size increases beyond 40 μm. Any comparison of the two distributions beyond this point would be meaningless, since, beyond about 10 μm, the cyclone distributions are extrapolations of the data. Near the upper end of the Microtrac/sieve size distribution, the sieve analysis indicates that there is a large-particle mode that cannot be resolved by the cascade cyclones. The large-particle mode, which is centered about a particle size of 200 to 250 μm, is presumably composed of large sand particles carried out of the transport reactor system. This large-particle mode is not evident when the same hopper sample is analyzed by Microtrac alone, as shown in figure 3.7.5-1. There also appears to be some loss of small-particle data when the sample is analyzed directly on the Microtrac without first sieving out the larger (>45 μm) particles (i.e., the Microtrac-only distribution is truncated at about 0.6 μm, while the sieve/Microtrac distribution extends down to about 0.4 μm). Based on these results, it appears that the presence of high concentrations of large particles may have some adverse effect on the Microtrac's ability to resolve small particles. Gravitational settling and subsequent loss of the large particles in the Microtrac could also be responsible for the lack of the large-particle mode, which is evident in the sieve + Microtrac, but not evident with Microtrac analysis alone.

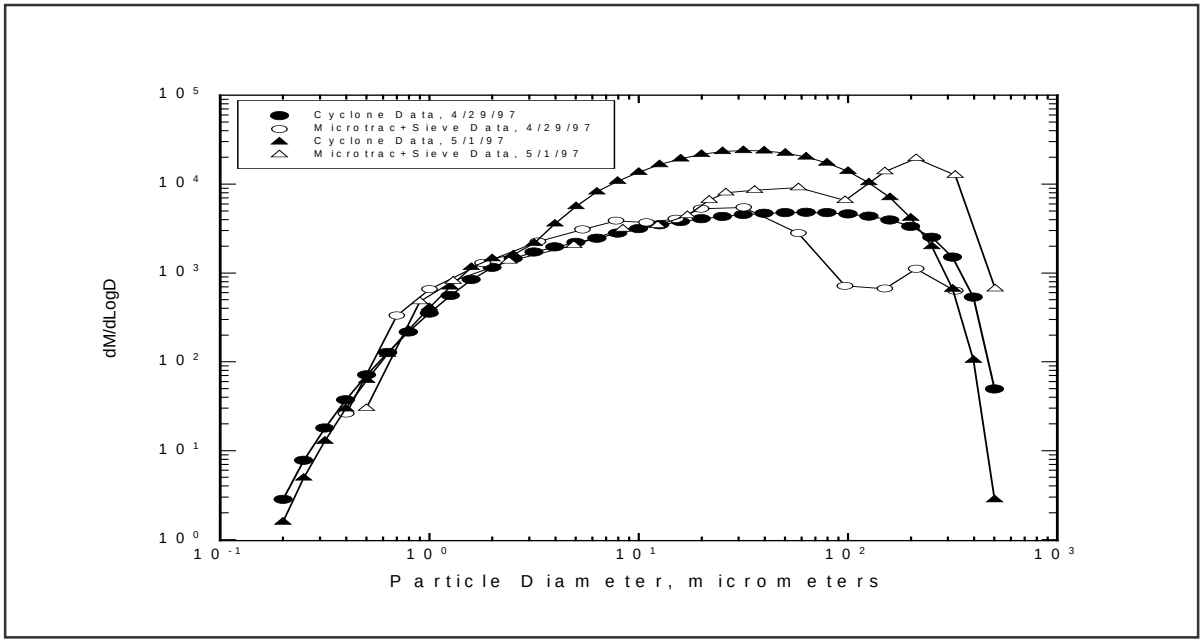


Figure 3.7.5-1 Comparison of Particle-Size Distributions Measured by Cascade Cyclones With Microtrac and Sieve Analysis of Hopper Samples

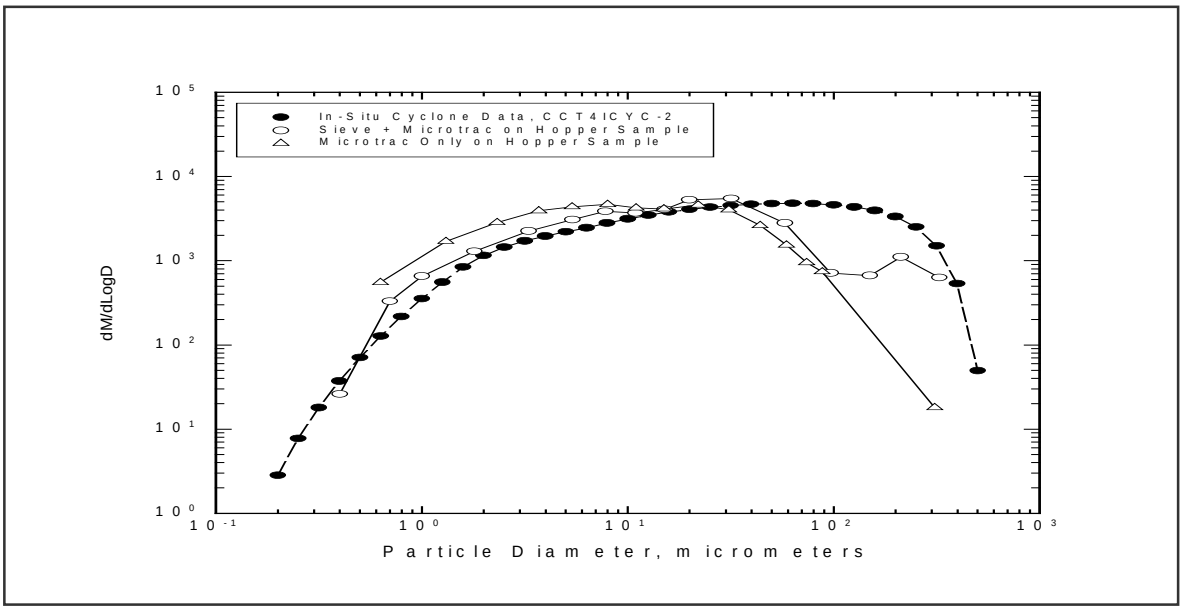


Figure 3.7.5-2 Comparison of Particle-Size Distributions Measured by Sieve and Microtrac Analysis and by Microtrac Analysis Alone

3.7.6 PCD Outlet Particle Concentrations

During CCT4, the in situ sampling system installed at the PCD outlet was used to collect data for the first time. Three samples were successfully collected, which are summarized in table 3.7.6-1. The particulate loadings given in the table suggest that there is an extremely low degree of ash penetration through the PCD. In fact, the weight gains on the particulate filters were comparable to the weight gains on blank filters that were inserted in the samplers after the particulate filters. These blank weight gains, which were presumably attributable to interaction of gas-phase species with the filter, produced an equivalent loading of about 0.18 to 0.24 ppmw. While the similarity of the particulate filter and blank makes it difficult to precisely quantify the outlet particulate loading, it is clear that the measured loadings are well below the levels required by the New Source Performance Standards (< 30 ppmw) and by the guidelines of the turbine manufacturers.

Because of the orifice calibration problems mentioned previously, the outlet sampling runs also had nozzle velocities that were unacceptably anisokinetic. The isokinetic correction procedure used on the inlet sampling runs could not be applied to the outlet runs, because the outlet samples were insufficient to make particle-size measurements. In any case, the correction is negligible for particles smaller than about 5 μm, which would presumably account for most or all of the particulate mass in the outlet samples. Despite any uncertainties in potential anisokinetic bias and in potential gas-phase interferences, it is safe to conclude from these results that the outlet particulate loadings measured during CCT4 are well below 1 ppmw.

Table 3.7.6-1

Results of Sampling Runs at PCD Outlet

Sampling Parameters			
Run No. CCT4OMT	1	2	3
Date	3/15/97	4/24/97	4/30/97
Start time	10:42	10:19	09:25
Duration, min	240	240	300
Process Parameters			
Fuel	Coal	Coal	Coal
Pressure, psig (bar)	98 (6.8)	158 (10.9)	178 (12.3)
Temperature, °F (°C)	788 (420)	867 (464)	836 (447)
Oxygen (%)	12.8	9.5	12.0
Carbon dioxide (%)	5.5	6.2	5.0
Water vapor (%)	1.4	2.6	3.5
Gas velocity, ft/sec (m/s)	20.2 (6.2)	18.1 (5.5)	16.7 (5.1)
Sampling Results			
Isokinetic agreement (%)	64.6	65.9	113.8
Loading (ppmw)	0.50	0.20	0.16

3.7.7 Ash Chemical Composition

Table 3.7.7-1 summarizes the results of chemical analyses performed on samples of PCD hopper ash collected during CCT4D. Because of operational problems and difficulties generating representative samples, chemical analyses were not performed on hopper samples from CCT4A, B, and C. The table includes analytical results for one sample of residual dustcake, which was scraped off the surface of a candle filter at the end of test no. CCT4C. Although the dustcake is from a prior test series, it is interesting to note that its silica content is much lower than the silica content of most of the hopper samples. This result suggests that most of the hopper samples contain a significant amount of sand carryover. Only the hopper samples collected on April 29 and on May 3 have compositions similar to that of the dustcake, suggesting carryover was relatively low on these days.

Table 3.7.7-1

Results of Chemical Analyses of PCD Hopper Samples and Residual Dustcake

Major Constituents, Weight Percent as Element, Dry Basis												
Type of Sample	Dustcake	Hopper	Hopper	Hopper	Hopper	Hopper	Hopper	Hopper	Hopper	Hopper	Hopper	Hopper
Date	4/10/97	4/22/97	4/23/97	4/24/97	4/25/97	4/27/97	4/28/97	4/29/97	4/30/97	5/1/97	5/2/97	5/3/97
Time	10:00	0:00	08:00	0:00	0:05	0:00	0:25	8:00	0:00	0:00	0:00	0:00
Silicon	26.72	35.84	34.66	34.35	34.62	35.36	37.54	29.05	33.99	35.87	33.24	26.52
Aluminum	5.79	0.16	2.94	2.65	3.97	3.46	2.32	6.26	3.23	3.03	3.06	5.71
Titanium	0.69	0.01	0.31	0.35	0.43	0.46	0.24	0.74	0.41	0.39	0.40	0.65
Iron	1.79	0.07	0.85	0.92	1.27	1.18	0.62	2.24	1.06	1.04	1.14	2.16
Calcium	3.21	4.96	1.35	0.78	0.66	0.44	0.41	0.86	0.48	0.36	4.81	6.04
Magnesium	1.27	3.08	0.92	0.61	0.61	0.46	0.65	0.82	0.35	0.40	3.07	3.87
Potassium	0.72	0.00	0.19	0.26	0.20	0.17	0.10	0.26	0.34	0.17	0.27	0.08
Sodium	0.19	0.15	0.04	0.52	0.06	0.59	0.50	0.20	0.63	0.60	0.58	0.16
Phosphorous	0.07	0.00	0.02	0.03	0.03	0.05	0.05	0.07	0.04	0.03	0.04	0.09
Sulfur	1.01	0.09	0.73	0.45	0.60	0.55	0.26	0.87	0.41	0.40	0.58	0.80
Oxygen (Diff)	58.54	55.63	57.97	59.09	57.56	57.27	57.32	58.63	59.06	57.72	52.81	53.94
Loss on ignition	7.80	9.66	2.08	1.35	1.71	1.57	0.52	3.31	2.07	1.17	4.23	0.93

3.7.8 Characteristics of PCD Dustcake Samples

Figure 3.7.8-1 shows the results of particle-size analyses performed on the residual dustcake sample and on one of the in situ PCD inlet samples using a combination of sieves and the Microtrac X-100 particle-size analyzer. The dustcake sample had a mass-median particle size of 4.4 μm, while the in situ sample had a mass-median particle size of 220 μm. Comparing the distributions it is readily apparent that many of the particles larger than 10 μm that were in the inlet gas stream were not found in the candle dustcake.

Because of the coal dust fire and temperature excursion that occurred at the end of CCT4C, the properties of the residual dustcake sample may not be representative of normal filter operation. Nevertheless, measurements were made of the dustcake surface area, porosity, true density, and gas-flow resistance. The specific-surface area determined by the BET method, 3.8 m^2/g, was lower than most of the surface areas measured by SRI at other fluidized-bed combustors (see table below). The other measurements have ranged from 1.7 to 111 m^2/g. The relatively low surface area may be the result of sintering caused by the fire and temperature excursion in the PCD. Despite the unusually low surface area, other dustcake properties appeared to be within the range of previous measurements at other fluidized-bed combustors, as shown below.

	In Situ Samples	CCT4 Dustcake	Dustcakes from Other PFBCs
Uncompacted Bulk Porosity (%)	56.9 to 60.2	85	72 to 94
True Particle Density (g/cc)	2.53 to 2.54	2.6	2.5 to 3.3
Drag Equivalent Diameter (μm)	9.3 to 13.4	2.05	0.65 to 8.6
Specific Surface Area (m^2/g)	0.48 to 0.94	3.8	1.7 to 111
Mass Median Diameter (μm)	83 to 136	4.7	1.3 to 51

The physical properties of the in situ samples are almost all outside the range of the dustcake samples from other PFBCs, but this may not be meaningful. If the largest particles are not collected on the candles, but immediately drop into the hopper after entering the PCD, this would account for the differences. This should be evaluated during future test programs.

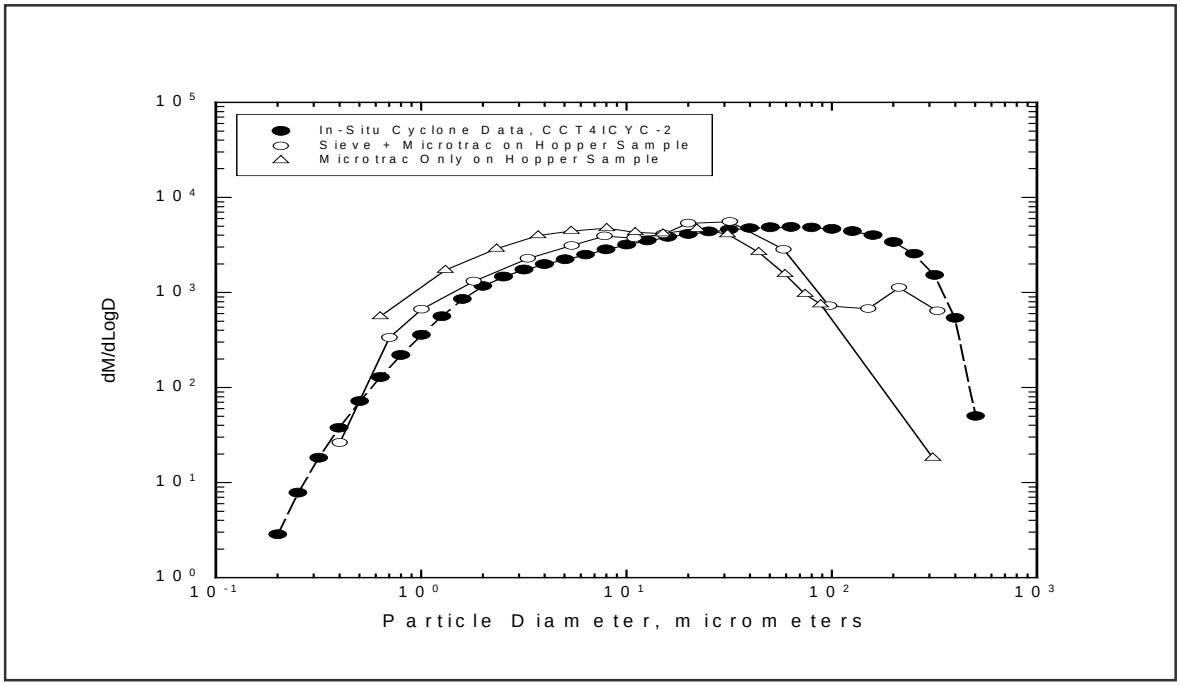


Figure 3.7.8-1 Comparison of Particle-Size Distributions of Dustcake and of In Situ Sample (chart 1 of 2)

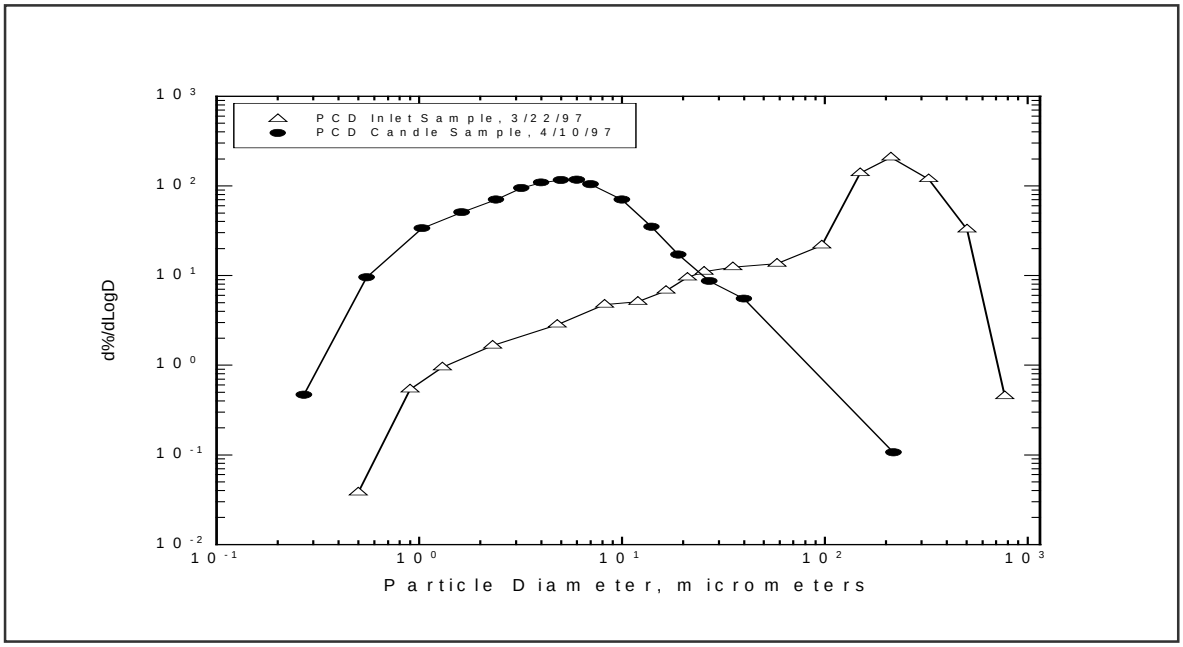


Figure 3.7.8-1 Comparison of Particle-Size Distributions of Dustcake and of In Situ Sample (chart 2 of 2)

3.8 PCD OPERATION DURING TEST RUN CCT5A

3.8.1 Run Summary

Combustion characterization test CCT5A was begun on May 10, 1997. The PCD inlet temperature was raised from the previous test run, CCT4D, from 1,000 to 1,350°F (538 to 732°C). The temperature increase was accomplished by completely bypassing the primary gas cooler. The run lasted until May 20, 1997, when a clinker plugged the primary cyclone dipleg.

In previous test runs the primary gas cooler was used to preheat the PCD gas outlet to 200°F before firing BR0201. However, since the primary gas cooler was bypassed the sulfator start-up heater was used for the preheat.

During this test run the back-pulse started for the first time to negatively impact the transport reactor operation by, at times, causing the primary cyclone dipleg seal to be lost. Apparently, the pressure wave induced in the reactor by the back-pulse resulted in the seal being lost. When the dipleg seal was lost, a large quantity of solids was carried over to the PCD and the solids circulation and coal feed would have to be reduced or stopped. In previous test runs the primary gas cooler was damping the pressure wave induced by the back-pulse, and the reactor operations were not affected.

The pulse valve open time signal, the back-pulse pressure setting, and the time between the back-pulse sequences were all varied in an effort to determine the effect of the back-pulse parameters on the reactor operations. Despite the back-pulse system parameter changes the back-pulse still often caused the primary cyclone dipleg seal to be lost.

The pulse valves were tested during this run and the data continued to indicate a sharp drop in the back-pulse mass flow when the back-pulse pressure was increased from 500 to 600 psig (34.5 to 41.4 bar,g). All four of the pulse valves indicated the same behavior. The pulse valves were tested in runs TC01C through TC01E using a high-speed data acquisition computer. Refer to section 3.27, Pulse Valve Report, for the in-depth results and analysis.

The spent fines transport system (FD0520) was troublesome during the run. FD0520 would fail to cycle, then would be forced to cycle one time and would then cycle numerous times afterward. It appeared that fine ash might have been bridging above the top spheri valve. During this run the FD0520 system was manually forced to cycle every 30 minutes. For an in-depth report on FD0520, refer to section 3.30.

As of this test run the coal feed into the transport reactor was steady for a record 181 hours. The reactor pressure was between 160 and 175 psig for this test run. While on coal the baseline DP was about 20 inWG (50 mbar) and the DP rise between back-pulses cycles was typically anywhere from 10 to 15 inWG (25 to 27 mbar). The face velocity while on coal was typically 4 ft/min (73 m/hr).

At the conclusion of this run the filter elements installed in the filter vessel had accumulated 362 hours on coal.

3.8.2 Test Objectives

The test objectives for PCD operation were:

- Support the transport reactor operations.
- Expose the filter elements to a nominal 1,350°F (732°C).
- Continue testing the pulse valve performance.

3.8.3 Observations/Events

A. Test Started – May 10 at 06:30. The primary gas cooler was bypassed for this test run. In previous test runs, the primary gas cooler was used to preheat the PCD. Since the primary gas cooler was not available for the preheat the sulfator start-up heater was used to preheat the PCD to 350°F, and then the start-up burner was lit at 08:56.

B. Back-pulse Pressure Varied – May 12 at 10:16 to May 14 at 18:50. Flow problems with the pulse valves had been suspected. A series of back-pulse test were carried out through May 14. The peaks shown in figure 3.8.3-2 are the times when the back-pulse tests were carried out. Refer to section 3.27 for an in-depth discussion on the back-pulse testing carried out in runs TC01C through TC01E.

C. Coal Feed Started – May 12 at 22:09. The coal feed into the transport reactor continued steadily for the next 7.5 days.

D. Back Pressure Regulator Arm Broke – May 19 at 02:25. A pin in the transport reactor back-pressure regulator broke. During the next 11 minutes the system pressure increased to 225 psig and then dropped to 115 psig.

E. Pulse Parameters Varied – May 19 at 17:43. The back-pulse valve signal to open time, the back-pulse pressure, and the time between the back-pulse sequences were all varied in an effort to determine the effect of the back-pulse parameters on the reactor operations.

F. Run Terminated and Primary Cyclone Dipleg Plugged – May 20 at 11:10. Coal feed to the transport reactor was stopped because of excessive solids carryover to the PCD. During that time a transport reactor skin temperature survey revealed a hot spot in the primary cyclone dipleg and it was determined the dipleg was plugged. Attempts to clear the dipleg were unsuccessful and the run was ended.

Table 3.8.3-1

CCT5A Run Statistics

Start Time:	5/10/97 12:58
End Time:	5/20/97 11:10
Coal Type:	Calumet Alabama Bituminous
Hours On Coal:	181
Sorbent Type:	Plum Run Dolomite
Number of Filter Elements:	91
Filter Element Layout No.:	3 (Figure 3.8.3-7)
Filtration Area:	255 ft^2 (23.7 m^2)
Pulse Valve Open Time:	0.3 to 0.5 seconds
Pulse Time Trigger:	30 to 45 minutes
Pulse Pressure:	400 to 950 psig (27.6 to 65.5 bar,g)
Pulse DP Trigger:	100 inWG (249 mbar)

Table 3.8.3-2

CCT5A Major Events (Refer to Figures 3.8.3-1 through -6)

Event	Description	Date at Time
A	Test Started	May 10 at 06:30
B	Back-pulse Pressure Varied	May 12 at 10:16
C	Coal Feed Started	May 12 at 22:09
D	Back Pressure Regulator Arm Broke	May 19 at 02:25
E	Pulse Parameters Varied	May 19 at 17:43
F	Run Terminated - Primary Cyclone Dipleg Plugged	May 20 at 11:10
*	Plant Information (PI) System Shutdown	May 12 at 21:45

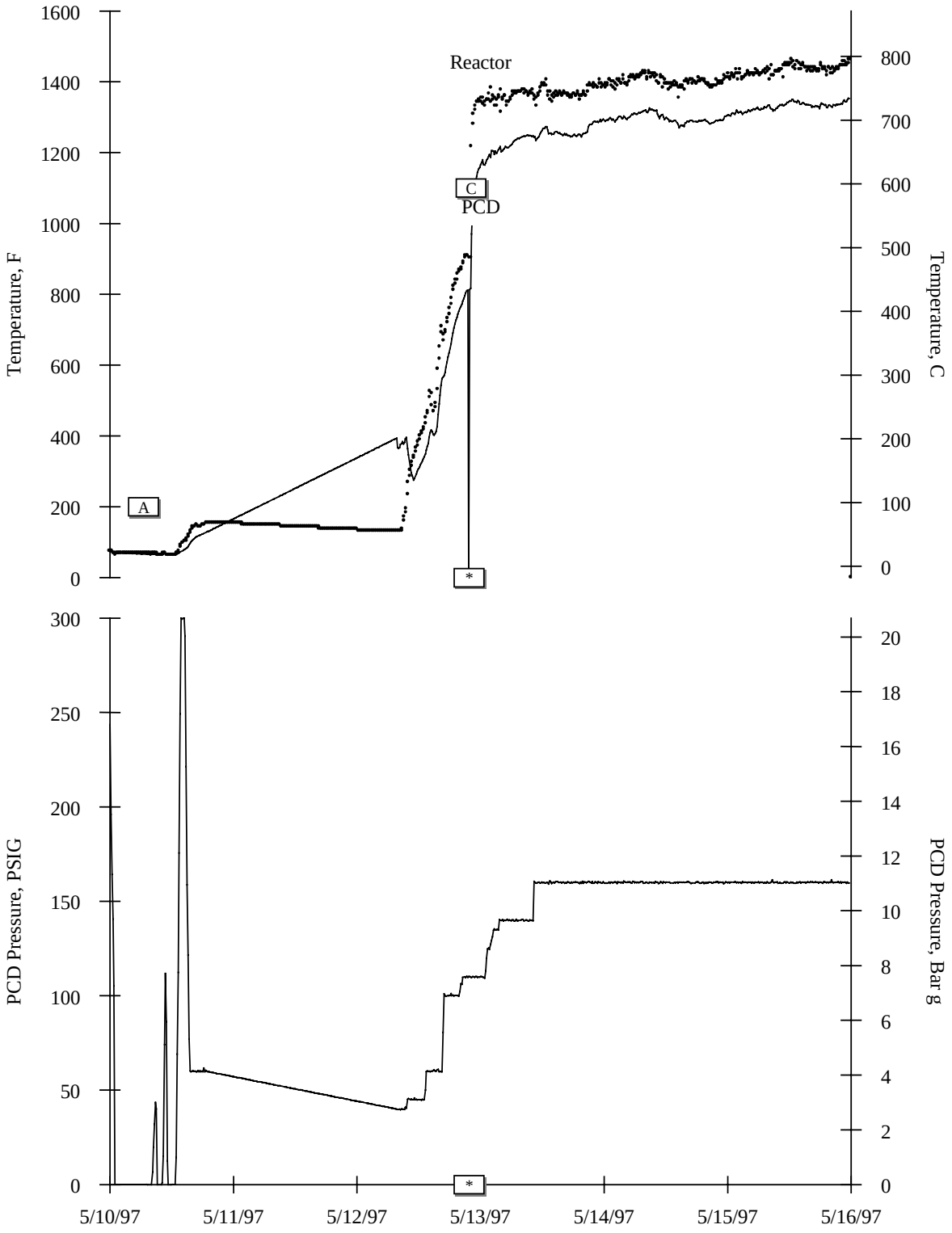


Figure 3.8.3-1 CCT5A Temperature and Pressure for May 10 Through 16, 1997

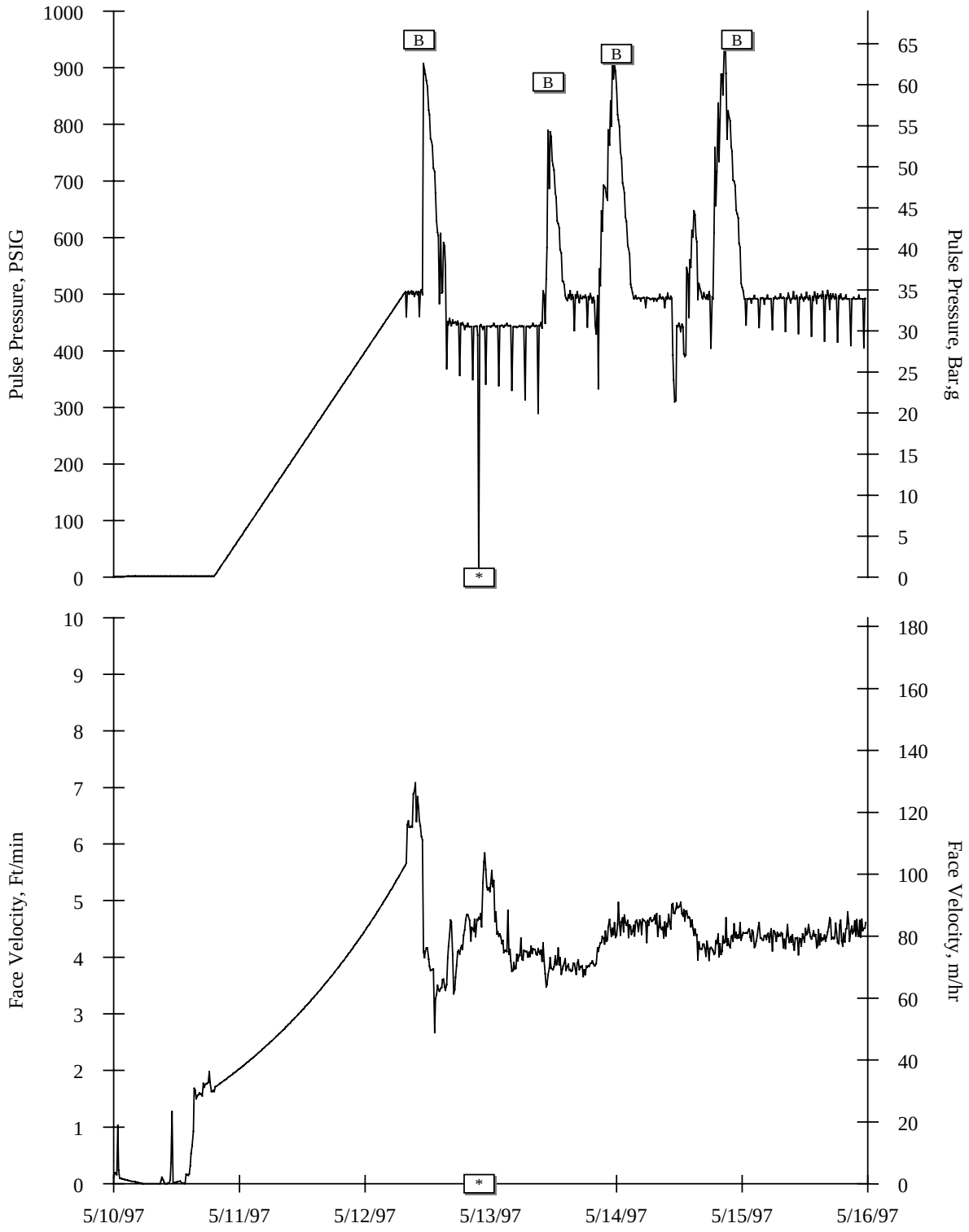


Figure 3.8.3-2 CCT5A Pulse Pressure and Face Velocity for May 10 Through 16, 1997

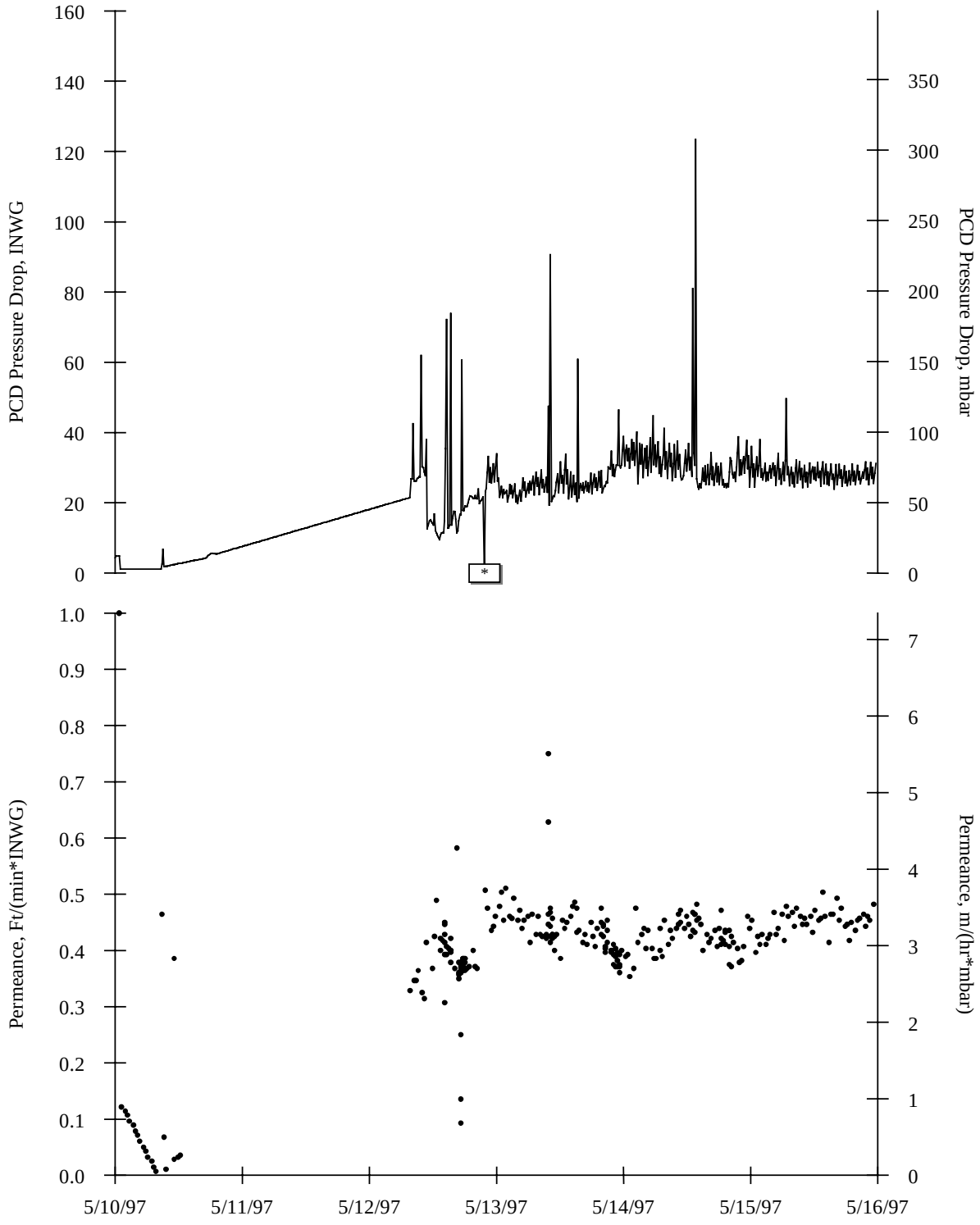


Figure 3.8.3-3 CCT5A Pressure Drop and Permeance for May 10 Through 16, 1997

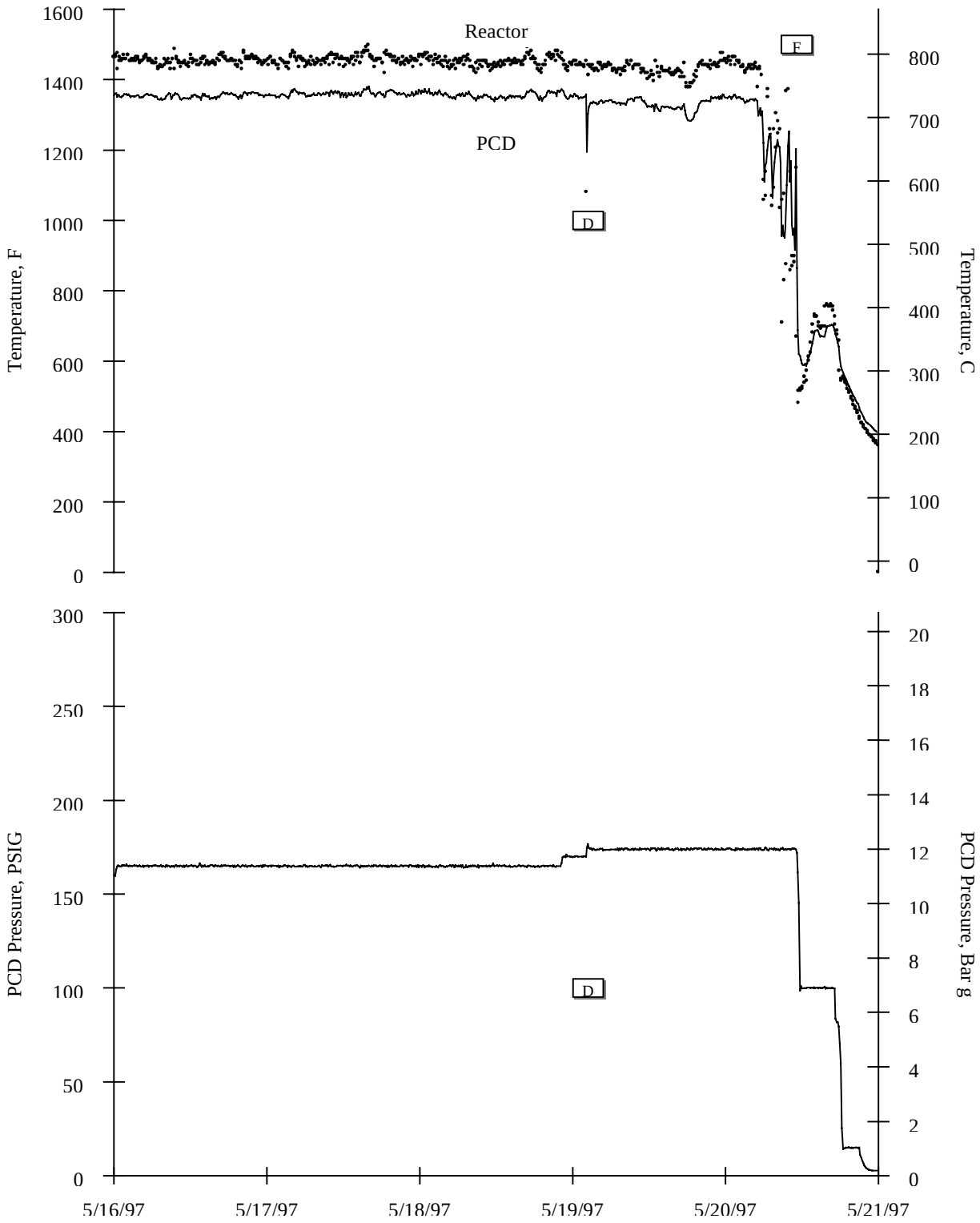


Figure 3.8.3-4 CCT5A Temperature and Pressure for May 16 Through 21, 1997

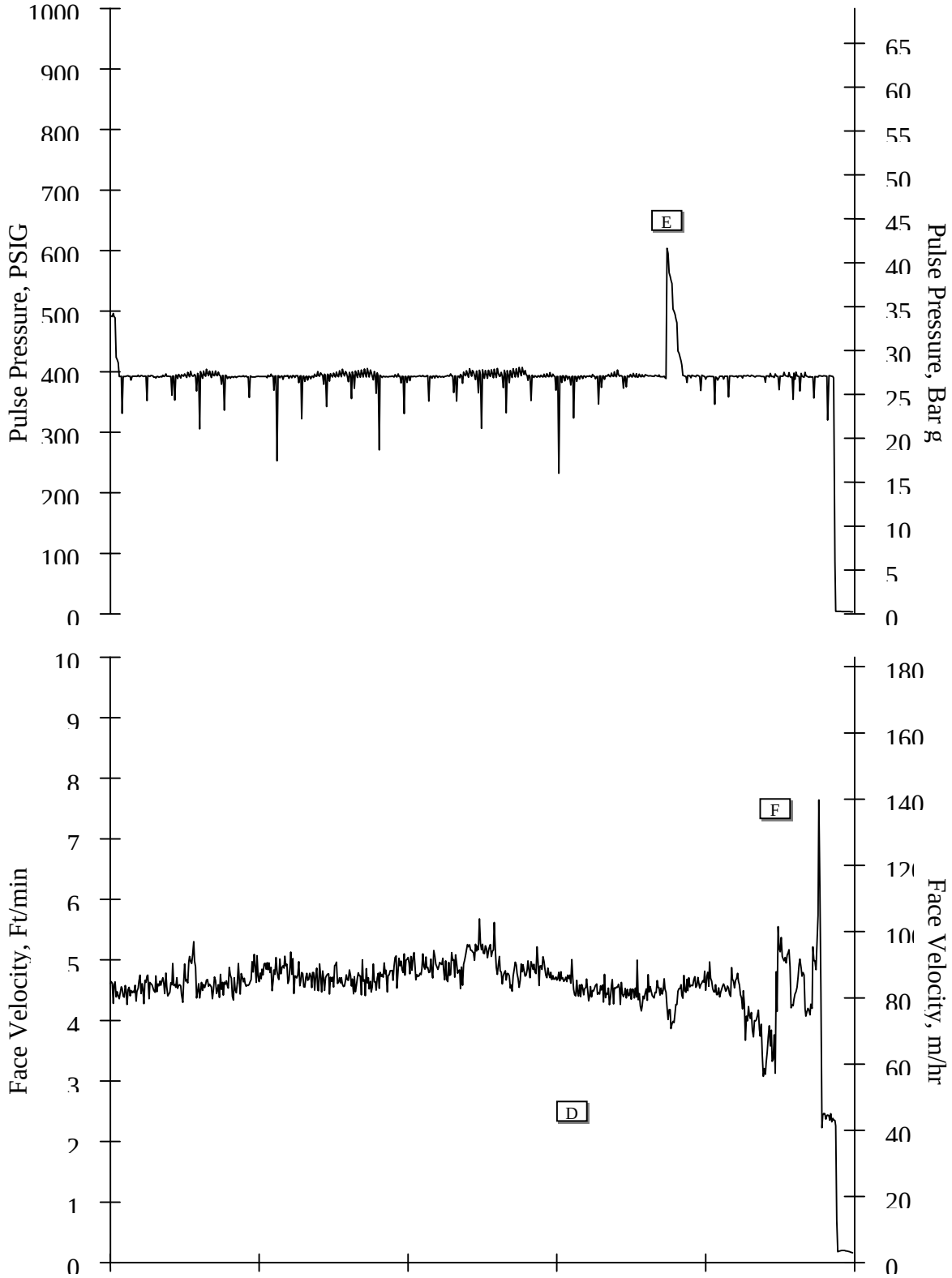


Figure 3.8.3-5 CCT5A Pulse Pressure and Face Velocity for May 16 Through 21, 1997

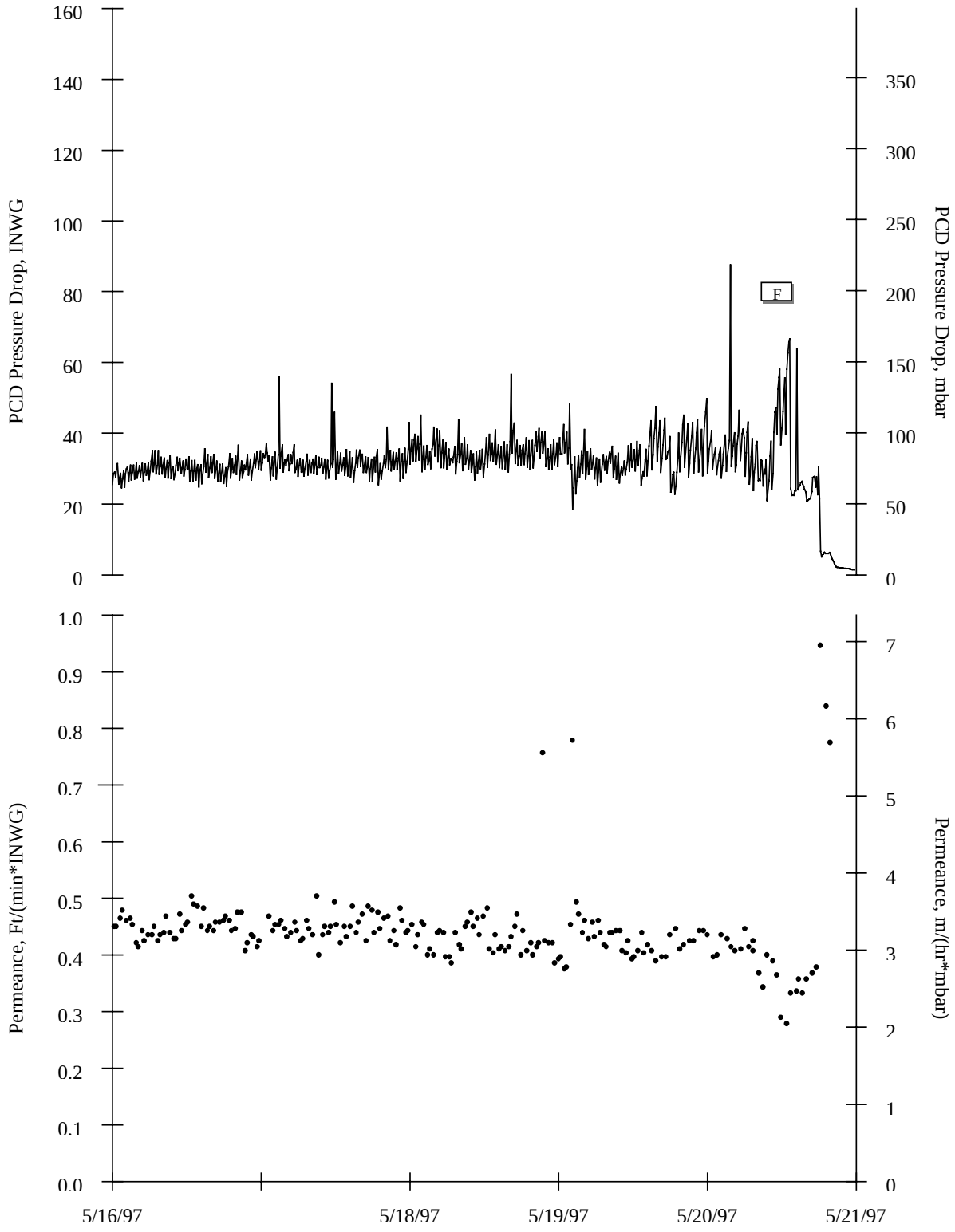


Figure 3.8.3-6 CCT5A Pressure Drop and Permeance for May 16 Through 21, 1997

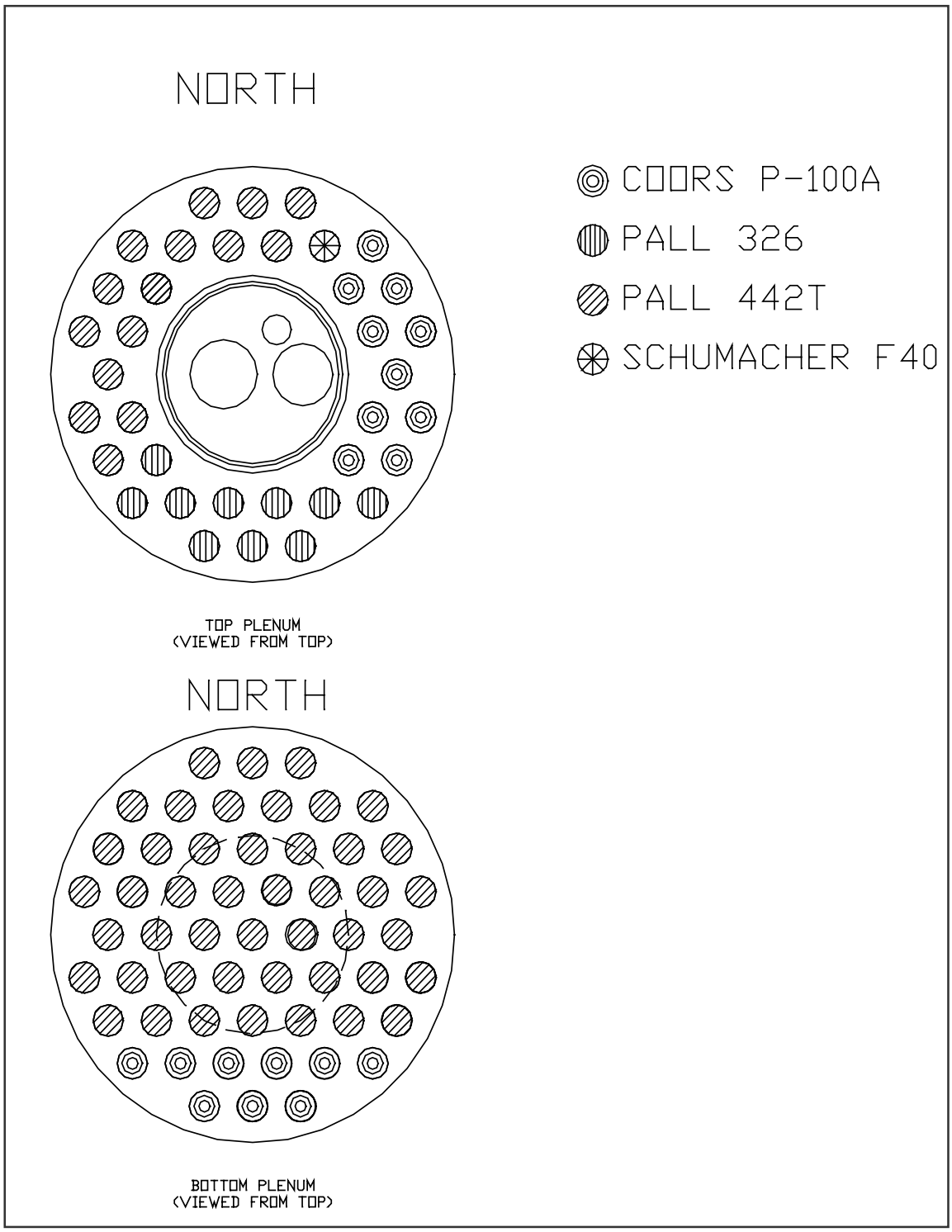


Figure 3.8.3-7 Layout for CCT5A (Layout 3)

3.8.4 Run Outcome

The TR was shut down when the primary cyclone dipleg became plugged.

Despite the back-pulse system operating parameter changes the back-pulse still at times caused the primary cyclone dipleg seal to be lost.

The pulse valves were tested during this run and the data indicated a drop in the mass flow when the back-pulse pressure was increased from 500 to 600 psig (34.5 to 41.4 bar,g). This behavior was the same for all of the pulse valves, which indicated a potential problem with the pulse valves. The pulse valves were tested in runs TC01C through TC01E with a high-speed data acquisition computer. Refer to section 3.27, Pulse Valve Report, for the in-depth results and analysis.

3.9 PCD OPERATION DURING TEST RUN CCT5B

3.9.1 Run Summary

Combustion characterization test CCT5B, which began on the evening of May 22, 1997, was a continuation of test CCT5A, which had ended on the afternoon of May 20, 1997. The CCT5 series of tests were distinguished from previous tests in that the temperature in the PCD was the hottest to date, reaching as high as 1,397°F (758°C) due to the bypass of the heat exchanger (primary gas cooler) upstream of the PCD.

While the transport reactor (RX0201) was burning coal the temperature in the PCD was generally 1,300 to 1,400°F (704 to 760°C). Operating pressure was increased from 100 psig (6.9 bar,g) at the start of coal feed to 180 psig (12.4 bar,g), with most operation occurring at 160 to 180 psig (11.0 to 12.4 bar,g). Gas flow was maintained around 20,000 lb/hr (9,000 kg/hr). The time interval between pulse cleanings was established at 45 minutes in order to minimize any adverse effects of the back-pulse on RX0201 operation. This became an issue in the CCT5 tests due to the elimination of the primary gas cooler flow path which, when coupled with the bypass flow path for temperature control, had been creating a buffer against the back-pulse in previous tests. However, even though the pulse interval was increased the base-line differential pressure across the PCD still remained at 30 to 40 inWG (75 to 100 mbar,g) as it had in previous tests. The face velocity in the PCD was relatively steady at 4 to 5 ft/min (73-91 m/hr).

Table 3.9.1-1

CCT5B Run Statistics

Start time	May 22 at 19:22
End time	May 27 at 08:12
Coal type	Calumet Alabama Bituminous
Hours on coal	98
Sorbent type	Plum Run Dolomite
Number of filter elements	91
Filter element layout number	3 (see Figure 3.9.1-4)
Filtration area	255 ft^2 (23.7 m^2)
Pulse valve open time	0.3 seconds
Pulse time trigger	45 minutes
Pulse pressure	425-475 psig (29.3-32.8 bar,g)
Pulse DP trigger	100 inWG (249 mbar,g)

Table 3.9.1-2

CCT4C Major Events (Refer to Figures 3.9.1-1 through -3)

Event	Description	Date at Time
A	Test started	May 22 at 19:22
B	Sulfator start-up heater on	May 22 at 20:20
C	Main burner on	May 22 at 21:07
D	Sand feed to RX0201 started	May 23 at 00:45
E	Coal feed to RX0201 started	May 23 at 04:15
F	Sorbent feed to RX0201 started	May 23 at 06:50
G	Coal feed tripped	May 24 at 14:00
H	Coal feed tripped	May 26 at 07:40
I	Coal and sorbent feed tripped	May 26 at 09:15
J	Coal feed problems	May 27 at 06:00 to 06:30
K	Main pressure control valve problems	May 27 at 06:40
L	Test ended	May 27 at 08:12

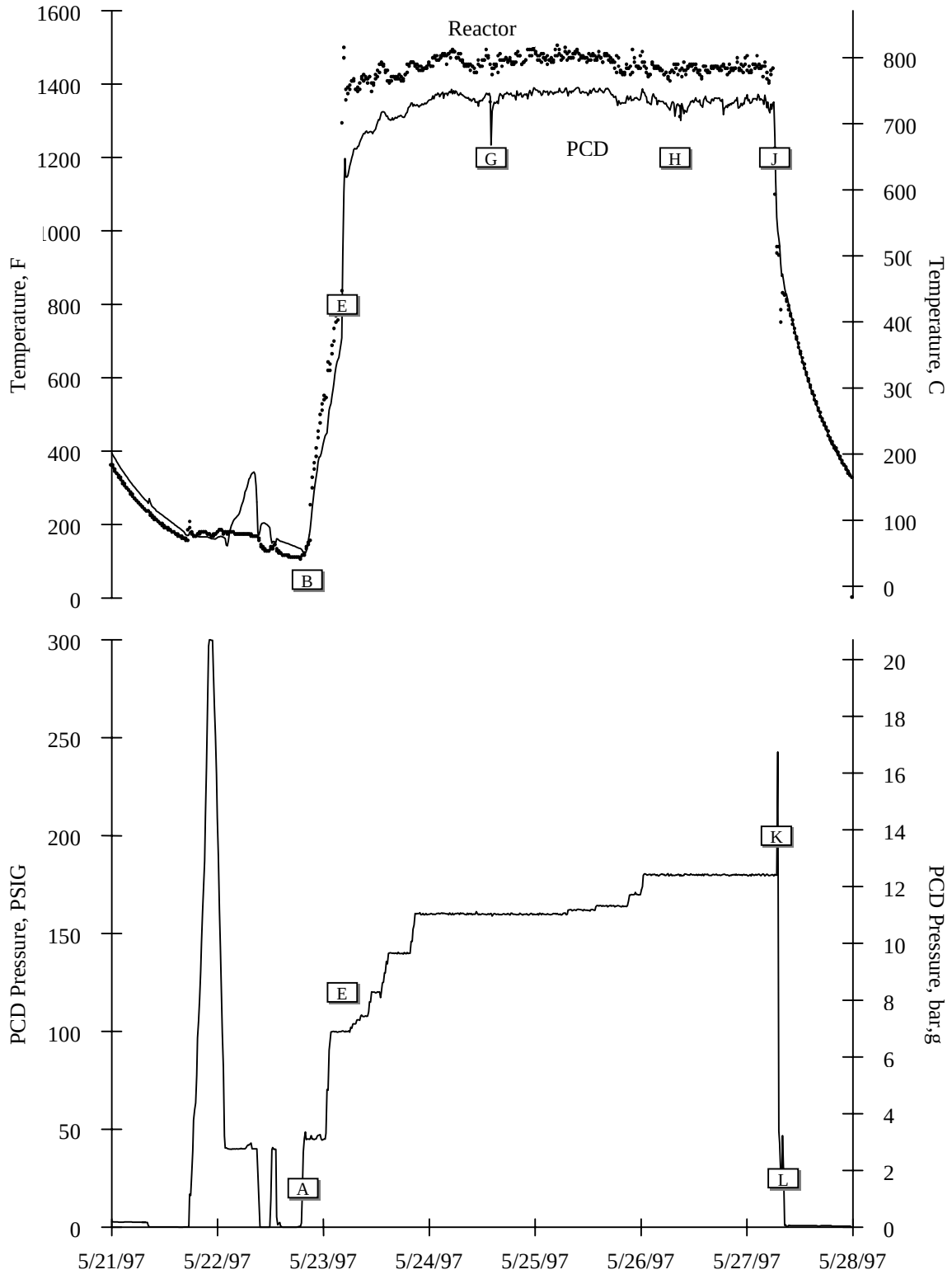


Figure 3.9.1-1 CCT5B Temperature and Pressure for May 21 to 27, 1997

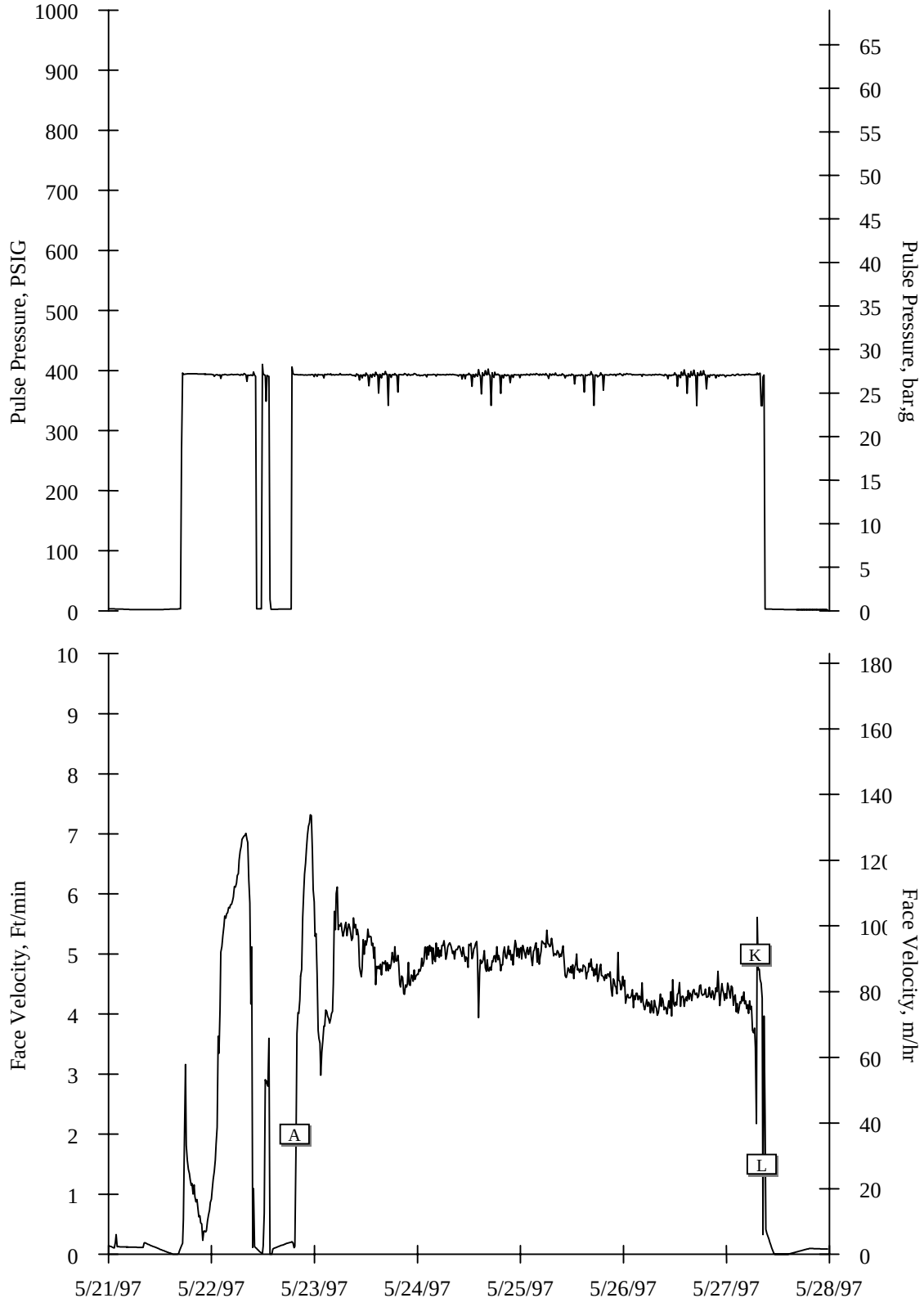


Figure 3.9.1-2 CCT5B Pulse Pressure and Face Velocity for May 21 to 27, 1997

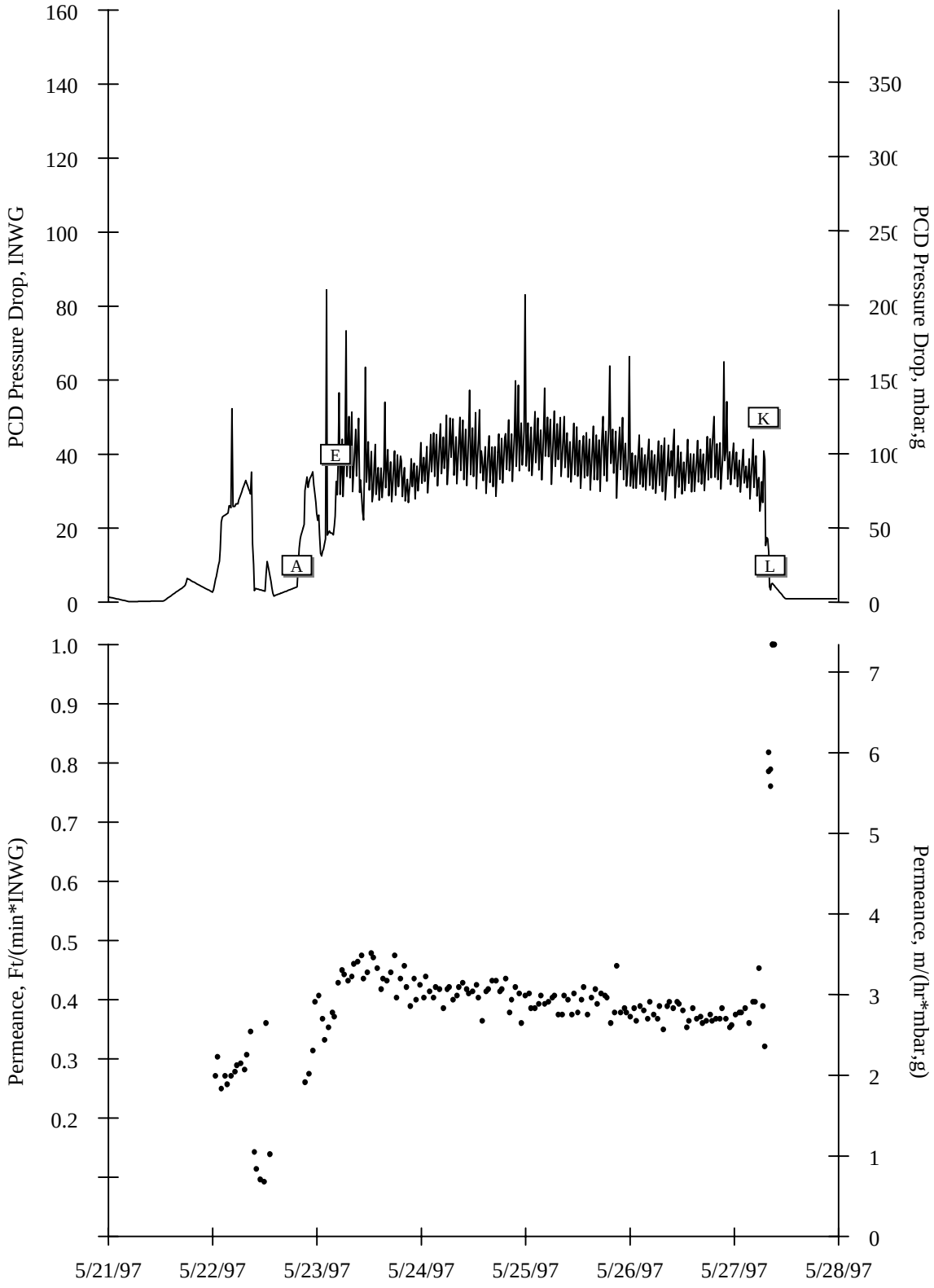


Figure 3.9.1-3 CCT5B Pressure Drop and Permeance for May 21 to 27, 1997

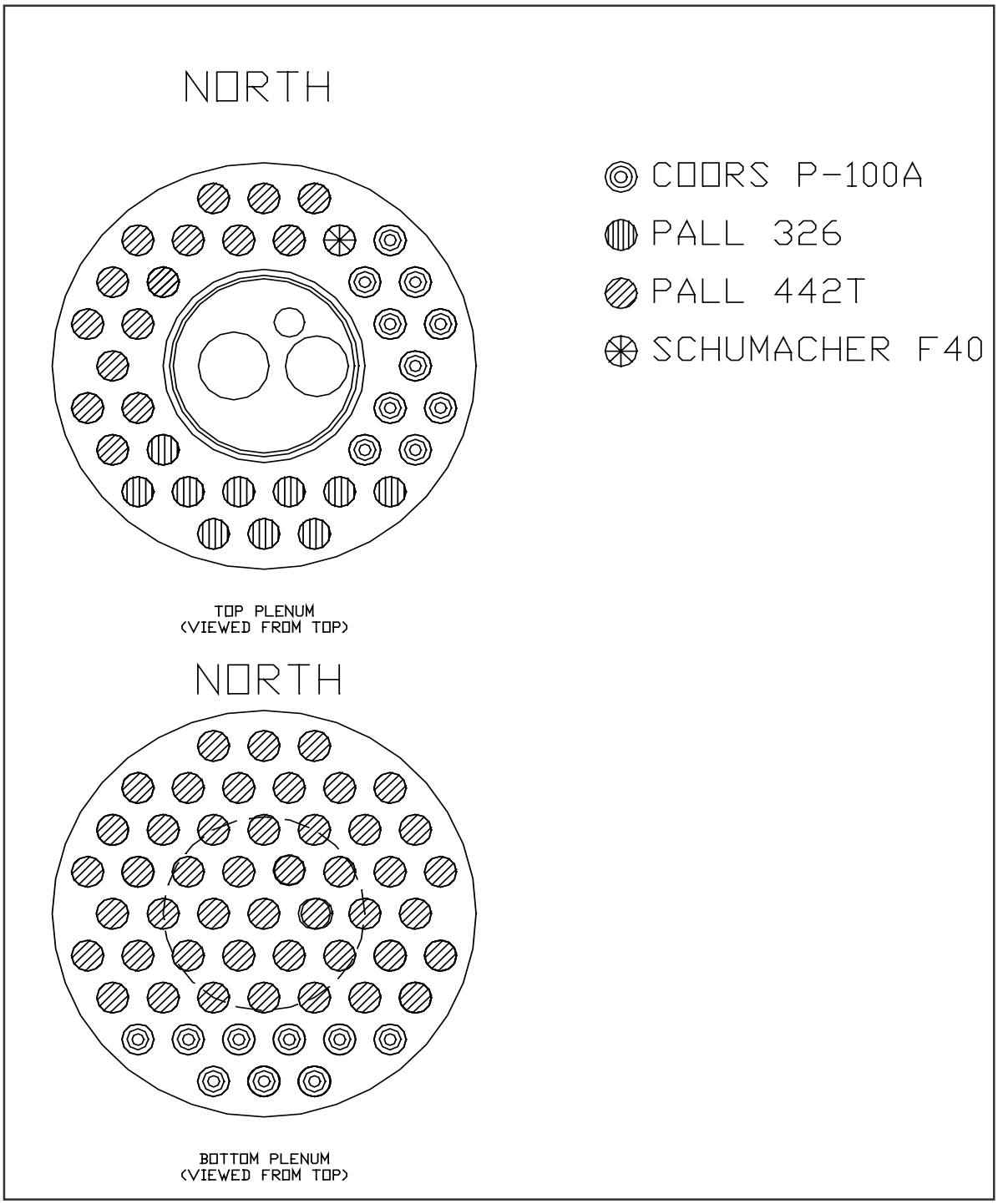


Figure 3.9.1-4 Filter Element Layout for CCT5B (Layout No. 3)

3.9.2 Test Objectives

The PCD objectives of CCT5B were the same as those of CCT5A, to support the test run and evaluate the effect of higher temperature on filter operation. The overall plant objective of the test run was to operate as long as possible (and practical) and collect as much combustion data at higher temperatures as possible, as well as to increase and refine an understanding of the operation of RX0201.

3.9.3 Observations/Events

A. Test Started–May 22 at 19:22. The test was originally scheduled to start on the morning of May 22, but problems with the main start-up burner delayed the start-up. Finally, after the burner problems were resolved the main air compressor (CO0201) was started at 19:22, signifying the start of CCT5B.

B. Sulfator Start-Up Heater On–May 22 at 20:20. The sulfator start-up heater was needed for preheat of the PCD because the primary gas cooler, which was previously used as a heater of the CO0201 discharge for PCD preheat, was completely bypassed for the CCT5 test runs.

C. Main Burner On–May 22 at 21:07. The main burner was started shortly after the sulfator start-up heater because it was assumed that the PCD preheat that had occurred using the sulfator start-up heater during the night of May 21 and22 had been sufficient to maintain the PCD above dew-point during the main burner problems of May 22.

D. Sand Feed to RX0201 Started–May 23 at 00:45.

E. Coal Feed to RX0201 Started–May 23 at 04:15.

F. Sorbent Feed to RX0201 Started–May 23 at 06:50.

G. Coal Feed Tripped–May 24 at 14:00. The feed piping to RX0201 from the coal feeder became plugged but was cleared within 10 minutes. System temperatures dropped but easily recovered

H. Coal Feed Tripped–May 26 at 07:40. Problems with the transport air dryer (dries the air used to assist the rotofeed reactor feeders) caused a momentary drop in transport air pressure and a loss of coal feed for several minutes. The transport air was quickly restored and, therefore, the coal feed was also restored.

I. Coal and Sorbent Feed Tripped–May 26 at 09:15. The RX0201 feeders tripped again due to transport air dryer problems, but both were quickly restored.

J. Coal Feed Problems–May 27 at 06:00 to 06:30. Coal was agglomerating and bridging in the lock vessel of the coal feeder as it was attempting to empty into the dispense vessel. Very little coal was dropping into the dispense vessel and, therefore, very little was being fed into the reactor.

K. Main Pressure Control Valve Problems–May 27 at 06:40. Since coal feed was lost it was necessary to lower system pressure from 180 to 100 psig (12.4 to 6.9 bar,g) in preparation for relighting the start-up burner. As pressure was being reduced the main pressure control valve mechanically failed and completely closed. RX0201 pressure increased to 244 psig (16.8 bar,g) in 2 minutes. Plant operations personnel forced

CO0201 to trip so that manual control of the pressure control valve could be established. Once this pressure control was established, CO0201 was restarted so that a controlled shutdown could be implemented. It was decided to shut down due to the compound coal feed and pressure control problems.

L. Test Ended–May 27 at 08:12. CO0201 was stopped after a controlled shutdown, signifying the end of the test run.

3.9.4 Run Outcome

A post test inspection of the PCD vessel revealed no apparent damage to the filter elements or breach of dust-laden gas to the gas outlet. There was very little residual filter cake on the elements of the bottom plenum and appeared to be almost no residual filter cake on the elements of the top plenum. Additionally, the clean side of the PCD had been turned a black color from oxidation of the metal at the higher temperature.

The CCT5 test runs accomplished their objectives of increasing understanding of transport reactor operation and exposing the PCD to extended higher temperature operation. However, there were still aspects of RX0201 operation which needed further understanding, and there was a need to operate the PCD at even higher temperatures for process evaluations. The CCT6 test series would continue to address RX0201 operation issues and expose the PCD to higher temperatures due to the elimination of the RX0201 fluidized bed heat exchanger (MWK combustion heat exchanger).

3.10 ASH CHARACTERISTICS AND PCD PERFORMANCE FOR TEST RUN CCT5

In test CCT5 six in situ particulate sampling runs were performed at the PCD inlet. These sampling runs were primarily directed at monitoring changes in solids carryover from the transport reactor system. All of the samples collected at the PCD inlet were total particulate mass samples collected on a single filter (mass samples). No samples were collected at the PCD outlet since the primary focus of CCT5 was on evaluating particulate carryover from the transport reactor system under various conditions.

Throughout the CCT5 tests SRI sampling personnel coordinated with SCS operations personnel to ensure that the transport reactor system was operating under steady-state conditions during each 30-minute sampling run. Although test conditions were maintained relatively constant throughout a given sampling run there was considerable variability in transport reactor operating conditions between runs. Consequently, there was also considerable varibility in solids carryover from the transport reactor system to the PCD. During the CCT5 particulate sampling runs the average recorded temperature at the PCD inlet was 1,325 ±39°F (718 ± 22°C) and the average recorded pressure was 160 ± 11 psig (11.0 ± 0.8 bar). The average gas velocities measured at the sampling nozzle varied from 23.9 to 28.9 ft/sec (7.3 to 8.8 m/sec) and were within ±5 percent of the average process gas velocity for all but one of the sampling runs. The particulate loading that was measured for the one anisokinetic run (CCT5IMT-1) was corrected back to isokinetic conditions using the technique described in the CCT4 ash report.

This report summarizes the particulate mass loadings determined from the CCT5 sampling runs. Particle-size distributions determined by particle-size analysis in the laboratory are discussed, and significant physical and chemical characteristics of the in-situ samples are presented and compared to the characteristics of ash samples taken from the PCD hopper and of dustcake samples taken from the filter elements during the PCD inspection in July. The various types of samples are compared in terms of their chemical composition, permeability, particle-size distribution, and other relevant properties.

3.10.1 Measurements of Particulate Mass Loadings

Table 3.10.1-1 gives a summary of the results of the PCD inlet particle mass concentration measurements performed during CCT5. As indicated in the table, the measured inlet loading varied from 4,200 to 25,600 ppmw with a mean value of 14,600 ppmw ± 8,200 ppmw (56 percent relative standard deviation, rsd). The changes in inlet mass loading have not been correlated with specific variations in process operations but are apparently related to intermittent reentrainment of solids from the cyclone dipleg and to disruptions in the coal and sorbent feeds.

Table 3.10.1-1

PCD Inlet Particulate Mass Loading Data for Test Program CCT5

SRI	Date	Run Time[1]		Particle Loading[2]		
Run No.	Sampled	Start	End	ppmw	gr/acf	mg/scm
CCT5IMT-1	5/13/97	09:08	09:38	9,900	14.7	12,000
CCT5IMT-2	5/14/97	09:03	09:33	14,200	26.2	17,200
CCT5IMT-3	5/15/97	10:00	10:30	10,700	20.0	13,200
CCT5IMT-4	5/16/97	08:50	09:20	25,600	47.1	30,500
CCT5IMT-5	5/16/97	13:32	13:52	23,000	42.6	27,400
CCT5IMT-6	5/19/97	10:23	10:43	4,200	8.16	5,060

1. All times are Central Standard Time.
2. Standard conditions taken at 14.7 psia (1.01 bar) and 70°F (21°C).

3.10.2 Measurements of Particle-Size Distributions

Particle-size distributions were measured on two of the in situ particulate samples (CCT5IMT-4 and -5) using a Leeds and Northrup Microtrac X-100 particle-size analyzer. The resulting particle-size distributions are plotted and compared to comparable size distributions from the other runs in the ash report for TC01 (see section 3.25). In general, the CCT5 samples were considerably finer than the CCT4 samples (MMD ≅ 54 μm versus 109 μm for CCT4). In particular, the distinct large-particle mode that was evident in the CCT4 data is not present in the CCT5 size distributions. The elimination of this large-particle mode is a direct result of the improved control of solids carryover from the transport reactor system.

3.10.3 Chemical Analyses

The results of selected CCT5 ash mineral analyses are summarized in table 3.10.3-1. All of the results given in the table are for PCD hopper samples. Because of the highly variable process conditions no chemical analyses were done on in situ samples. All of the analytical results are reported as the element on an ignited basis. The elemental concentrations are not reported in their oxide forms since calcium is predominantly present in the form of the sulfate and carbonate. Other ash constituents are also present as sulfates and carbonates as well as other forms such as silicates, aluminosilicates, halides, and sulfides.

Based on the hopper ash analyses shown in table 3.7.2-1 the average calcium utilization (i.e., the percentage of the calcium that is converted to calcium sulfate on a molar basis) was 8.6 percent ± 2.4 percent. This low value of utilization reflects the large feed rates of dolomite and the resulting high calcium-to-sulfur ratios that were being used during CCT5. Since the sorbent is dolomite and the inherent calcium in the coal is quite low (typically < 1.0 percent of the coal ash) the calcium-to-magnesium molar ratio would be expected to be close to 1-to-1 in the ash. The average value ratio calculated from the hopper ash analysis is 1.02-to-1.

The hopper ash analyses were used to calculate the average chemical composition of the solids collected in the PCD, assuming that all of the sulfur was present as $CaSO_4$ and all of the carbon was present as $CaCO_3$. Any remaining calcium that was not accounted for as $CaSO_4$ or $CaCO_3$ was assumed to be present as CaO•MgO. Any remaining magnesium that was not accounted for as CaO•MgO was assumed to be present as MgO. The balance of each sample was assumed to be ash and sand (bed material). The choice of these particular calcium and magnesium compounds was based on free-energy minimization calculations performed by Dr. L. Shadle at the U. S. Department of Energy/FETC and reported by P. Smith (personal communication, March 6, 1998). The average chemical composition calculated in this manner is as follows:

- 2.72 percent ± 0.41 percent $CaSO_4$.
- 16.7 percent ± 2.0 percent CaO•MgO.
- 7.89 percent ± 4.59 percent $CaCO_3$.
- 2.61 percent ± 1.66 percent MgO.
- 70.1 percent ± 5.7 percent ash/sand.

Table 3.10.3-1

Elemental Analysis of Selected CCT5 Hopper Samples[1]

I. D. No. (ABO)	1274	1275	1276	1324	1325			
Date Collected	5/17/97	5/18/97	5/19/97	5/26/97	5/27/97	Avg	S.D.	RSD (percent)
Measured Composition								
Silicon (percent)	19.89	20.84	21.27	22.01	23.17	21.44	1.10	5.16
Aluminum (percent)	9.98	9.36	11.88	11.98	11.59	10.96	1.20	10.99
Titanium (percent)	0.52	0.50	0.58	0.61	0.58	0.56	0.046	8.22
Iron (percent)	2.71	2.90	2.62	3.09	3.14	2.89	0.228	7.89
Calcium (percent)	12.73	11.79	6.53	8.97	8.70	9.74	2.51	25.73
Magnesium (percent)	7.74	6.99	4.03	5.19	5.09	5.81	1.52	26.09
Potassium (percent)	1.21	0.94	1.87	1.01	0.65	1.14	0.456	40.07
Sodium (percent)	1.11	1.14	1.01	1.30	1.33	1.18	0.134	11.39
Phosphorous (percent)	0.10	0.10	0.10	0.16	0.15	0.12	0.030	25.27
Sulfur (percent)	0.65	0.64	0.59	0.79	0.53	0.64	0.096	15.07
Carbon (percent)	1.17	1.02	1.72	0.37	0.46	0.95	0.553	58.20
Oxygen (percent) (diff)	42.19	43.78	47.80	44.52	44.61	44.58	2.04	4.58
Calculated Parameters								
Utilization (percent)[2]	6.38	6.79	11.3	11.0	7.62	8.62	2.36	27.3
Ca/S Molar Ratio	15.7	14.7	8.85	9.08	13.1	12.29	3.17	25.8
Ca/Mg Molar Ratio	1.00	1.02	0.98	1.05	1.04	1.02	0.029	28.1
$CaCO_3$ (percent)	9.75	8.50	14.3	3.08	3.83	7.89	4.59	58.3
$CaSO_4$ (percent)	2.76	2.72	2.51	3.36	2.25	2.72	0.411	15.2
CaO•MgO (percent)	19.2	18.2	14.2	16.2	15.6	16.7	2.01	12.0
MgO (percent)	4.74	3.92	0.72	1.79	1.88	2.61	1.66	63.6
Ash/Sand (percent) (diff)	63.55	66.66	68.27	75.57	76.44	70.1	5.66	8.1

Notes: 1. Weight percent ignited basis, expressed as element (not oxide); excludes samples for which the sum of the oxides is less than 90 percent.
2. Calcium utilization (i.e., percent of Ca converted to $CaSO_4$ assuming all sulfur is present as $CaSO_4$.).

3.10.4 Measurements of Permeability and Related Properties

Permeability tests were performed on two of the in situ samples from CCT5 (CCT5IMT-4 and -5). Only two CCT5 samples were tested because of the unstable operation of the transport reactor. Table 3.10.4-1 gives a summary of the permeability test results, which are expressed in terms of drag-equivalent diameter (DED) along with the results of other significant physical measurements, including: true (skeletal particle) density, bulk density, uncompacted bulk porosity (UBP), surface area, and mass median diameter (MMD). The DED is not a physical size but rather a fitted parameter that can be used to rank the characteristic gas flow resistance of ashes at equal porosities. Measurements of physical size generally correlate with DED, but the DED best expresses the *fineness of an ash* as it relates to its effect on gas flow resistance (drag). Increasing values of DED indicate lower resistance to gas flow (less drag) at a given porosity. Using the DED as an indicator of flow resistance eliminates much of the ambiguity associated with drag measurements, which are a strong function of porosity.

True density measurements were made by helium pycnometry using a Quantachrome Model 1000 Ultrapycnometer. Bulk density was determined by measuring the volume of a known weight of ash and uncompacted bulk porosity was calculated from the true density and bulk density. Specific surface area was determined by the BET method using a Micromeritics FloSorb-II analyzer and the mass medium diameter (MMD) was based on particle size analysis on a Leeds & Northrup Microtrac X-100 analyzer.

Comparison of the averages for the CCT5 and CCT4 test programs shows that improved reactor operation with increased operating time has resulted in a reduced median particle size, increased surface area, and increased dustcake flow resistance.

Table 3.10.4-1

Physical Properties of CCT5 In Situ Samples

Run Number	Date Sampled	Lab ID No.	True Density (g/cc)	Bulk Density (g/cc)	UBP[1] (Percent)	Surface Area (m^2/g)	MMD[2] (μm)	DED[3] (μm)
Test Program CCT4								
CCT4IMT-7	5/1/97	AB01289	2.54	1.01	60.2	0.94	83.1	9.28
CCT4IMT-8	5/2/97	AB01290	2.53	1.09	56.9	0.48	135.5	13.36
Average for CCT4			2.54	1.05	58.58	0.71	109.30	11.32
Test Program CCT5								
CCT5IMT-4	5/16/97	AB01294	2.85	0.92	67.7	1.26	53.0	7.02
CCT5IMT-5	5/16/97	AB01295	2.74	0.86	68.6	1.31	55.8	7.74
Average for CCT5			2.80	0.89	68.17	1.29	54.40	7.38

Notes:
1. Uncompacted Bulk Porosity.
2. Mass Median Diameter.
3. Drag Equivalent Diameter.

3.11 PCD OPERATION DURING TEST RUN CCT6

3.11.1 Run Summary

Combustion characterization test CCT6 was the most unusual of 1997 tests. What made the run unusual was that the transport reactor was operated with the combustion heat exchanger (CHE) out of service. The primary reason for this modification was the continued investigation into how to improve the primary cyclone (CY0201) performance with the combustion heat exchanger removed from the loop. The transport reactor system was greatly simplified. Several held the theory that the gas flow from the CHE aeration disrupted the cyclone either by the gas flowing up the cyclone dipleg or the vent disrupting the flow entering the cyclone.

The removal of the CHE alleviated essentially all concerns about filling the PCD with ash, since the solids inventory in the transport reactor was significantly reduced. However, the addition of coal to the transport reactor became more difficult since the coal feed system (FD0210) did not have sufficient turndown to be used as was the coal feeder with the CHE removed from service. Even at minimum speed in the coal feeder the temperature in the reactor would be too great without the CHE. During operation it was discovered that as the coal feed from the sorbent feeder (FD0220) increased, the discharge line between the feeder and the transport reactor would plug. The feed rate from FD0220 was optimized to prevent plugging, but supplemental firing of the start-up burner (SUB) was required to maintain reactor temperature. This limited the operating pressure to about 100 psig (6.9 bar). However, on June 25 during the run the PCD inlet temperature reached a maximum value for 1997 of 1,505°F (818°C).

3.11.2 Run Objectives

For the PCD group, the only objective was to support the transport reactor engineers and the operations staff while they investigated how to improve the cyclone collection efficiency.

3.11.3 Observations/Events

A. Pressure Test–June 17 at 12:00. After maintenance completed modifications to the transport reactor, a pressure test was performed to test the integrity of the pressure boundary.

B. PCD Preheat Started–June 18 at 01:35. Using the sulfator start-up burner, the PCD was preheated with hot air prior to lighting the SUB.

C. PI System Shutdown–June 18 at 06:00. The plant information (PI) system was down for several hours; typically, this is recorded as a "break" in the data. However, in this case PI connected the end points with a smooth curve. The data represented by these curves are not real.

D. Shutdown for SUB–June 18 at 10:35. After several failed attempts at lighting the SUB, the plant was temporarily shutdown to inspect and repair the burner.

E. SUB Lit–June 18 at 14:20. The SUB was lit, and heating the system continues.

F. Coal Feed Started–June 19 at 02:26. With the combustion heat exchanger out of the loop, coal was fed through the sorbent feeder (FD0220). The discharge line of the sorbent feeder is significantly smaller than the discharge of the coal feeder, and as the feed rate was increased the line continually plugged. To keep the reactor at desired temperature supplemental firing using the SUB was required. Because of pressure limitations in the SUB system, this limited the operating pressure to ~100 psig.

G. Lost Coal Feed–June 19 at 15:00.

H. Coal Feed Resumed–June 20 at 02:00.

I. Changed Pulse Interval to 15 Minutes–June 24 at 14:00. Throughout this test series as well as in previous tests it was apparent that backpulsing the PCD had a negative impact on the cyclone dipleg. It was not known if the dipleg upset was caused by the pressure wave propagating upstream during the back-pulse or the sudden change in PCD ΔP once the back-pulse was over. For a period of 18 hours the back-pulse interval was decreased from 40 to 15 minutes to generate data. It is very interesting that this change in pulse interval caused a decrease in permeance, which recovered when the pulse interval was increased back to 40 minutes. Some sources of literature report the opposite affect in testing. This will be further investigated in 1998 (TC02).

J. Changed Pulse Interval to 40 Minutes–June 25 at 08:10.

K. Run Ended–June 26 at 19:50.

3.11.4 Run Outcome

The PCD completed the run without incident. A visual inspection of the PCD after the run indicated no failed or leaking filter elements.

During June, Westinghouse requested that the PSDF perform a 1,000-hour combustion run to investigate possible physical changes to SiC filter elements at an operating temperature of 1,350 to 1,400°F. Westinghouse requested data only on Pall 442T and Pall 326 filter elements. Prior to installation, the elements were dimensionally measured and a ΔP vs flow curve was generated for each element. Additionally, the filter elements were sent to Southern Research Institute (SRI) for profilometry. Profilometry is used to quantify any bowing that might occur in operation. At some future date these elements will be measured again to see if bowing occurred in operation.

In addition to the Pall filters requested by Westinghouse, Schumacher TF20 and 3M Type 203 (SiC) filters were measured prior to installation. Profilometry was not performed on these elements.

Table 3.11.4-1

CCT6 Run Statistics

Start Time:	June 18–01:35
End Time:	June 26–19:50
Coal Type:	Calumet Alabama Bituminous
Hours On Coal:	177.5
Sorbent Type:	Plum Run Dolomite
TR Bed Material	Sand
Number of Filter Elements:	91
Filter Element Layout No.:	3 (Figure 3.11.4-6)
Filtration Area:	255 ft^2 (23.7 m^2)
Pulse Valve Open Time:	0.3 seconds
Pulse Time Trigger:	15 and 40 minutes
Pulse Pressure:	400 psig (27.6 bar,g)
Pulse ΔP Trigger:	100 inWG (248.8 mbar,g)

Table 3.11.4-2

CCT6 Major Events (Refer to Figures 3.11.4-1 through -6)

Event	Description	Date at Time
A	Pressure Test	June 17 at 12:00
B	PCD Preheat Started	June 18 at 01:35
C	PI System Shutdown	June 18 at 06:00
D	Shutdown for SUB	June 18 at 10:35
E	SUB Lit	June 18 at 14:20
F	Coal Feed Started	June 19 at 02:26
G	Lost Coal Feed	June 19 at 15:00
H	Coal Feed Resumed	June 20 at 02:00
I	Changed Pulse Interval to 15 Minutes	June 24 at 14:00
J	Changed Pulse Interval to 40 Minutes	June 25 at 08:10
K	Run Ended	June 26 at 19:50

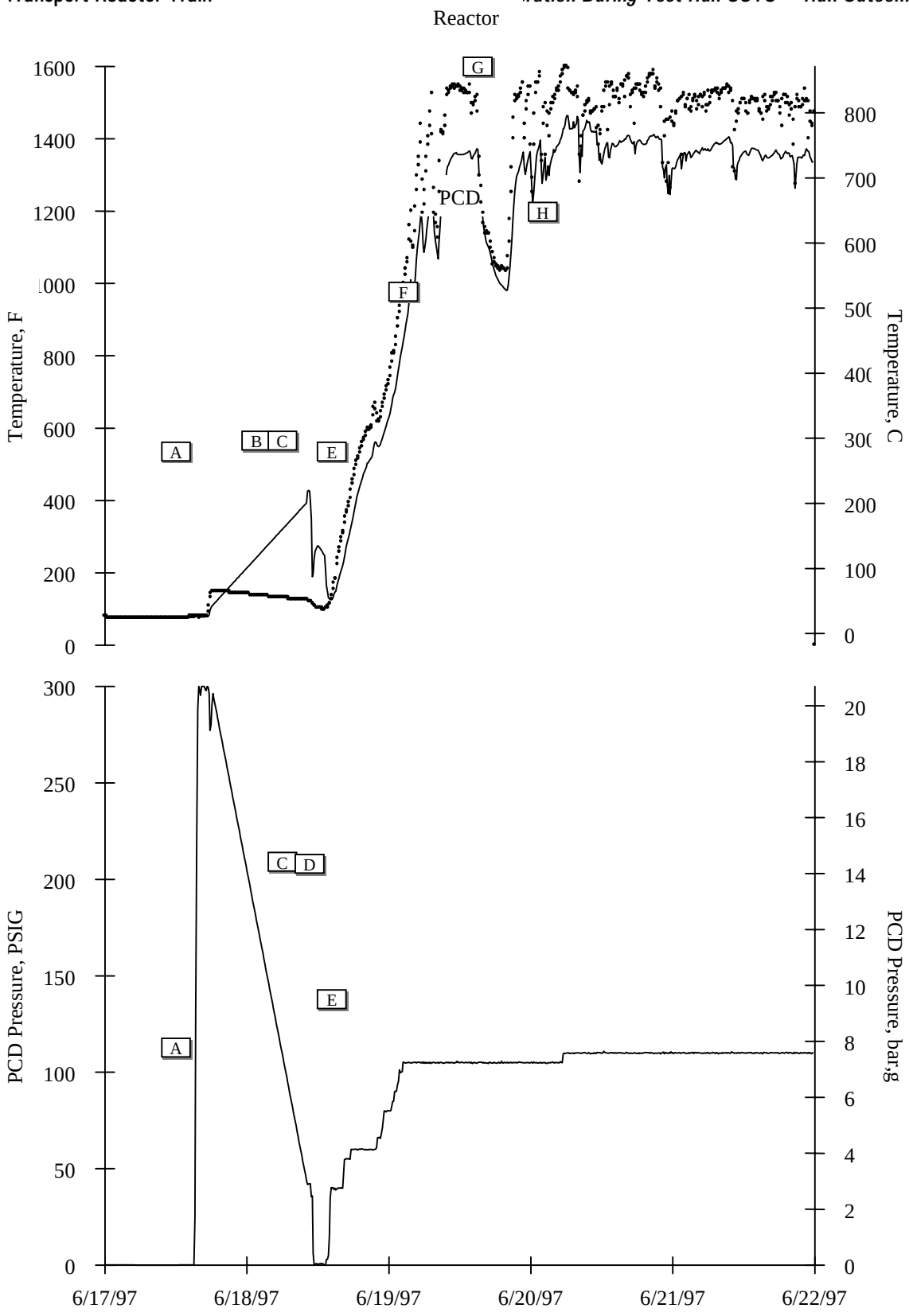


Figure 3.11-4-1 CCT6 Temperature and Pressure for June 17 Through 22

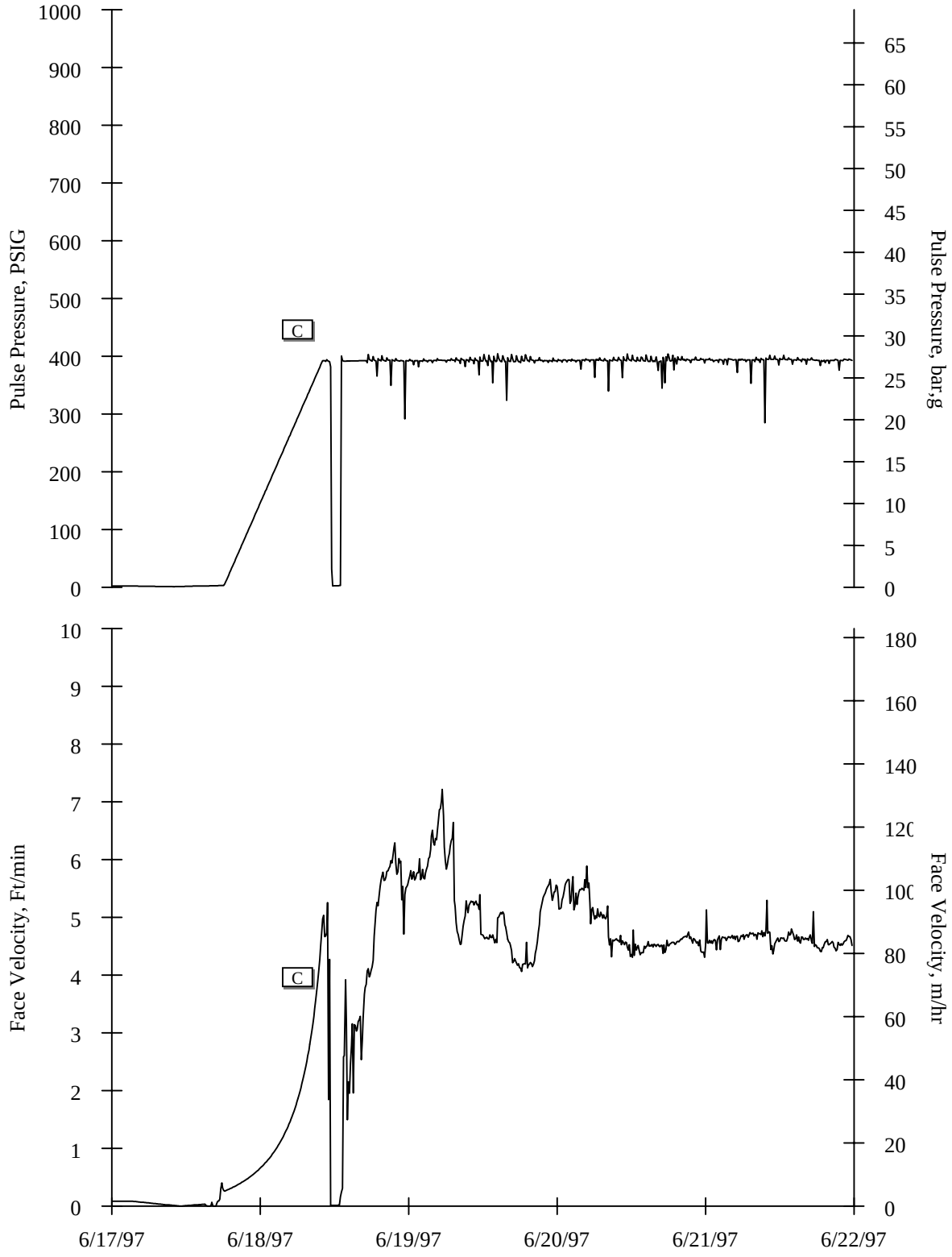


Figure 3.11-4-2 CCT6 Pulse Pressure and Face Velocity for June 17 Through 22

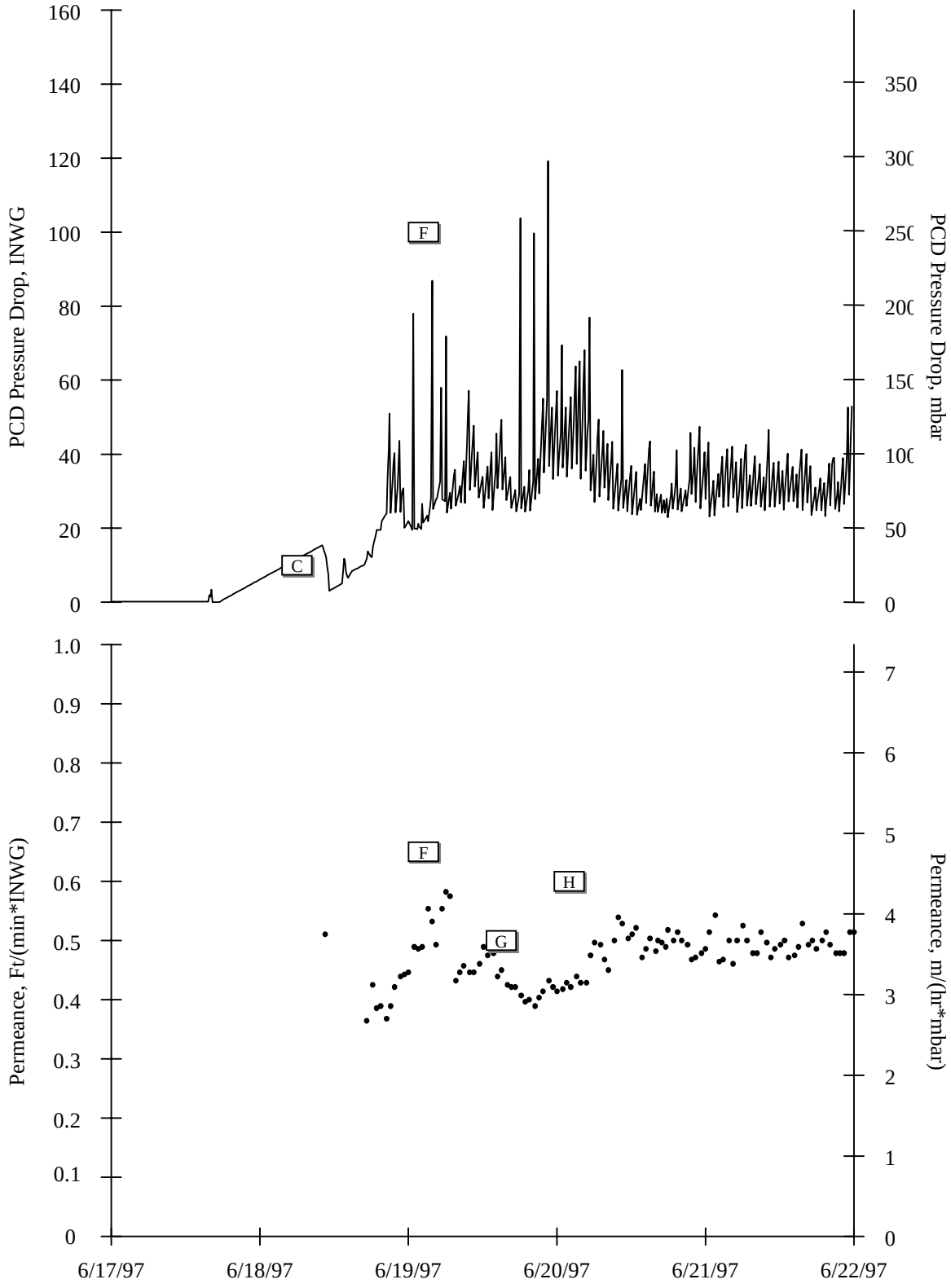


Figure 3.11.4-3 CCT6 Pressure Drop and Permeance for June 17 Through 22

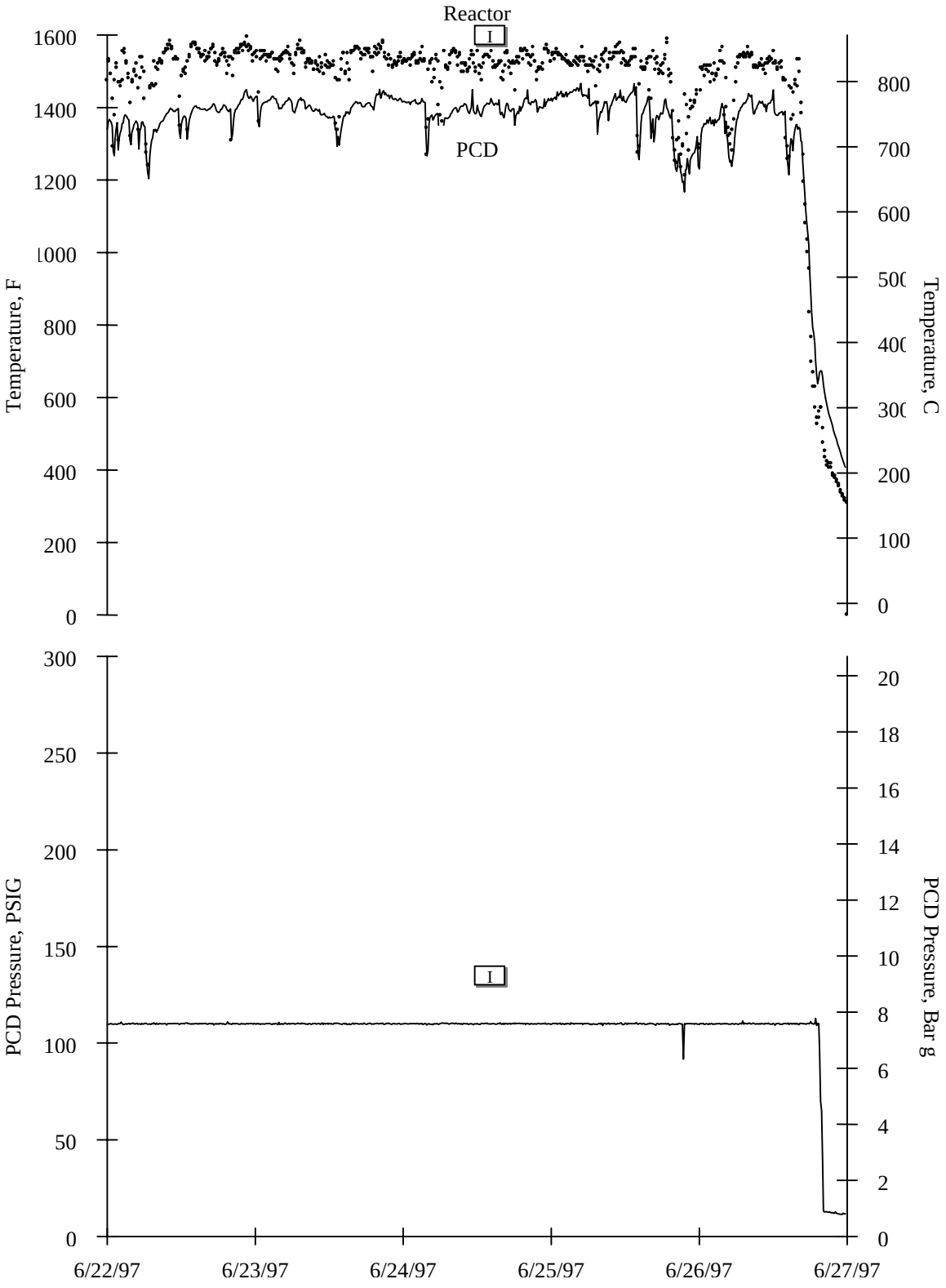


Figure 3.11.4-4 CCT6 Temperature and Pressure for June 22 Through 27

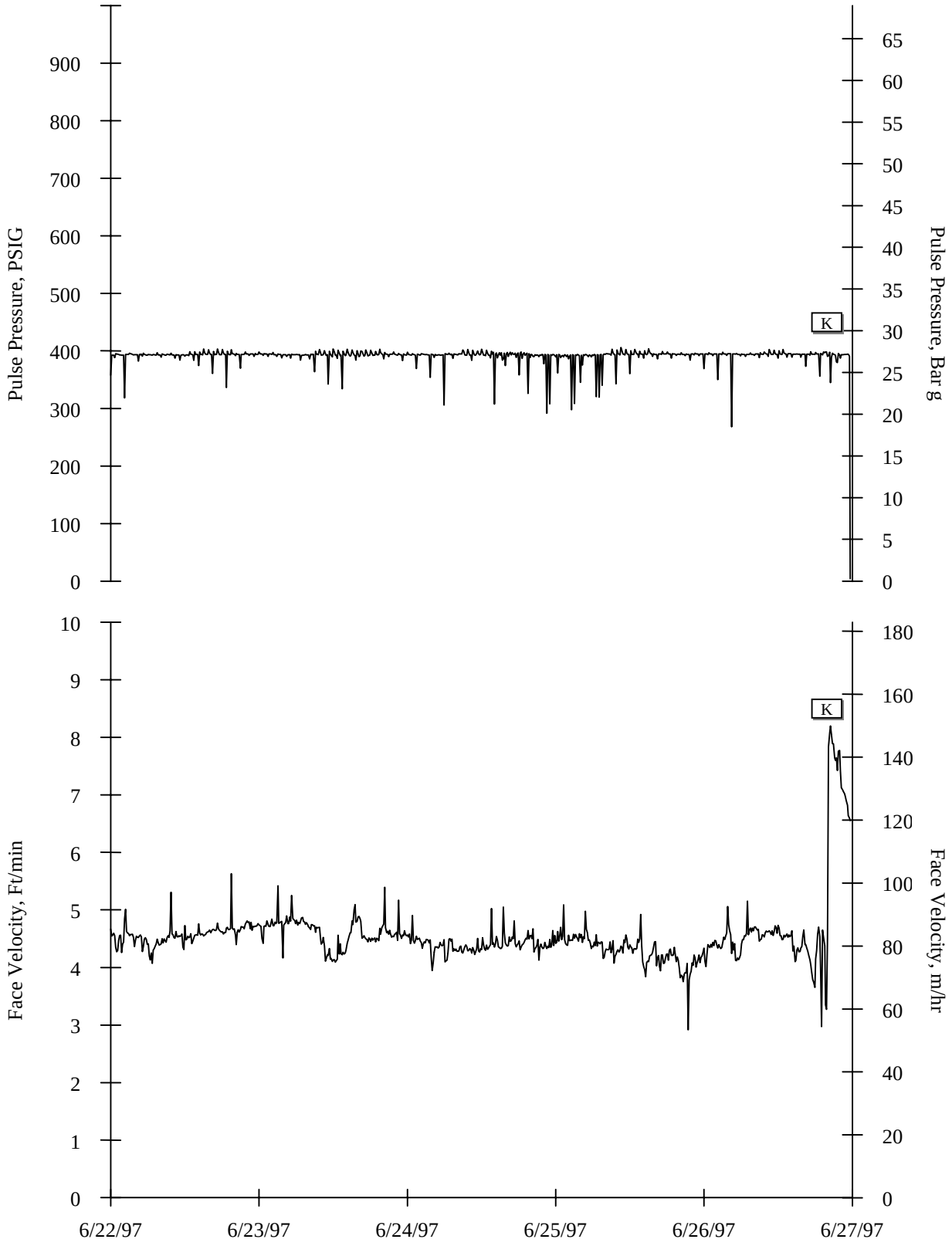


Figure 3.11.4-5 CCT6 Pulse Pressure and Face Velocity for June 22 Through 27

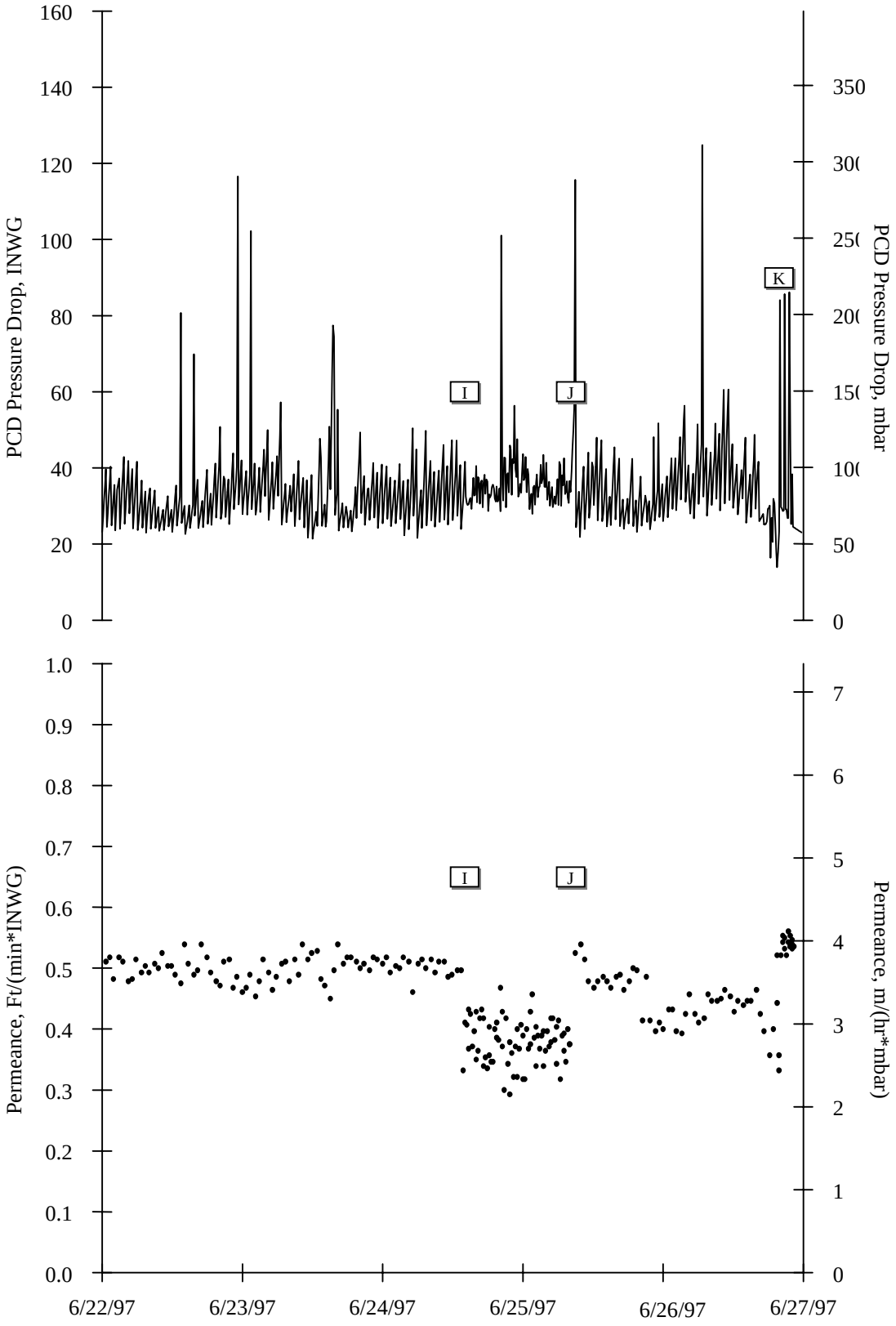


Figure 3.11.4-6 CCT6 Pressure Drop and Permeance for June 22 Through -27

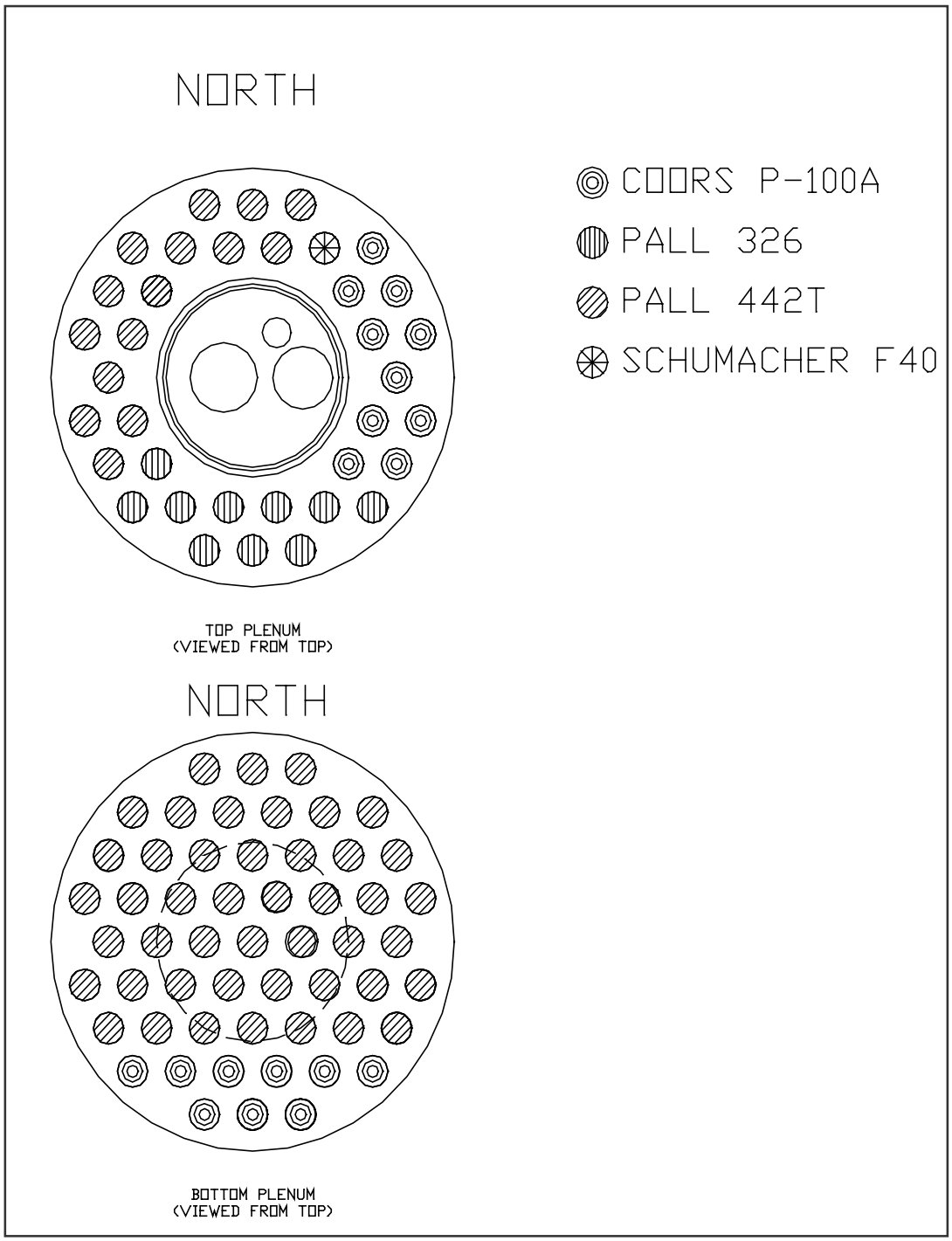


Figure 3.11.4-7 Filter Element Layout for CCT6 (Layout No. 3)

3.12 ASH CHARACTERISTICS IN TEST RUN CCT6

During previous test programs it was learned that instability of the cyclone dipleg was probably responsible for the high rates of carryover of bed material to the PCD. The purpose of test program CCT6 was to develop a better understanding of cyclone dipleg operation and test the limits of stable cyclone operation. Because these objectives resulted in rapidly changing operating conditions and unstable PCD operation, the amount of data collected on the PCD performance and the characteristics of the dust produced during CCT6 was very limited.

3.12.1 PCD Inlet Particle Concentrations and Size Distributions

Two in situ samples of the particle mass entering the PCD were collected during CCT6. The calculated mass concentrations are shown in table 3.12.1-1. As expected, given the test objectives, the particle concentrations were highly variable with relatively high mass carryover to the PCD under both test conditions. Neither of the tests was conducted during a PCD backpulse that could have contributed to upsetting the cyclone dipleg.

Particle-size distributions were measured on both in situ samples using the Microtrac size analyzer. The differential distributions for the two samples are compared to results for CCT4 and CCT5 in Figure 3.12.1-1. The lack of a peak in the CCT6 distribution in the very large particle range (>100 μm) indicates that the carryover of very large sand particles was lower than had been observed during the previous test programs. The increase in mass concentration seen between the two runs (25,500 ppmw to 41,100 ppmw) occurred entirely in particles in the size range smaller than 100 μm.

Table 3.12.1-1

PCD Inlet Particle Mass Concentrations

Run Number	Date Sampled	Run Time		Particle Concentration			PCD Pulse
		Start	End	ppmw	gr/acf	mg/scm	
CCT6IMT-1	6/24/97	10:39	11:09	25,500	32.7	31,000	No
CCT6IMT-2	6/24/97	15:10	15:24	41,100	52.1	49,900	No

3.12.2 Lab Measurements of Ash Characteristics

Selected physical properties of the in situ samples were measured in the lab. This included measurement of true particle density with helium pycnometer, BET particle surface area, mass median diameter, and drag-equivalent diameter using the SRI permeability apparatus. The results of these measurements are shown in the top half of table 3.12.2-1. Comparison of these data to the results of the other test programs is covered in the TC01 section of this report and will not be repeated here.

After the end of CCT6 the PCD was disassembled and samples of the residual dust cake were removed from the candle filters. Separate samples were collected from the upper and lower tiers of candles. The results of lab measurements of the physical properties of these samples are shown in the bottom half of table 3.12.2-1. The candle samples had a slightly finer particle-size distribution than the in situ samples, but most of the properties were not significantly different. However, because of the variability of the CCT6 test conditions and because the PCD was repeatedly backpulsed after shutdown the significance of these samples of residual cake is not clear.

Table 3.12.2-1

Physical Properties of In Situ and Candle Samples

Run ID	Date Sampled	True Density, g/cc	Bulk Density, g/cc	UBP,[1] %	Surface Area, m^2/g	MMD,[2] μm	DED,[3] μm
CCT6IMT-1	6/24/97	2.94	0.75	74.5	2.23	20.6	4.56
CCT6IMT-2	6/24/97	3.12	0.74	76.3	2.56	11.5	2.65
Top Tier[4]	7/29/97	2.92	0.53	82	NA	8.1	3.04
Bottom Tier[4]	7/29/97	2.90	0.73	75	NA	9.9	4.79

Notes:
(1) Uncompacted Bulk Porosity
(2) Mass Median Diameter.
(3) Drag Equivalent Diameter
(4) Candle Sample

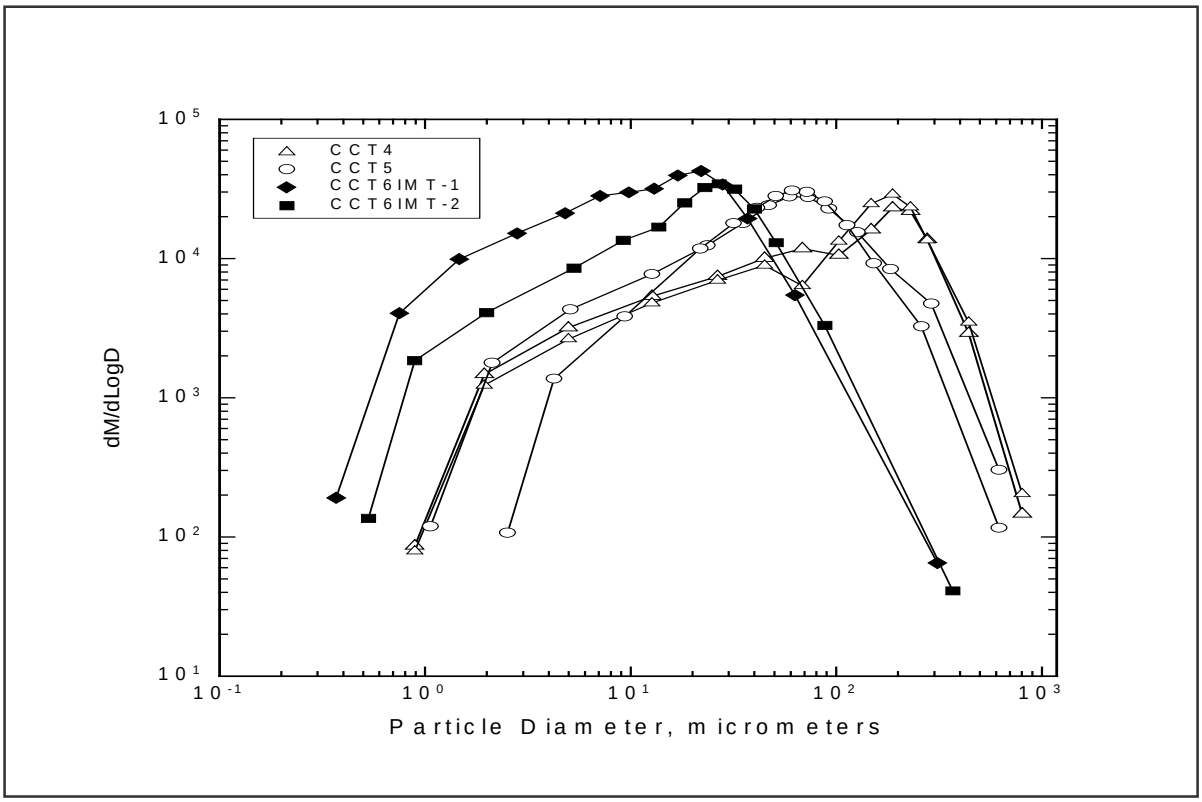


Figure 3.12.1-1 PCD Inlet Particle-Size Distribution for CCT4, CCT5, and CCT6

3.13 INSPECTION REPORT FOR TEST RUN CCT6

3.13.1 Run Summary

On July 28, 1997, the PCD internals were removed for an inspection and replacement of selected filter elements. The internals had not been removed since being installed in early April following run CCT4C. The filter elements installed were as shown in layout 3, section 3.29, Filter Element Report. All of the filter elements in layout 3 had accumulated 616 hours of exposure on coal during runs CCT4D, CCT5A, CCT5B, and CCT6.

This was the first time the internals were removed when no filter elements had broken during operations. Since the last removal of the internals, the operating temperature had been increased from 600 to 1,350°F (316 to 732°C). This was the first occurrence of flow patterns evident in the residual ash deposits on the filter elements and the vessel shroud. The patterns indicated a stronger swirling flow field was present during operations than was previously expected.

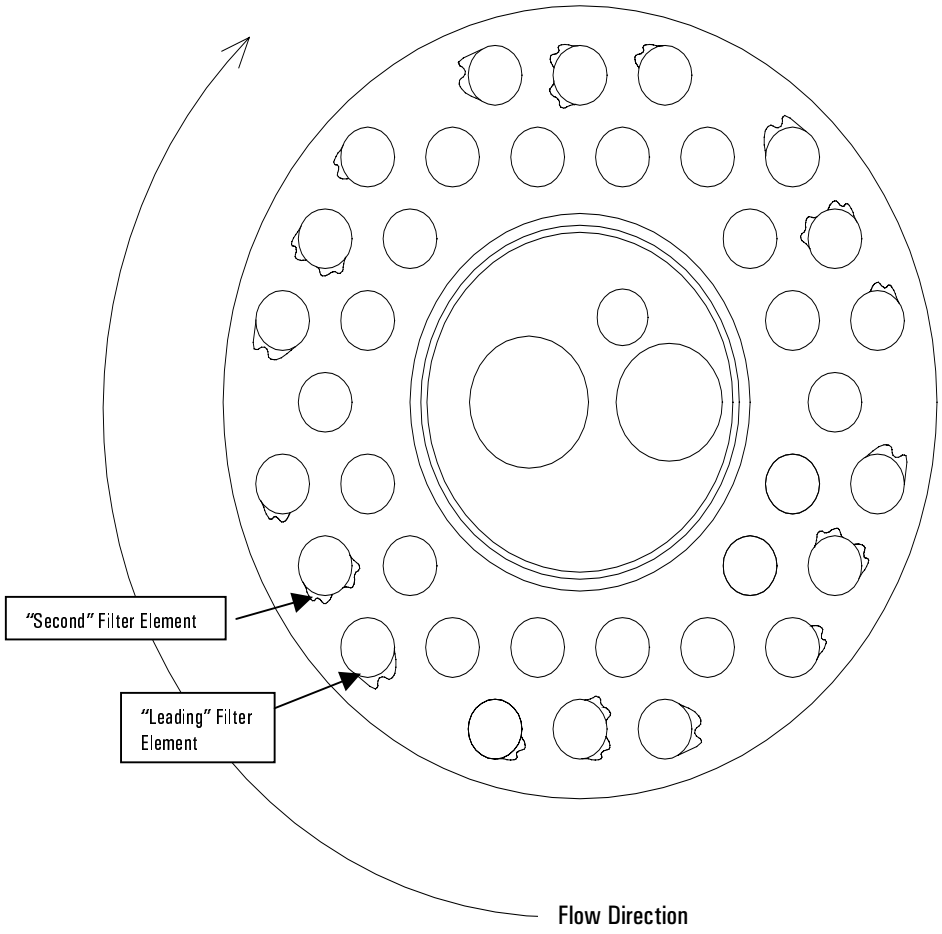
3.13.2 Filter Element Cluster Inspection

All of the filter elements were intact when the internals were removed from the filter vessel, and of the 45 filter elements removed none of them broke during or after the removal. The filter elements were covered with a light-tan generally nonuniform layer of ash.

Windward side deposits were visible on the outer filter elements as shown in figures 3.13.2-1 and -2. The residual deposits had concave depressions located in about the center of the windward deposits. The pattern of ash deposition appeared to be similar to those observed in boiler tube banks except for the presence of the center depressions, and the deposits were located on the windward side and not the downstream side. Similar windward ash deposits were not present on the inner filter elements. The windward side deposits on the filter elements were only on the bottom half of the top plenum filter elements and the top half of the bottom plenum filter elements as shown in figure 3.13.2-3. The windward deposits tapered and were not present toward the opposite end of the filter elements (that is, the top of the top plenum filter elements and the bottom of the bottom plenum filter elements).

The filter vessel has a tangential inlet and, therefore, the inlet flow swirls outside of the shroud goes up, over, down, and under the shroud and continues to swirl toward the filter element clusters. The gas velocity slows as the swirling gas moves up from the bottom and down from the top.. Apparently, the gas velocity is sufficiently high just after going under and over the shroud that the portions of the filter elements exposed to the higher velocity flow were scoured and, therefore, exhibited less of a buildup.

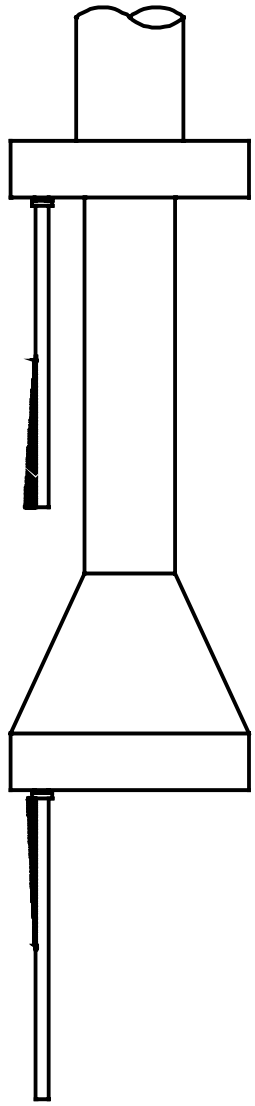
The flow effect on the ash deposits resulting from the process gas splitting and going around the leading outer filter elements is also evident in figure 3.13.2-1. The "second" filter elements exhibited ash deposits indicating a split-flow pattern originating from the leading filter element.



For clarity, only the windward deposits are shown. In addition, the ash deposition thickness is exaggerated.

Figure 3.13.2-1 CCT6 Inspection – Ash Deposit on Outer Filter Elements

Figure 3.13.2-2 CCT6 Inspection – Outer Row Filter Elements on Bottom Plenum



For clarity, the filter elements are turned. See figure 3.13-1 for the radial location of the windward ash deposit. In addition, the uniform ash deposits are not shown in this figure.

Figure 3.13.2-3 CCT6 Inspection – Windward Ash Deposit

3.13.3 Filter Vessel Shroud Ash Deposit Inspection

Figure 3.13.3-1 is a photograph that was taken following CCT6. During the inspection circumferential, striated deposits of ash were noted on the shroud surface facing the filter elements. The striations in the shroud ash deposits suggested the flow angled downward from the top of the shroud and upward from the bottom of the shroud. These angled striations disappeared toward the middle of the shroud.

The pattern of ash deposition on the shroud suggested the gas velocity inside the shroud was much faster and with more of a swirl than was previously expected. Because the face velocity during the runs was generally between 4 to 7 ft/min (73 to 128 m/hr); the velocity inside the shroud was expected to be much slower than the velocities sufficient to leave striations. The flow patterns evident on the shroud side facing the filter elements indicated a swirling gas flowing from both under the shroud bottom edge and over shroud top edge.

Figure 3.13.3-1 CCT6 Inspection – Shroud Ash Deposits

3.13.4 Conclusion

The deposit patterns on the filter elements, and those on the shroud, suggest there is a significant swirling gas flow between the shroud and the outer filter elements, at least in the bottom-third and top-third region of the shroud. Based on the ash deposit patterns the gas flowed over both the top and bottom of the shroud and both portions of the gas flow apparently retained a significant tangential, swirling component.

3.14 INSPECTION REPORT FOR TEST RUN TC01A

3.14.1 Run Summary

Test campaign 01A (TC01A) was started on August 22 and ended on September 2, 1997. During the transition from the start-up burner to coal, three Coors P100A filter elements broke and plugged the spent fines transporter system (FD0520) outlet. Repeated plugging problems with the FD0520 outlet forced the reactor shutdown after being on coal for 7.5 hours. The decision was made to remove the filter cluster for inspection. One additional Coors P100A filter element broke when it was being removed.

The filter elements installed for this run were a combination of filter elements installed before run CCT4D and after run CCT6. The filter elements installed before CCT4D accumulated 635 hours on coal; the filter elements installed after CCT6 accumulated 7.5 hours on coal.

3.14.2 Test Objectives

The main objective for the PCD was to obtain 1,000 hours exposure for the filter elements at a nominal 1,400°F (760°C). This test was undertaken at the request of Westinghouse to determine if the Pall 326 silicon carbide filter elements would elongate when exposed at the nominal 1,400°F (760°C) for 1,000 hours.

3.14.3 Observations/Events

A. Test Started–Main Air Compressor (MAC) Started – August 22 at 10:00. The main air compressor (MAC) was started for the system leak test. The MAC was shutdown on August 22 at 23:35.

B. Preliminary Back-Pulse System Test Started–August 22 at 11:06. Back-pulse system tests were conducted during the day on August 22. In previous test runs the mass flow during the back-pulse event dropped as the back-pulse pressure was increased. A series of back-pulse system performance tests were carried out during the TC01 test runs. Refer to section 3.27 (pulse valve report) for the back-pulse system performance testing results and discussion.

C. MAC Started–24-Hour Air Cure Out Initiated–August 22 at 20:46.

D. MAC and PCD Preheat Started–August 25 at 13:30. Since the primary gas cooler (HX0202) was bypassed the PCD was preheated using the sulfator start-up heater (BR0602). The PCD preheat began 4 hours after the MAC was started, but was interrupted to install 2 hangers missing on the HX0202 bypass line. Problems with the spent solids transporter system (FD0530) fluidizing pads also delayed the PCD preheat.

E. PCD Preheat Completed–August 27 at 17:45. The PCD preheat was completed; however, problems continued with the FD0530 fluidizing pad. A leaking check valve forced the transport reactor to be shutdown on August 28 at 17:42.

F. Transport Reactor Shutdown for Repairs–August 28 at 17:42.

G. Back-Pulse System Shutdown–August 28 at 21:00. The back-pulse system was shutdown until August 30 at 08:00 while the transport reactor repairs were underway.

H. Repairs Completed, Operations Resumed–August 30 at 21:08. The repairs to the FD0530 system were completed. The MAC and BR0602 were restarted, the PCD was preheated, and the transport reactor start-up burner (BR0201) was lit.

I. First Coal Feed for TC01A–August 31 at 23:40. Shortly after the coal feed was initiated the FD0520 outlet became plugged with what appeared to be wet agglomerated ash and broken Coors P100A filter elements. The FD0520 outlet continued to plug with broken Coors P100A filter element pieces throughout the morning of September 1.

J. Coal Feed Restarted–September 1 at 10:13. A spheri valve seal failed in the limestone feed system (FD0220) at 11:30 and caused the coal feed system (FD0210) and FD0520 to trip.

K. Coal Feed Restarted–September 1 at 20:41. After the coal feed was restarted the FD0520 outlet became plugged again with broken Coors P100A filter element pieces. The decision was made to shutdown because of the FD0520 outlet plugging problems.

L. TC01A Ended–September 2 at 13:30.

3.14.4 Run Outcome

TC01A ended because of repeated plugging problems on the outlet of FD0520. Three Coors P100A filter elements failed during the transition from the start-up burner to coal. The filter elements that failed during operation failed during the first 30 minutes of coal feed. Despite the breakage the coal feed continued for a total of 7.5 hours before repeated plugging of the FD0520 forced the run to be terminated.

Figure 3.14.4-1 shows the process gas temperatures when the three Coors P100A filter elements failed. Three temperature rises in the bottom plenum thermocouple (TI3014) are visible in this figure that are believed to represent when a Coors P100A filter element failed.

During the transition to coal the process gas temperature entering the PCD (TI458) rose at approximately 300°F (149°C) per hour. This rise in the inlet temperature placed a thermal gradient across the filter element walls.

Table 3.14.4-1

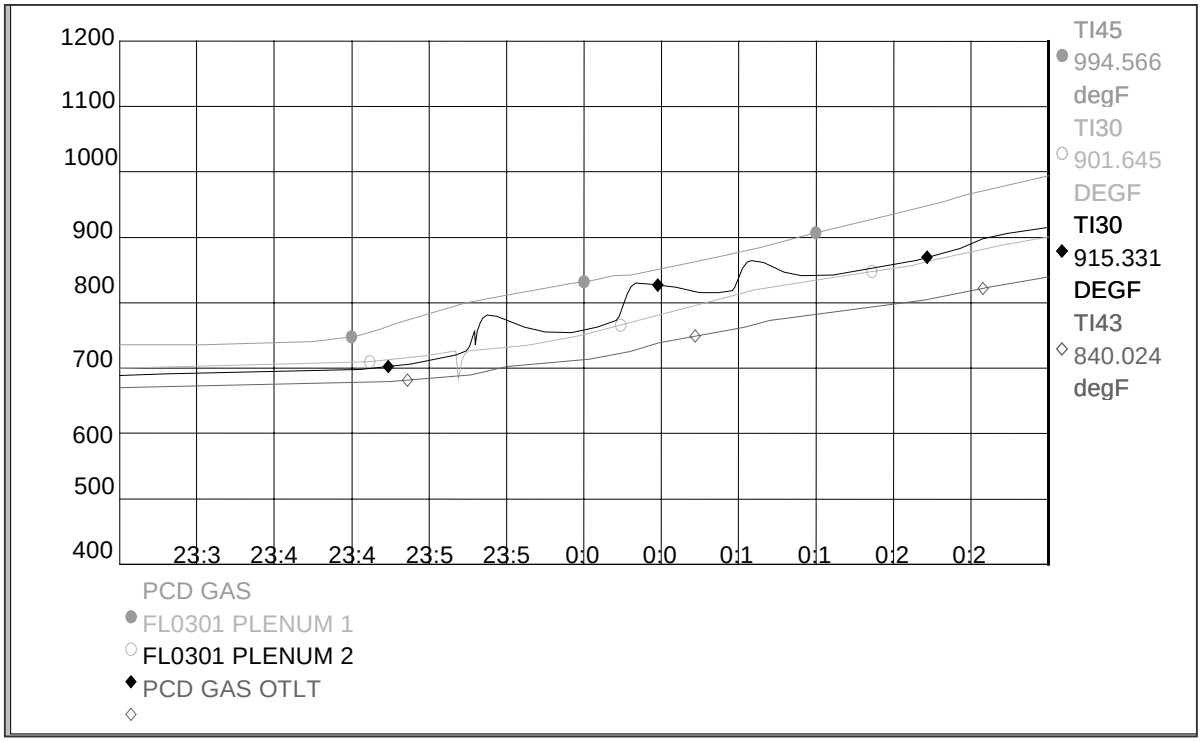
TC01A Run Statistics

Start Time:	8/22/97 10:00
End Time:	9/2/97 13:30
Coal Type:	Calumet Alabama Bituminous
Hours On Coal:	7.5
Sorbent Type:	Plum Run Dolomite
Number of Filter Elements:	88 (three broke during operations)
Filter Element Layout:	4 (Figure 3.14.4-2)
Filtration Area:	246 ft^2 (22.6 m^2)
Pulse Valve Open Time:	0.3 seconds
Pulse Time Trigger:	45 minutes
Pulse Pressure:	400 psig (27.6 bar,g)
Pulse DP Trigger:	100 inWG (249 mbar)

Table 3.14.4-2

TC01A Major Events

Event	Description	Date at Time
A	Test Started – Main Air Compressor (MAC) Started	8/22 at 10:00
B	Preliminary Back-Pulse System Test Started	8/22 at 11:06
C	MAC Started – 24 Hour Air Cure Out Initiated	8/22 at 20:46
D	MAC and PCD Preheat Started	8/25 at 13:30
E	PCD Preheat Completed	8/27 at 17:45
F	Transport Reactor Shutdown for Repairs	8/28 at 17:42
G	Back-Pulse System Shutdown	8/28 at 21:00
H	Repairs Completed, Operations Resumed	8/30 at 21:08
I	First Coal Feed for TC01A	8/31 at 23:40
J	Coal Feed Restarted	9/1 at 10:13
K	Coal Feed Restarted	9/1 at 20:41
L	TC01A Ended	9/2 at 13:30
*	Plant Information (PI) Shutdown	8/25 at 08:21



TI458: PCD Inlet
TI3013: Bottom Plenum
TI3014: Top Plenum
TI439: PCD Outlet

Figure 3.14.4-1 Thermal Event on August 31 Through September 1

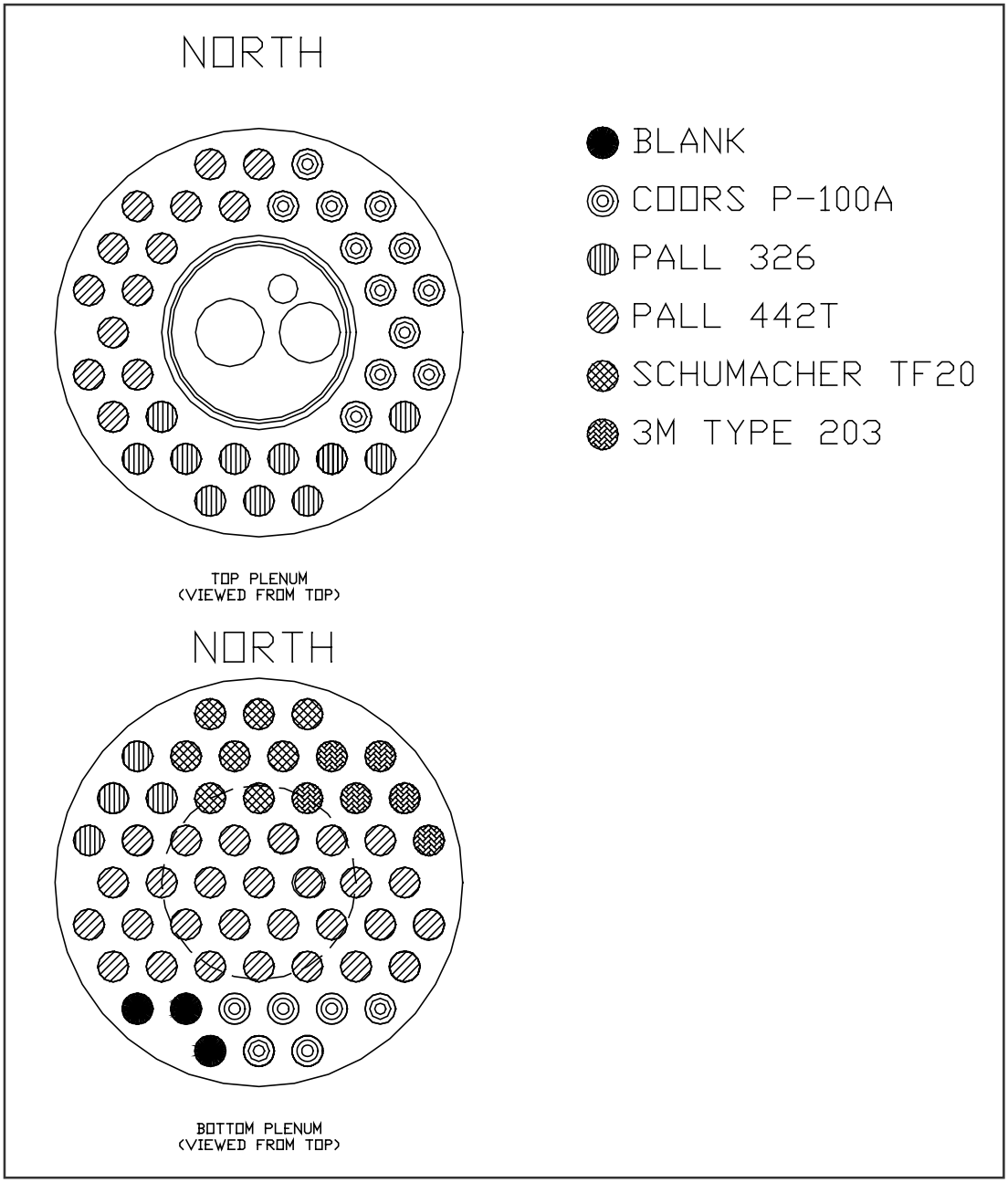


Figure 3.14.4-2 Filter Element Layout for TC01A (Layout No. 5)

3.15 INSPECTION REPORT FOR TEST RUN TC01A

3.15.1 PCD Inspection

Inspection of the PCD began on September 2 with the bottom plenum through the lower manway door using a mirror attached to a pole. This method was used due to concern about falling filter element pieces as experienced in the CCT4C inspection. Approximately 15 lb (6.8 kg) of alumina mullite (but no silicon carbide) material had been removed from the ash removal system so it was suspected that two or more Coors P-100A elements had broken. This was confirmed as stated with the mirror, revealing that the Coors P-100A elements in tubesheet locations B26, B27, and B28 were broken.

3.15.2 Cluster Inspection

Removal and inspection of the cluster occurred September 4 and 5. The three Coors P-100A filter elements that had been observed through the man-way to be broken were found broken. As shown in figure 3.15.2-3 the fractures occurred in the upper third of each filter element. The breaks were all "V" shaped (see figure 3.15.2-4), two on each element 180°apart; the point of each "V" was to the side of the centerline of each element (see figure 3.15.2-5). Two of the elements had "V's" oriented in one direction while the third was 90° in the other direction. In addition, there was a lip on one side of the outside diameter (OD) of two of the elements at the fracture line, which tends to indicate that the element cracked on one side and then broke off at the crack due to its inability to support the weight below the fracture line. On some of the broken pieces there were cracks randomly throughout the material, only some of which completely penetrated from the inside diameter (ID) to the OD of the element. Some of the cracks in the ceramic had propagated into and were visible in the dust cake.

The remaining Coors P-100A filter elements were checked by slightly pulling on the bottom of each element. When element B9 was pulled it broke off with practically no force applied. About 90° of the circumference of the fracture surface was covered with ash, whereas the rest of the surface was clean. This indicates that the crack formed during operation and ash was able to penetrate the crack. This penetration could have ultimately widened the crack and caused complete failure of the element had the run continued.

Generally, there was very little dust cake on the elements, the internals, or the inside of the PCD vessel and no evidence of ash bridging. In addition, none of the silicon carbide elements appeared damaged. Dirty side sample posts that had been installed showed very little ash accumulation.

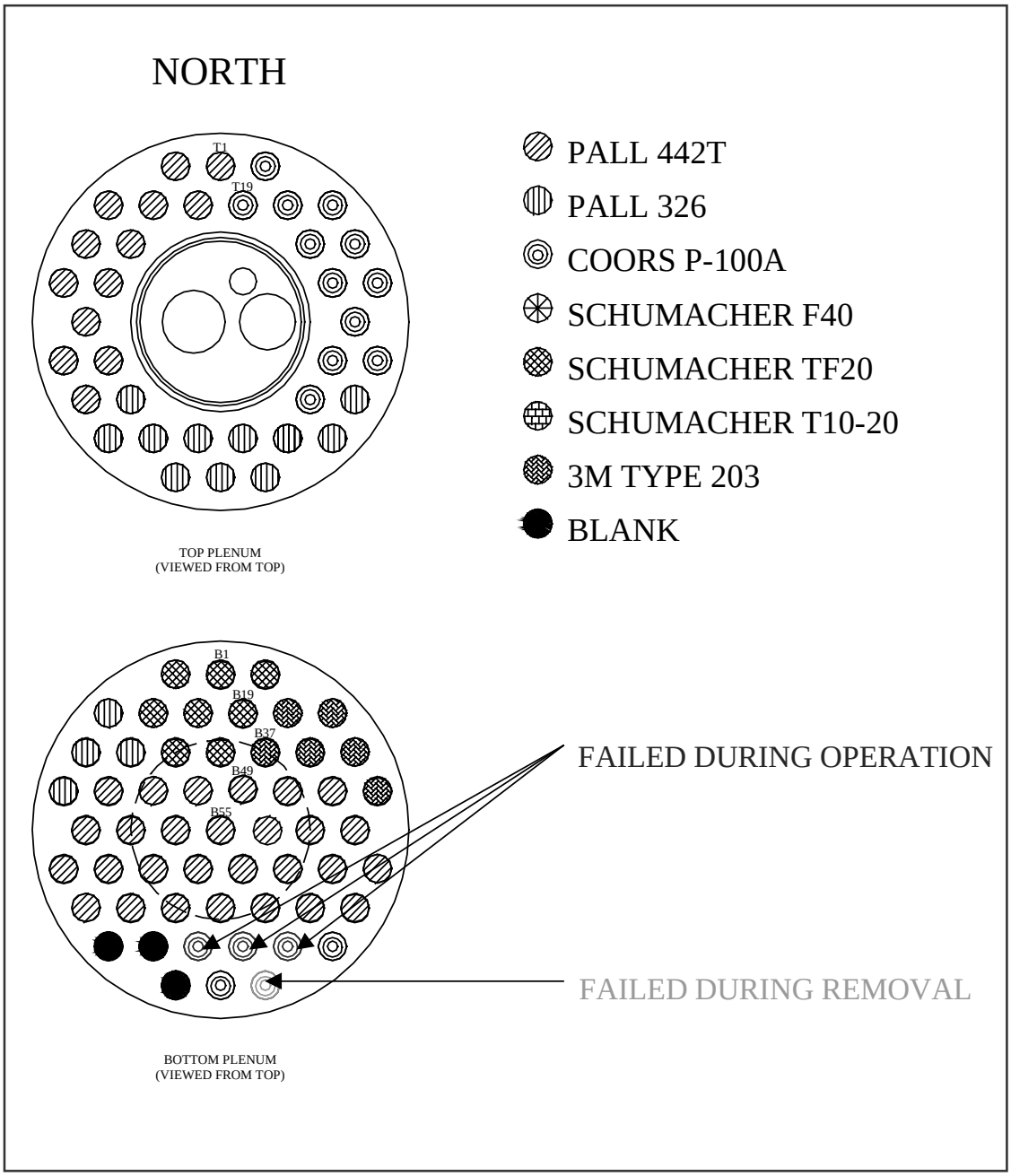


Figure 3.15.2-1 TC01A Inspection – Failed Elements

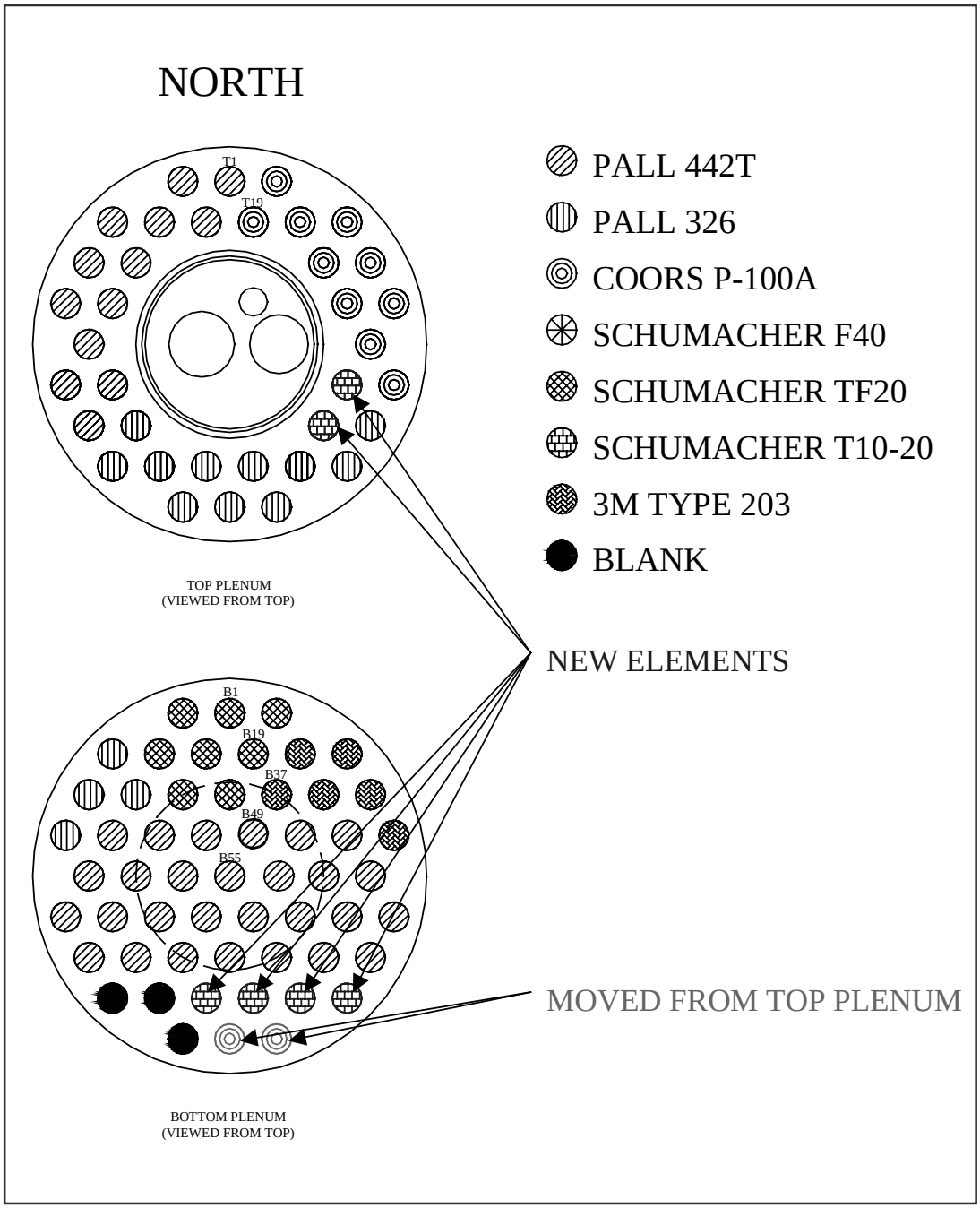


Figure 3.15.2-2 Layout Starting TC01B

Figure 3.15.2-3 TC01A Inspection – Fracture Points

Figure 3.15.2-4 TC01A Inspection – Fracture Surfaces

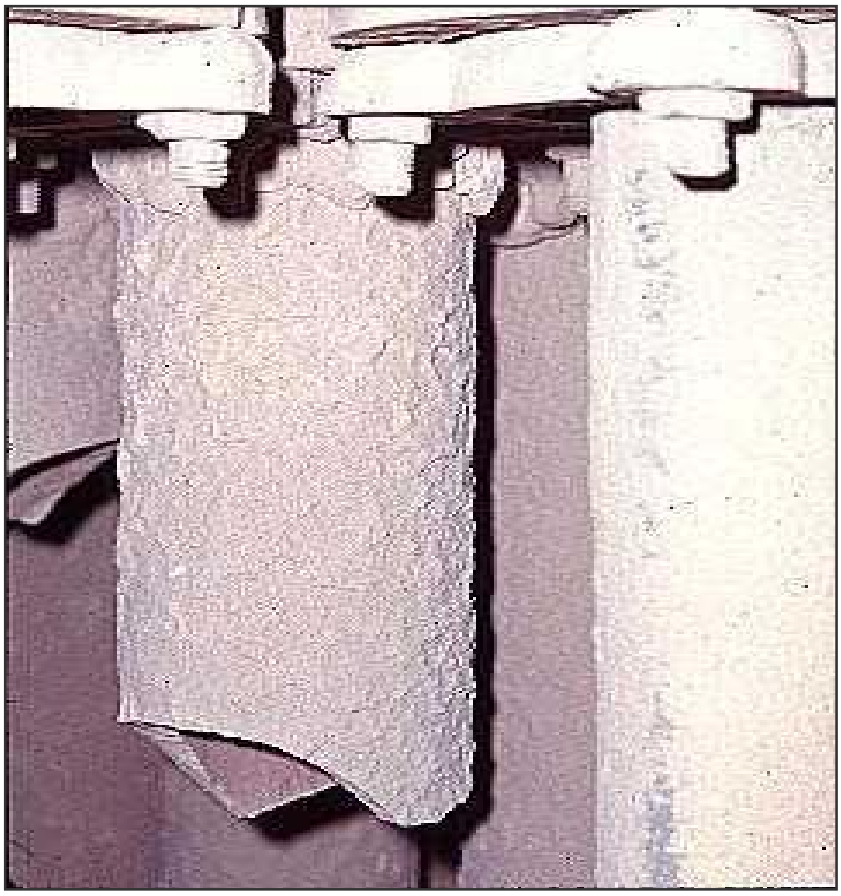


Figure 3.15.2-5 TC01A Inspection – Remnants of Element B26

3.15.3 Filter Element Layout #5

Of the eight Coors P-100A elements (two in the top plenum and six in the bottom plenum) that had been installed in the cluster since April 1997, all six in the bottom plenum were removed. The intact element from location B10 was given to SRI for strength testing and the intact element from B8 is being held on-site for possible further strength testing. The two Coors P-100A elements from the top plenum (locations T24 and T25) were moved to locations B9 and B10 of the bottom plenum for TC01B. Six Schumacher T10-20 elements were then installed in locations T24, T25, B8, B26, B27, and B28. These were the only changes made from layout 4 to layout 5.

3.16 PCD OPERATION DURING TEST RUN TC01B

3.16.1 Run Summary

The 3-day outage after TC01A ended on September 5. During the outage the plenum of the PCD was pulled out for inspection and filter element replacement. The broken Coors P100A filter elements were replaced. Due to the concerns about the temperature ramp rate in the PCD another nitrogen source was made available to moderate the temperature ramp rate below 200°F/hr (93.3°C/hr) during the initial coal feeding.

Test run TC01B began on September 6, 1997, at 03:35 and ended on September 22, 1997, at 23:15. The run was terminated because of a steam leak on the differential pressure gauge on the combustor heat exchanger (HX0203). Two Coors P100A filter elements were broken during this run of the PCD. One was broken during the start-up and the other during the stable operation about 2 hours after the back-pulse pressure sensitivity test. The stable operating temperature of the PCD was above 1,350°F (732.2°C). The stable operating pressure was 180±10 psig (12.4±0.7 bar,g). The face velocity was about 5 ft/min (91.4 m/hr). In general, the filter differential pressure (ΔP) increased during the run. The baseline value of the ΔP was about 30 inWG (75 mbar,g) in the first stable operating period and about 40 to 60 inWG (100 to 149 mbar,g) in the later stable operating periods. Other operating conditions are listed in table 3.16.1-1. The operating data are shown in figures 3.16.1-1 to -9.

Table 3.16.1-1

TC01B Run Statistics

Start Time	9/6/97 at 03:35
End Time	9/22/97 at 23:15
Coal Type	Calumet Alabama Bituminous
Hours on Coal	311
Sorbent Type	Plum Run Dolomite
Number of Filter Elements	88 (Two broken during the run)
Filter Element Layout No.	5 (See Figure 3.16.1-10)
Filtration Area	Initial: 246.3 ft^2 (22.9 m^2) After 9/7/97: 243.5 ft^2 (22.6 m^2) After 9/19/97: 240.7 ft^2 (22.4 m^2)
Back-Pulse Valve Open Time	0.3 to 0.4 seconds
Back-Pulse Time Trigger	40 to 45 minutes
Back-Pulse Pressure	400-600 psig (27.6-41.4 bar,g) in normal operation
Back-Pulse DP Trigger	110-125 inWG (274-311 mbar,g)

Table 3.16.1-2

TC01B Major Events (Refer to Figures 3.16.1-1 Through -9)

Event	Description	Time
A	Test started. Main air compressor (MAC) started	9/6/97 at 03:35
B	Start-up burner lit	9/6/97 at 15:02
C	Coal feed started	9/7/97 at 03:52
D	Spent fines transport system tripped	9/7/97 at 04:25
E	Start-up burner tripped	9/7/97 at 22:48
F	Coal feed started	9/8/97 at 09:15
G	Spheri valve on spent fines transport system tripped	9/8/97 at 19:58
H	Coal feeder failed	9/9/97 at 09:20
I	Coal feed started	9/9/97 at 19:55
J	Coal feed stopped	9/13/97 at 21:30
K	Start-up burner lit	9/14/97 at 02:16
L	Dipleg upset	9/14/97 at 18:45
M	Coal feed stopped	9/15/97 at 05:15
N	Coal feed started	9/15/97 at 17:10
O	Coal feeder tripped	9/16/97 at 18:00
P	Back-pulse pressure sensitivity test started	9/19/97 at 09:20
Q	Coors P100A filter element broken	9/19/97 at 18:25
R	Spheri valve on spent fines transport system failed	9/19/97 at 18:37
S	Coal feed stopped	9/19/97 at 21:08
T	Start-up burner lit	9/20/97 at 01:54
U	Coal feed started	9/20/97 at 12:22
V	Spent fines transport system tripped	9/22/97 at 08:15
W	Steam leak on combustor heat exchanger	9/22/97 at 19:18
X	Test stopped – MAC stopped	9/22/97 at 23:15

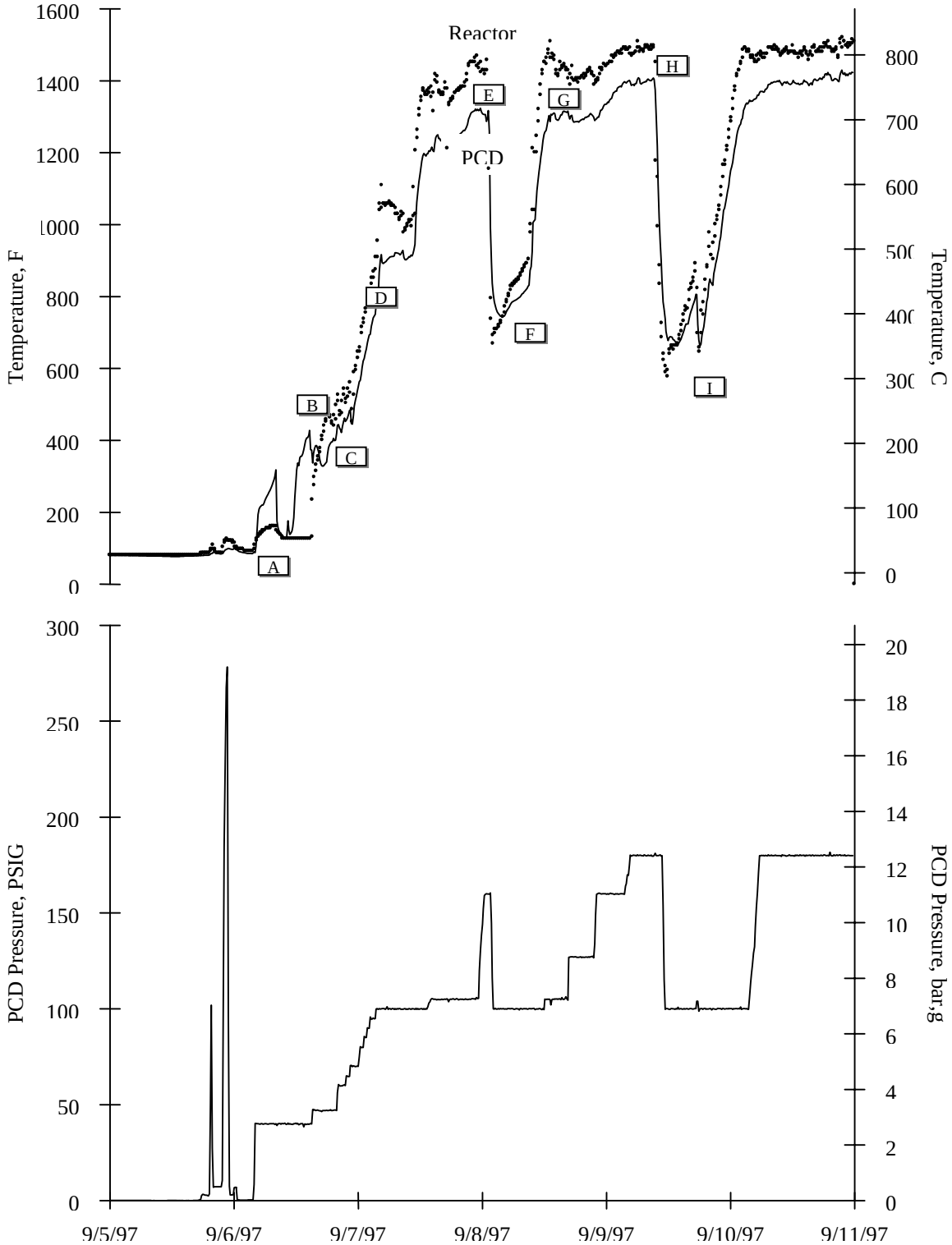


Figure 3.16.1-1 TC01B Temperature and Pressure for September 5 Through 11

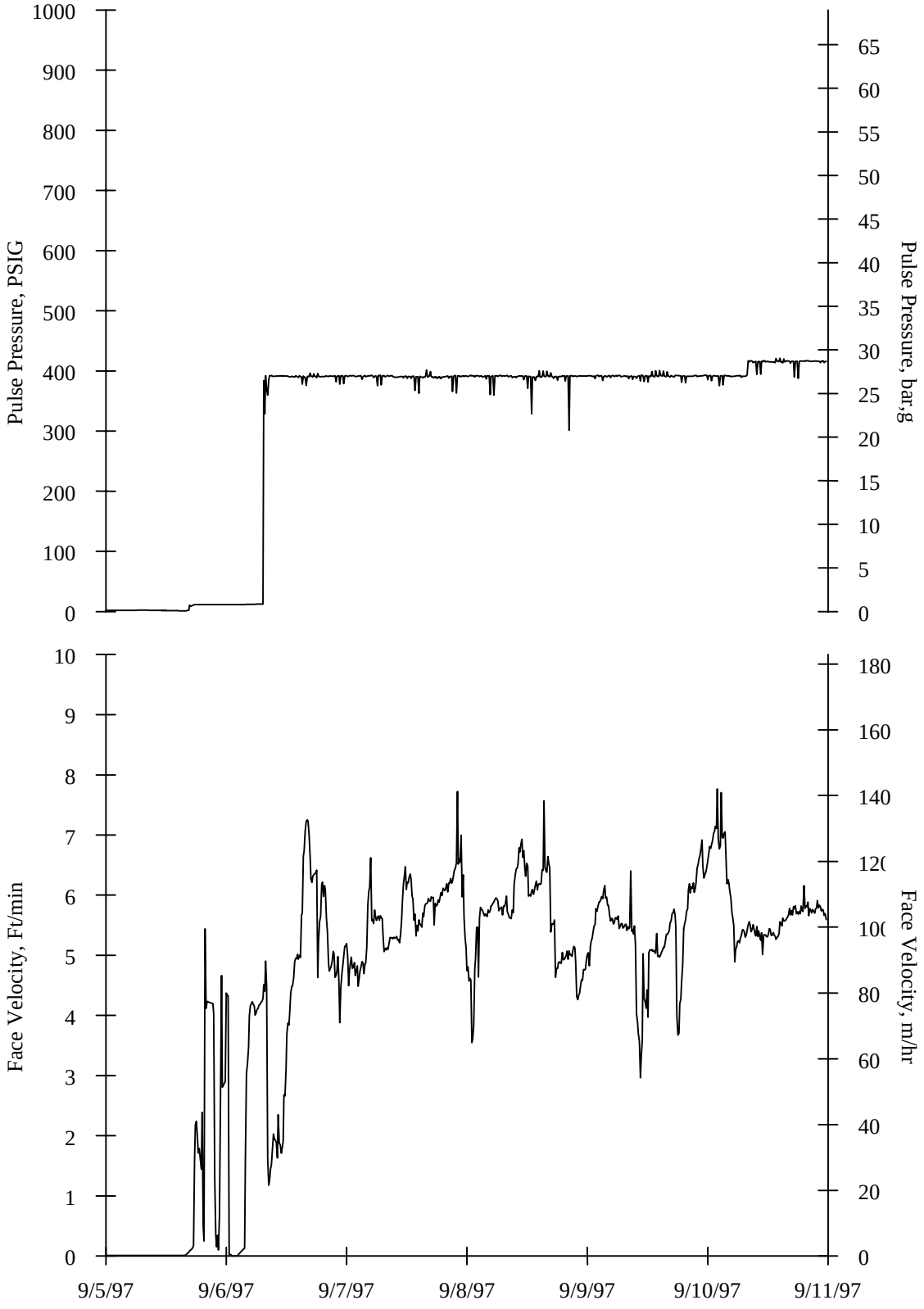


Figure 3.16.1-2 TC01B Back-Pulse Pressure and Face Velocity for September 5 Through 11

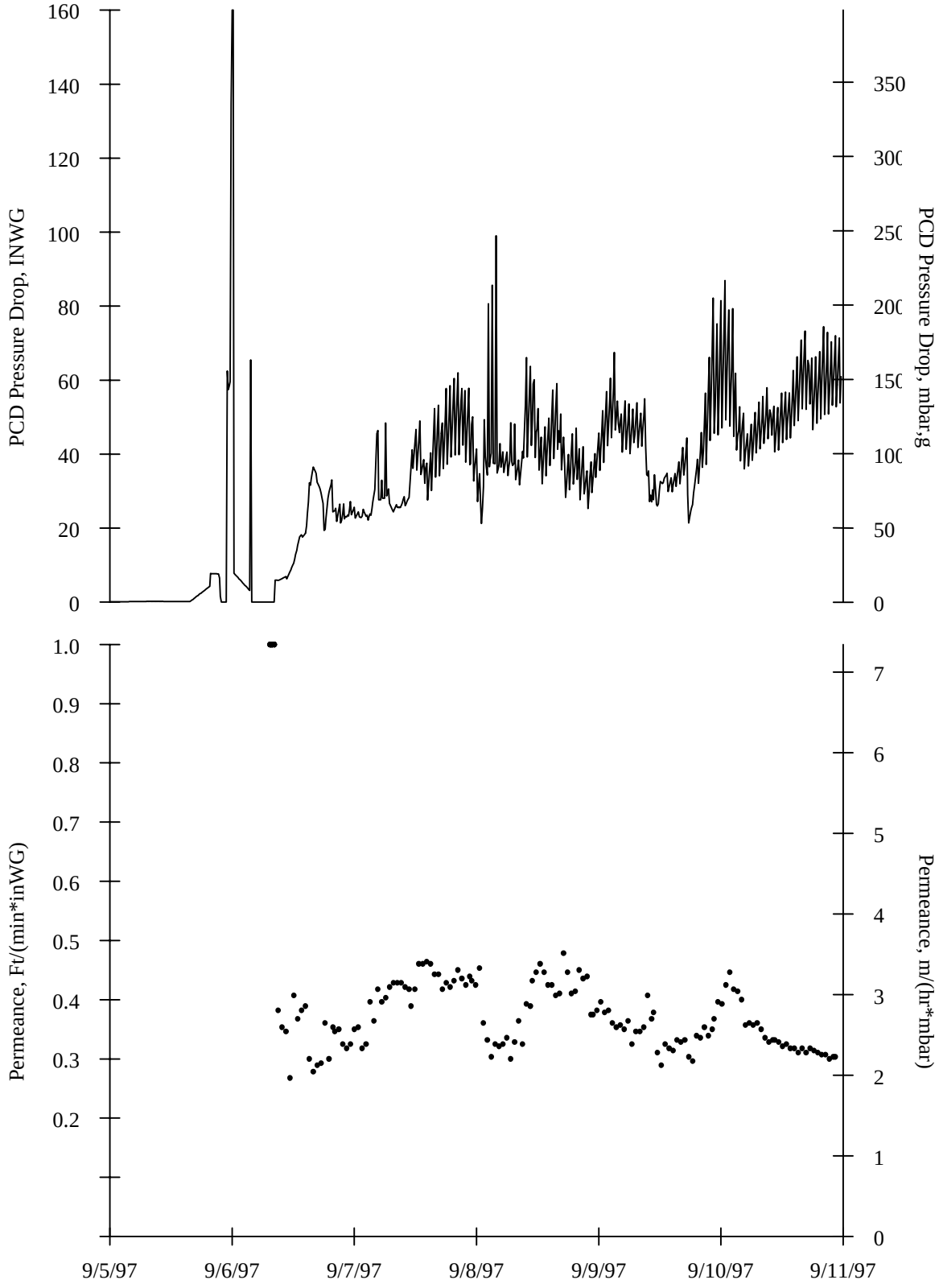


Figure 3.16.1-3 TC01B Pressure Drop and Permeance for September 5 Through 11

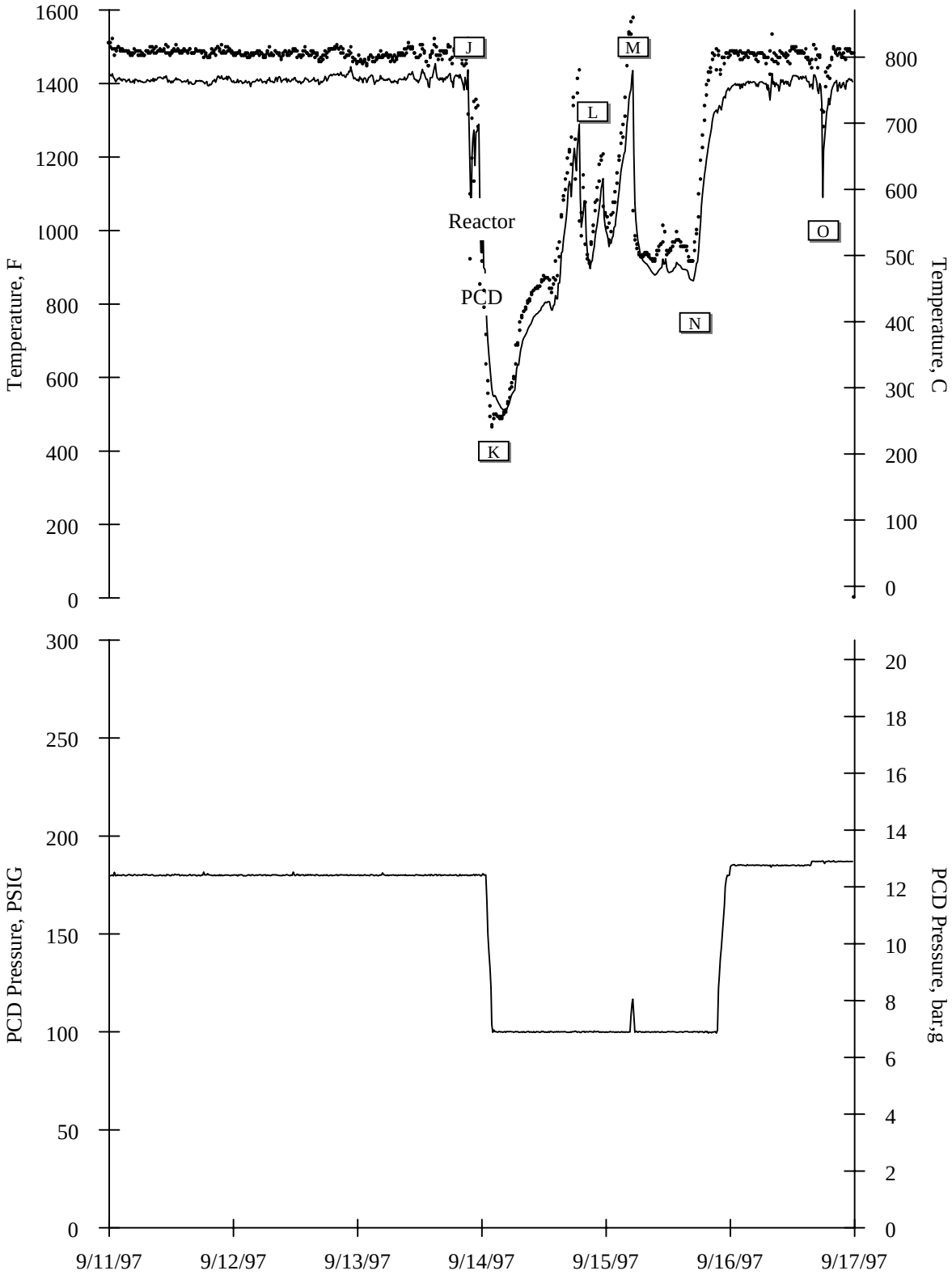


Figure 3.16.1-4 TC01B Temperature and Pressure for September 11 Through 17

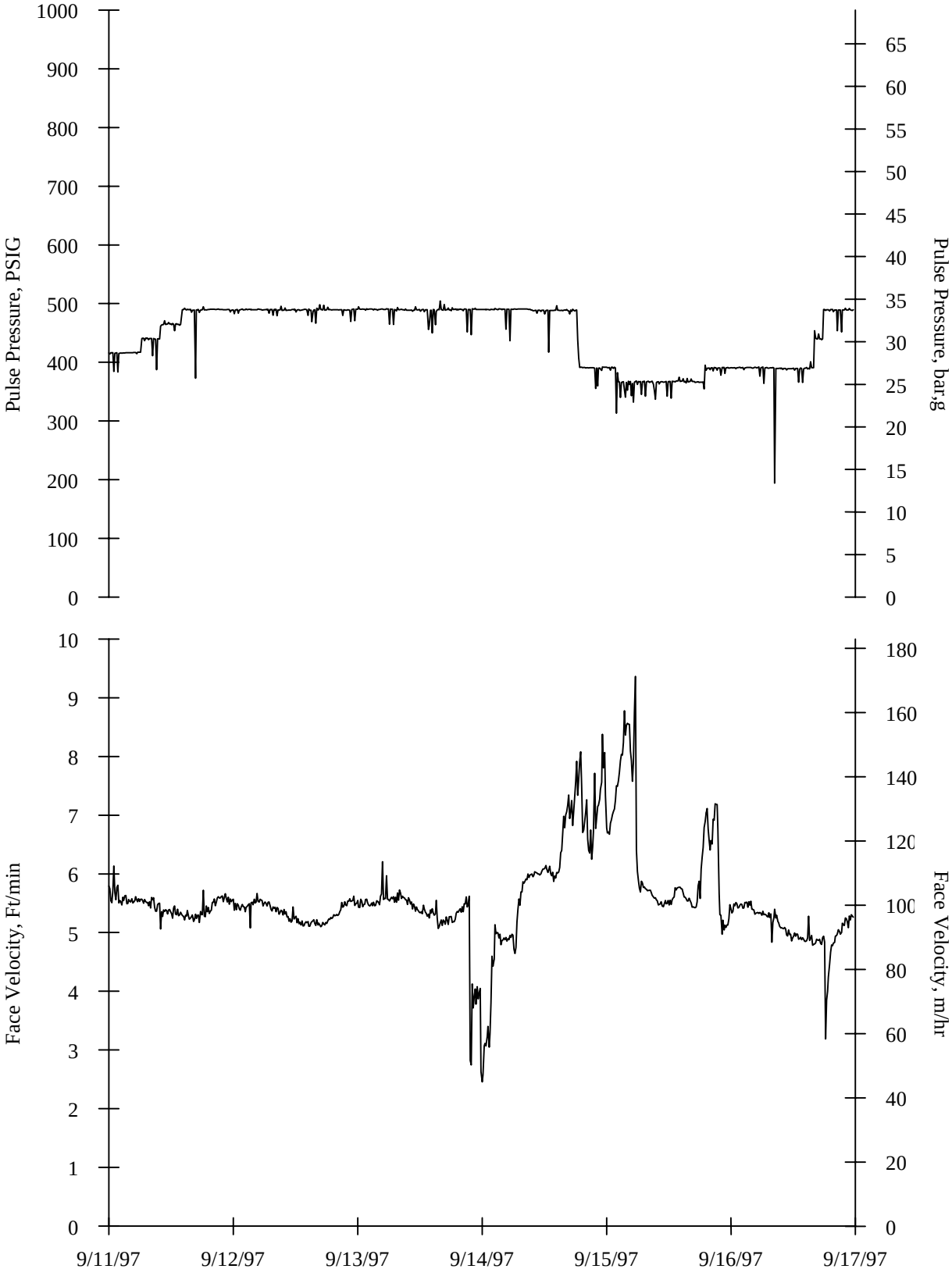


Figure 3.16.1-5 TC01B Back-Pulse Pressure and Face Velocity for September 11 Through 17

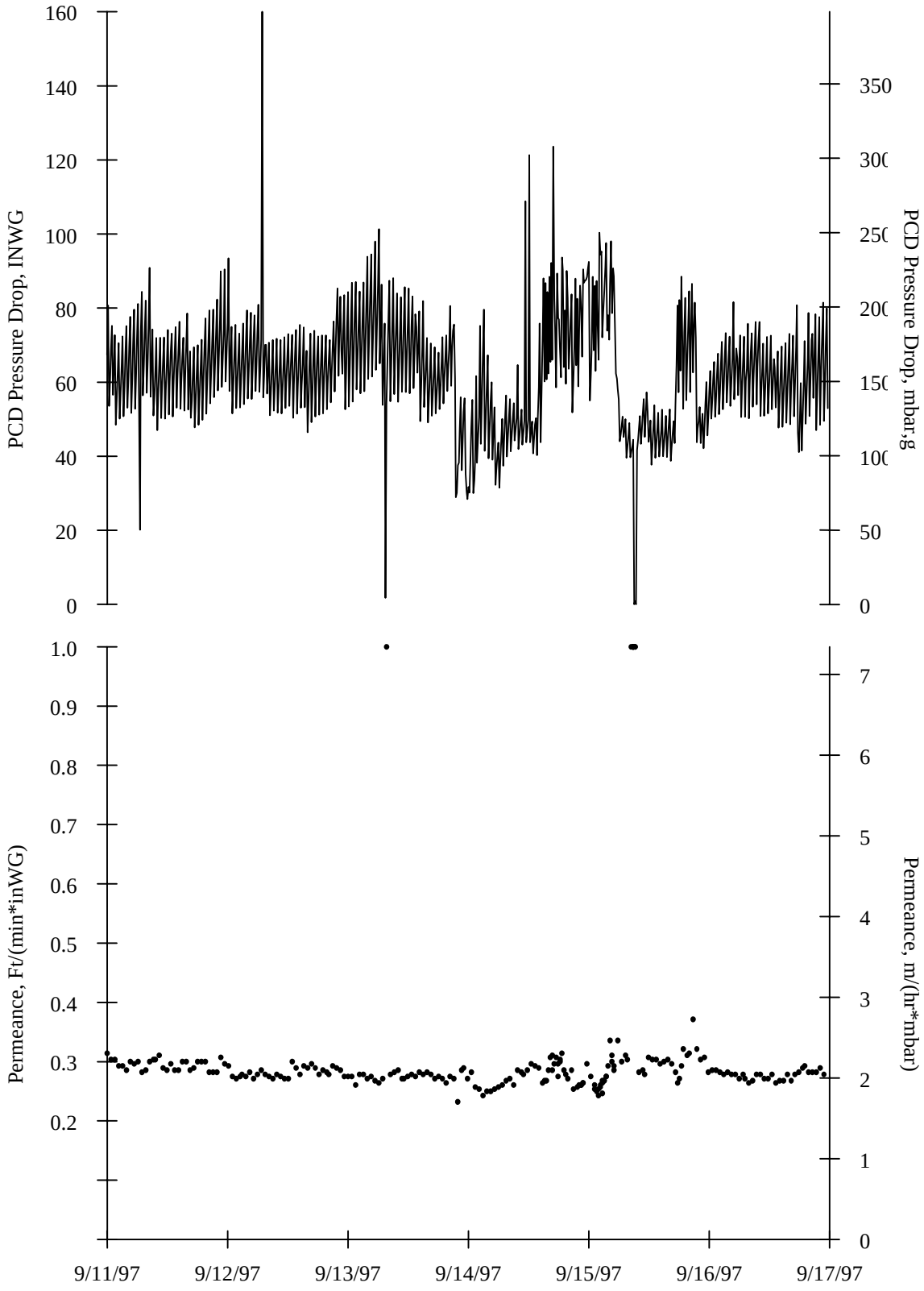


Figure 3.16.1-6 TC01B Pressure Drop and Permeance for September 11 Through 17

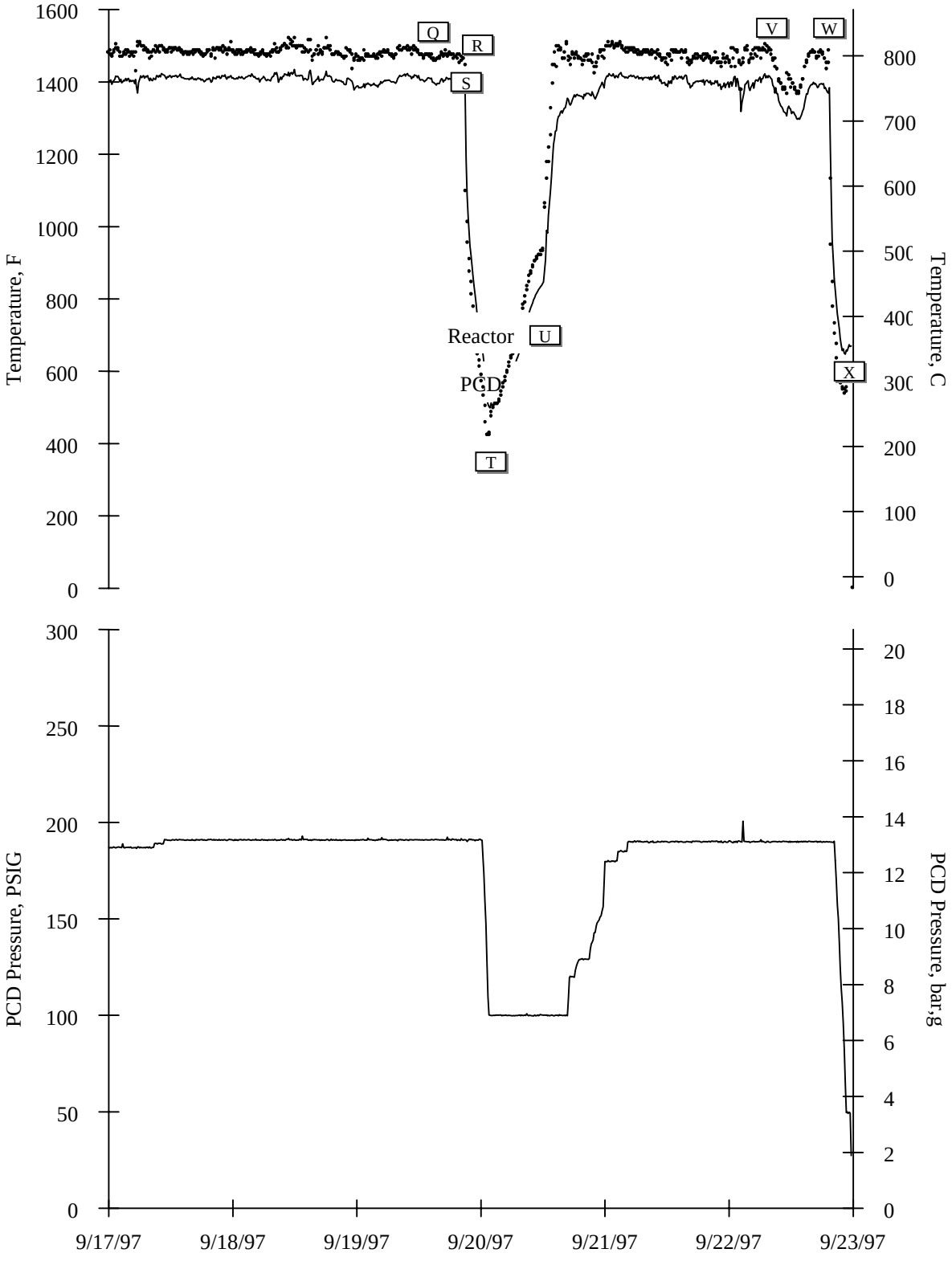


Figure 3.16.1-7 TC01B Temperature and Pressure for September 17 Through 23

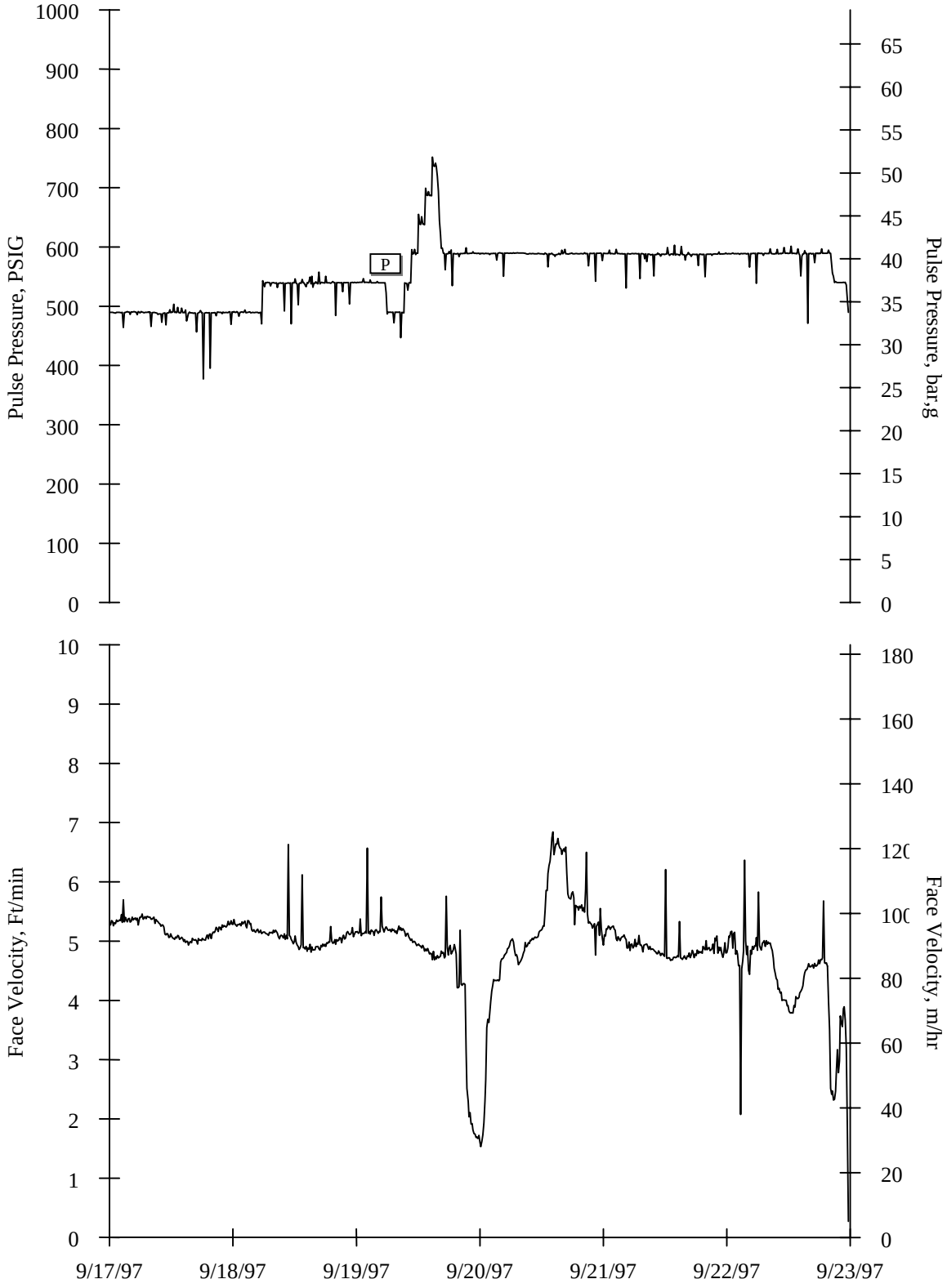


Figure 3.16.1-8 TC01B Back-Pulse Pressure and Face Velocity for September 17 Through 23

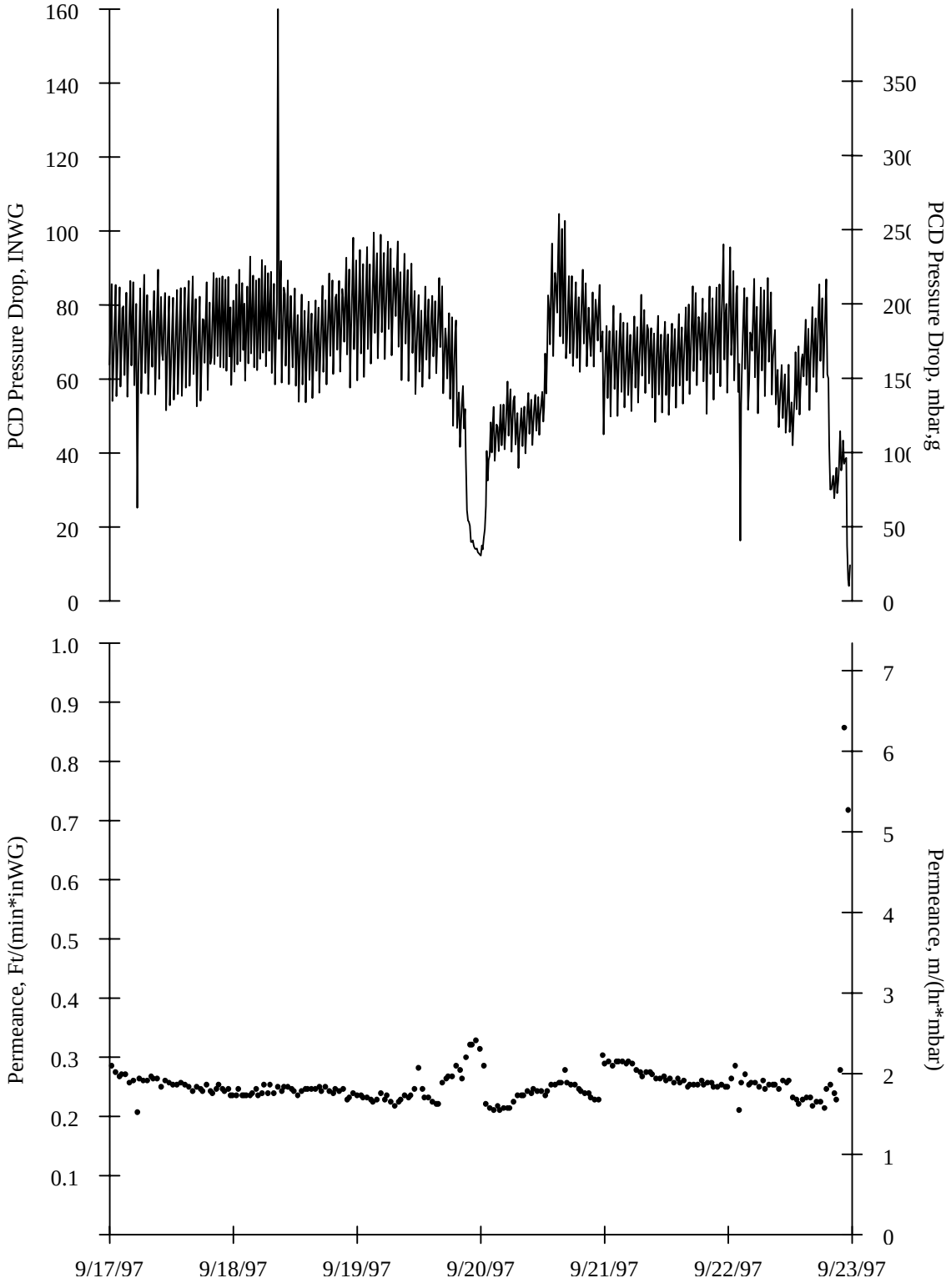


Figure 3.16.1-9 TC01B Pressure Drop and Permeance for September 17 Through 23

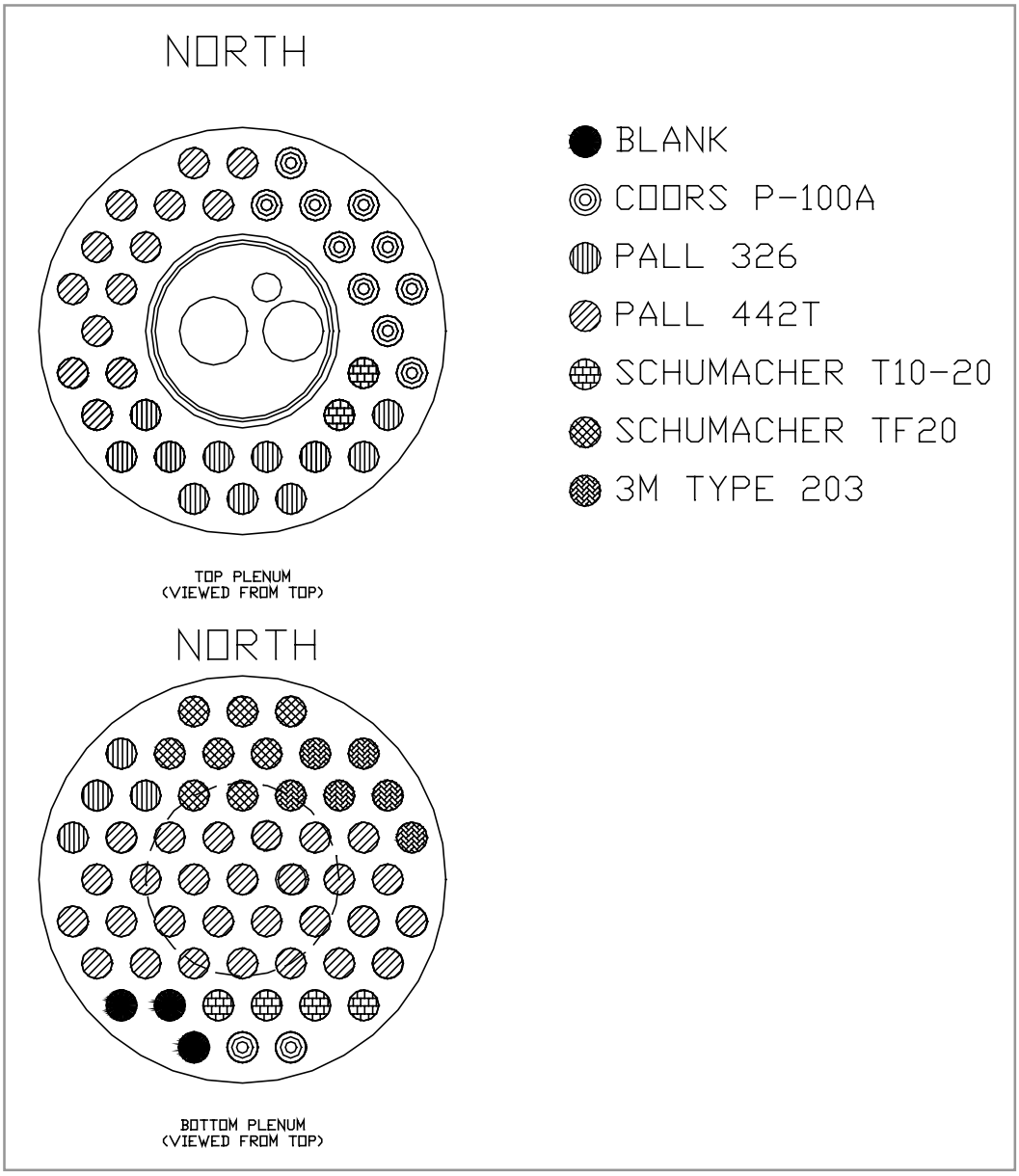


Figure 3.16.1-10 Filter Element Layout for TC01B (Layout No. 5)

3.16.2 Test Objectives

This test run was a continuation of the 1,000-hour test campaign (TC01). The main objective for the PCD was to obtain 1,000 hours exposure time for the filter elements at temperatures above 1,350°F (732.2°C).

3.16.3 Observations/Events

A. Test Started. Main Air Compressor (MAC) Started–September 6 at 03:35.

B. Start-Up Burner Lit–September 6 at 15:02.

C. Coal Feed Started–September 7 at 03:52.

D. Spent Fines Transport System Tripped–September 7 at 04:25. An abnormal spike (at 04:25) on the temperature curve for the bottom plenum indicated that filter element breaking might have occurred. Shortly after that event the spent fines transport system (FD0520) was tripped and the elbow of the dispense vessel on the FD0520 was plugged by broken pieces of Coors P100A filter element. All evidence suggested that one Coors P100A filter element was broken.

E. Start-up Burner Tripped–September 7 at 22:48.

F. Coal Feed Started–September 8 at 09:15.

G. Spheri Valve on Spent Fines Transport System Tripped–September 8 at 19:58. Before this event, the spheri valve on FD0520 system was not operating properly. The valve was not closing within allowed time.

H. Coal Feeder Failed–September 9 at 09:20.

I. Coal Feed Started–September 9 at 19:55.

J. Coal Feed Stopped–September 13 at 21:30.

K. Start-Up Burner Lit–September 14 at 02:16.

L. Dipleg Upset–September 14 at 18:45. The dipleg of the transport reactor was starting to slug. Particulate carryover to the PCD was observed. The back-pulse pressure was 400 psig (27.6 bar,g) at this time but was 500 psig (34.5 bar,g) 15 minutes before.

M. Coal Feed Stopped–September 15 at 05:15.

N. Coal Feed Started–September 15 at 17:10. A number of coal feed starts and stops were used to control the temperature rise in the PCD.

O. Coal Feeder Tripped–September 16 at 18:00.

P. Back-Pulse Pressure Sensitivity Test Started–September 19 at 09:20. Before conducting the back-pulse valve testing, a sensitivity test was initiated to examine the effect of back-pulse pressure on the dipleg stability. The back-pulse pressure was varied from 500 to 750 psig (34.5 to 51.7 bar,g) in 50 psig (3.4 bar,g) increments. The upset was observed at 550 psig (37.9 bar,g). However, higher back-pulse pressures

had no or very little effect on the dipleg. The transport reactor pressure during this period was 190 psig (13.1 bar,g).

Q. Coors P100A Filter Element Broken–September 19 at 18:25. An abnormal spike (at 18:25) on the temperature curve for the bottom plenum indicated that filter element breaking might have occurred.

R. Spheri Valve on Spent Fines Transport System Failed–September 19 at 18:37. The system was plugged by filter element pieces. Later, Coors P100A filter element pieces were removed from the FD0520 system.

S. Coal Feed Stopped–September 19 at 21:08.

T. Start-Up Burner Lit–September 20 at 01:54.

U. Coal Feed Started–September 20 at 12:22.

V. Spent Fines Transport System Tripped–September 22 at 08:15. Coors P100A filter element pieces were found from the exit of the system.

W. Steam Leak on Combustor Heat Exchanger–September 22 at 19:18.

X. Test Stopped. MAC Stopped–September 22 at 23:15.

3.16.4 Run Outcome

In this run (311) on-coal hours were achieved and the accumulative time for the PCD temperature above 1,350°F (732.2°C) was 215 hours 55 minutes from beginning to end of the TC01 run. The PCD temperature ramp rate was successfully controlled below 200°F/hr (93.3°C/hr) by starting and stopping the coal feed and by using the combustor heat exchanger. The additional nitrogen source made available during the last outage was used but did not produce significant effect on PCD inlet temperature as expected. Even though the temperature ramp rate was less than 200°F/hr (93.3°C/hr), there was still one Coors P100A filter element broken during the on-coal transition. On the other hand, another Coors P100A filter element failed during the stable operation while the temperature was above 1,350°F (732.2°C). The causes of this candle failure were unknown, but the higher back-pulse pressure employed earlier might have contributed to the final breaking. Despite the two broken filter elements, the rest of filter elements were working well so a decision was made not to pull out the PCD plenum for inspection in this outage.

The back-pulse pressure sensitivity test proved that higher back-pulse pressure did not induce the dipleg upsetting. This would make the back-pulse valve testing at higher back-pulse pressure possible in the subsequent normal operations.

3.17 PCD OPERATION DURING TEST RUN TC01C

3.17.1 Run Summary

Run TC01C was started on September 23, 1997, at 14:22 after a short outage (one-half day) and ended on September 28, 1997, at 01:00. During the outage after TC01B several changes were made for the PCD. The acoustic detector on the PCD outlet was removed and the nozzle blinded because the leakage of the process gas through the detector was found, making it very difficult to control the temperature at the transmitter below 200°F (93.3°C). A spheri valve seal on the spent fines transport system was replaced. The screw cooler (FD0502) was repacked to minimize the gas leakage.

No filter element breakage was observed during this run, and the PCD performed well. However, the spent fines transport system experienced several problems; finally the seal failures caused the shutdown of the transport reactor and the run was ended. Back-pulse valve testing was conducted for SV3112B.

In the stable operating period the temperature of the PCD was above 1,350°F (732.2°C), the pressure was 185 to 200 psig (12.8 to 13.8 bar,g). The face velocity was stabilized at about 4.5 ft/min (82.3 m/hr). The baseline value of the filter differential pressure (ΔP) increased from 43 to 68 inWG (107 to 169 mbar, g) in the stable operation. Other operating conditions are listed in table 3.17.1-1. The operating data are shown in figures 3.17.1-1 through -3.

Table 3.17.1-1

TC01C Run Statistics

Start Time	9/23/97 at 14:22
End Time	9/28/97 at 01:00
Coal Type	Calumet Alabama Bituminous
Hours on Coal	70.2
Sorbent Type	Plum Run Dolomite
Number of Filter Elements	86
Filter Element Layout No.	5 (See Figure 3.17.1-4)
Filtration Area	240.7 ft^2 (22.4 m^2)
Back-Pulse Valve Open Time	0.4 seconds
Back-Pulse Time Trigger	40 minutes
Back-Pulse Pressure	400-600 psig (27.6-41.4 bar,g) in normal operation
Back-Pulse DP Trigger	125 inWG (311 mbar, g)

Table 3.17.1-2

TC01C Major Events (Refer to Figures 3.17.1-1 through –3)

Event	Description	Time
A	Test started – main air compressor (MAC) started	9/23/97 at 14:22
B	Start-up burner lit	9/23/97 at 15:07
C	Coal feed started	9/24/97 at 00:55
D	Back-pulse valve testing started	9/24/97 at 15:20
E	MAC tripped	9/25/97 at 09:58
F	Back-pulse valve testing started	9/25/97 at 12:15
G	Pressure letdown valve failed	9/26/97 at 07:00
H	Coal feed stopped	9/26/97 at 09:17
I	MAC tripped	9/26/97 at 10:57
J	MAC started	9/26/97 at 19:30
K	Start-up burner lit	9/26/97 at 23:54
L	Coal feed started	9/27/97 at 10:20
M	Spheri valve seal on spent fines transport system failed	9/28/97 at 00:05
N	Test stopped – MAC stopped	9/28/97 at 01:00

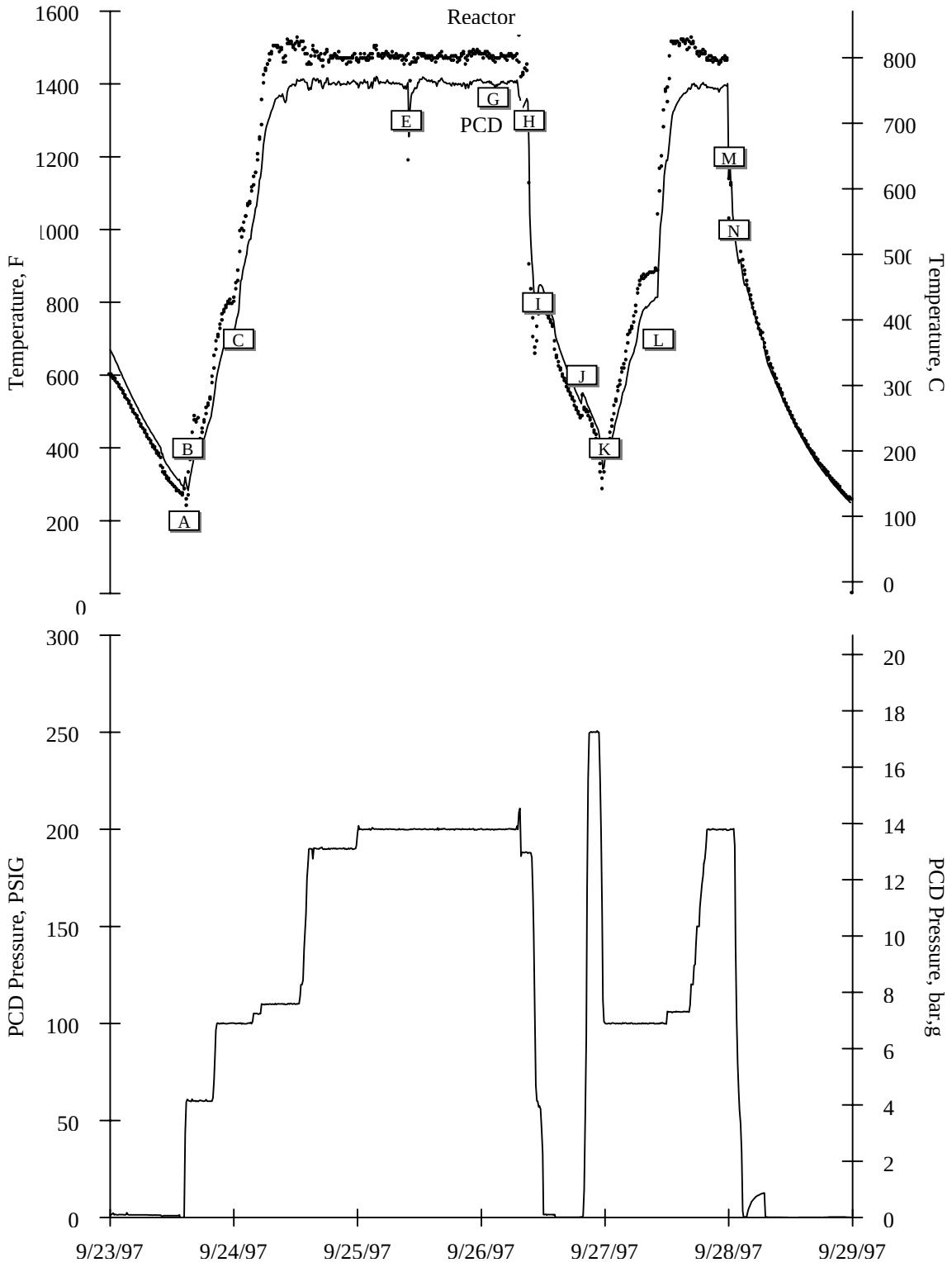


Figure 3.17.1-1 TC01C Temperature and Pressure for September 23 through 29

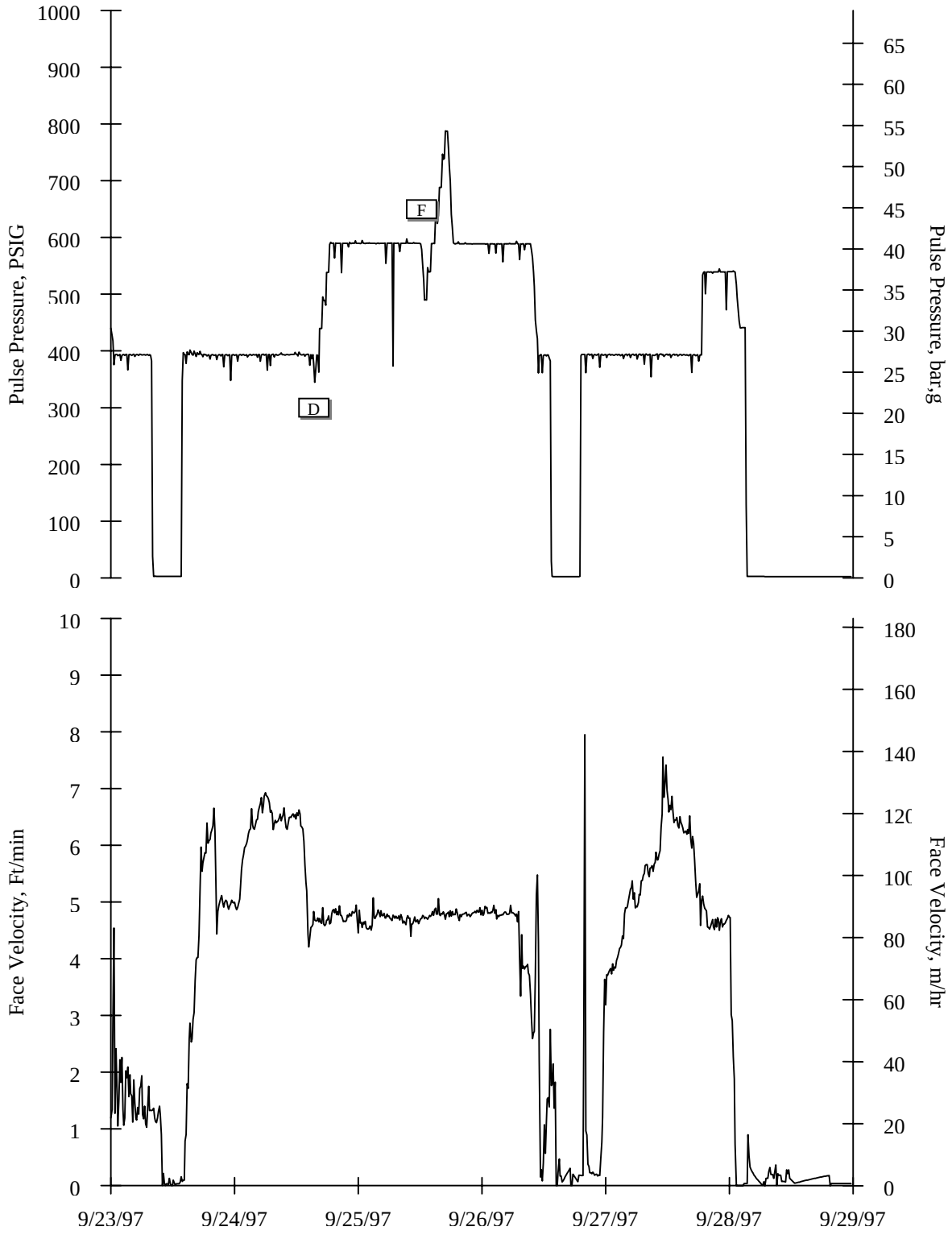


Figure 3.17.1-2 TC01C Back-Pulse Pressure and Face Velocity for September 23 through 29

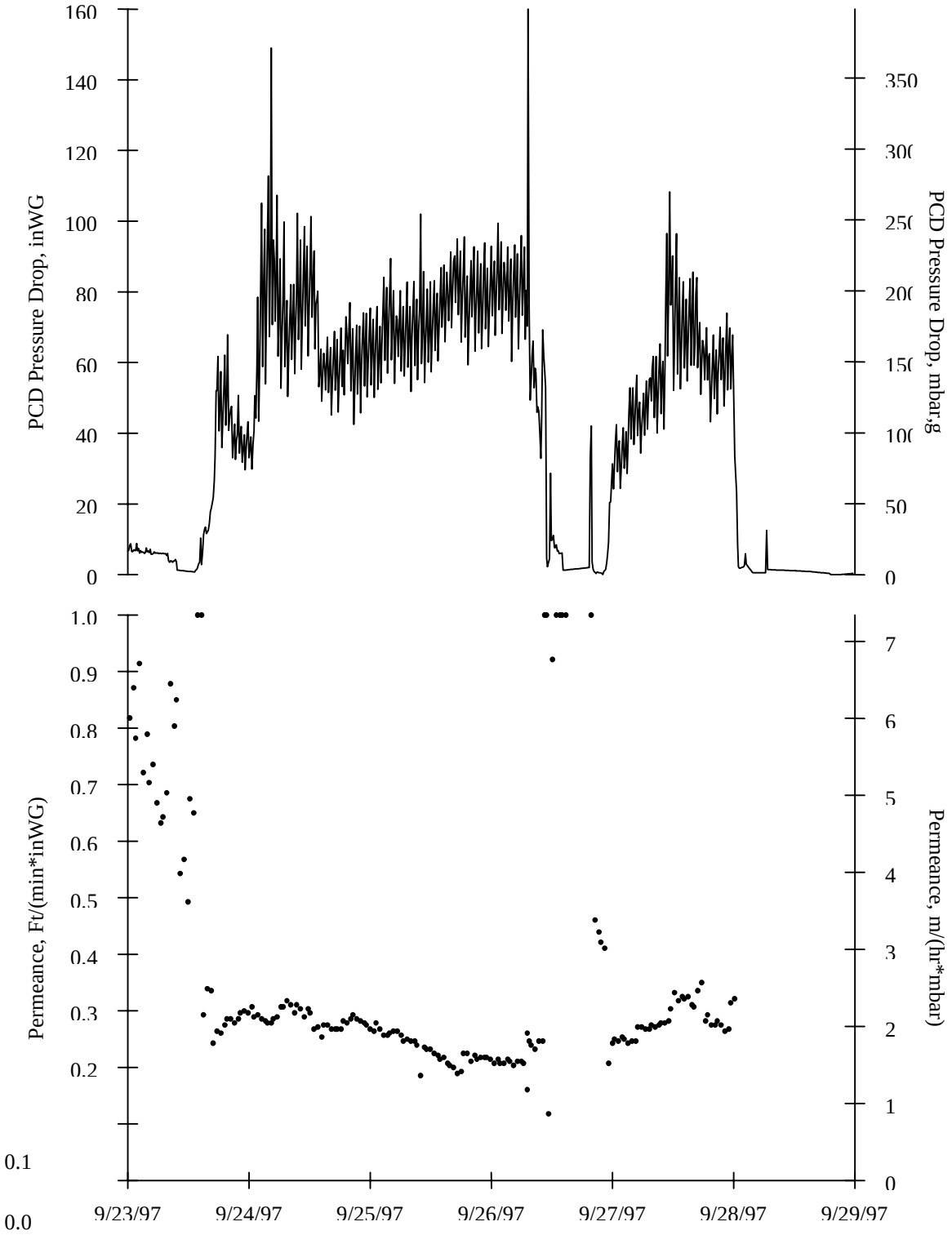


Figure 3.17.1-3 TC01C Pressure Drop and Permeance for September 23 through 29

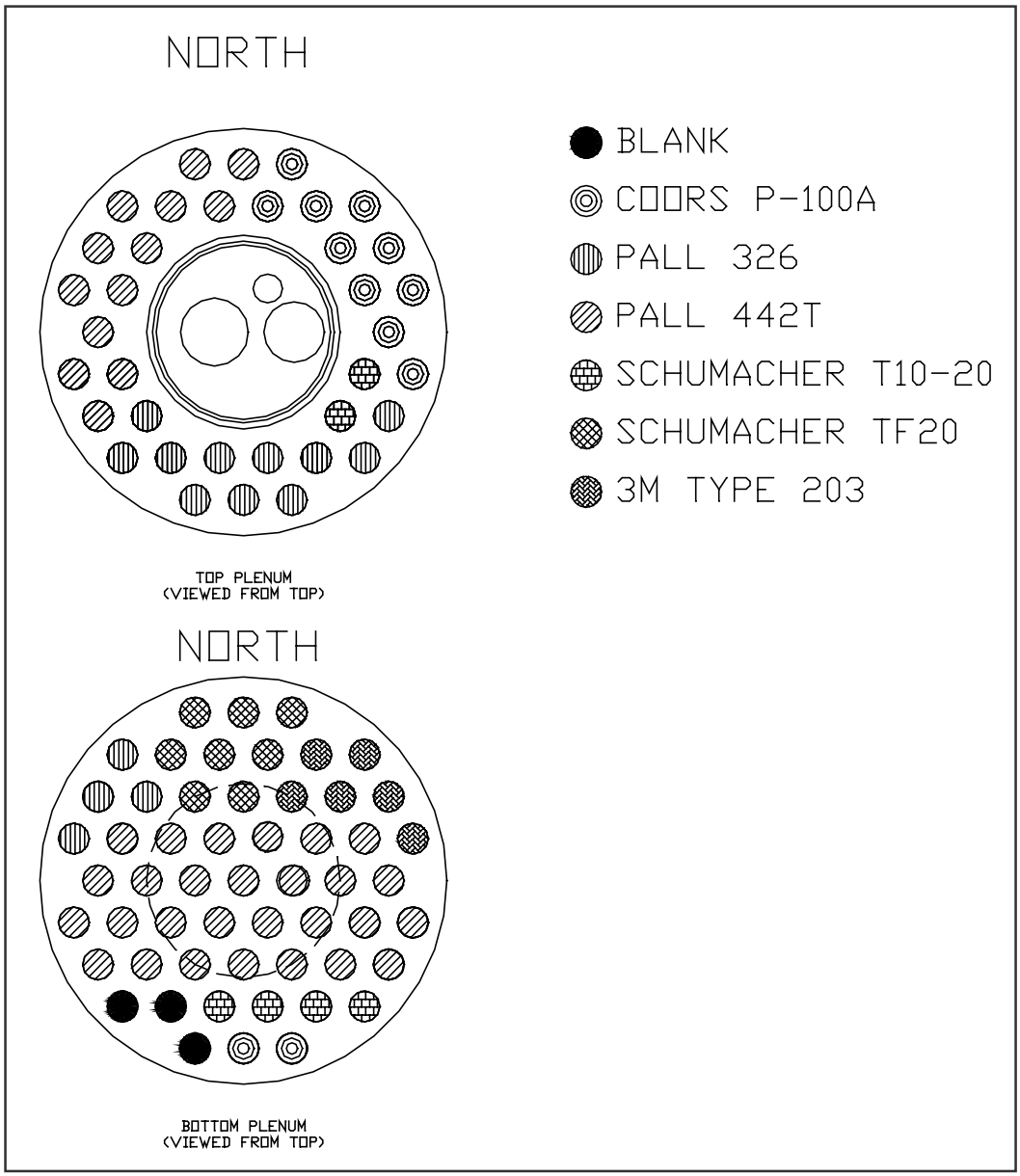


Figure 3.17.1-4 Filter Element Layout for TC01C (Layout No. 5)

3.17.2 Test Objectives

This test run was a continuation of the 1,000-hour test campaign TC01. The main objective for the PCD was to obtain 1,000 hours exposure time for the filter elements at temperatures above 1,350°F (732.2°C).

3.17.3 Observations/Events

A. Test Started – Main Air Compressor (MAC) Started – September 23 at 14:22.

B. Start-Up Burner Lit – September 23 at 15:07.

C. Coal Feed Started – September 24 at 00:55.

D. Back-Pulse Valve Testing Started – September 24 at 1520. Back-pulse valve testing was performed on SV3112B from 15:20 to 18:20. The back-pulse pressure was varied from 350 to 550 psig (24.1-37.9 bar,g). The valve open time was 0.3 seconds and the pilot pressure was 100 psig (6.90 bar,g).

E. MAC Tripped – September 25 at 09:58.

F. Back-Pulse Valve Testing Started – September 25 at 12:15. The back-pulse valve testing was continued for SV3112B from 12:15 to 18:30. The back-pulse pressure was varied from 500 to 800 psig (34.5-55.2 bar, g).

G. Pressure Letdown Valve Failed – September 26 at 07:00.

H. Coal Feed Stopped – September 26 at 09:17.

I. MAC Tripped – September 26 at 10:57.

J. MAC Started – September 26 at 19:30.

K. Start-Up Burner Lit – September 26 at 23:54.

L. Coal Feed Started – September 27 at 10:20.

M. Spheri Valve Seal on Spent Fines Transport System Failed – September 28 at 00:05. The bottom spheri valve seal failed. About 1 hour later the top spheri valve seal also failed.

N. Test Stopped – MAC Stopped – September 28 at 01:00.

3.17.4 Run Outcome

In this run the on-coal time was 70.2 hours and a total of 261 hours, 45 minutes for the PCD temperature above 1,350°F/hr (732.2°C/hr) was achieved. The PCD functioned normally with two broken Coors P100A filter elements that broke during TC01B. On the spent fines transport system both top and bottom spheri valves had failed. The seals were damaged and the domes were scratched leaving holes and grooves on them. It appeared that the filter element pieces from the previous run's filter element breakage might have contributed to the spheri valve damage.

3.18 PCD OPERATION DURING TEST RUN TC01D

3.18.1 Run Summary

After a 2-day outage the run TC01D began on September 29, 1997, at 21:30 and ended on October 5, 1997, at 22:25. During the outage after TC01C the dome of the top spheri valve on the spent fines transport system was repaired (the dome surface was covered with colloidal steel solution) and the seals were also replaced.

There was no filter element damage observed in this run. The PCD was able to run in two stable operating periods separated by a 24-hour outage caused by coal feeder problems. Three back-pulse valve tests were conducted during the run. The spent fines transport system (FD0520) worked well most of the time but the bottom spheri valve seal eventually failed and forced the shutdown.

In the two stable operating periods the temperature of the PCD was above 1,350°F (732.2°C), the pressure was 185 to 205 psig (12.8 to 14.1 bar,g). The face velocity was stabilized at about 4.5 ft/min (82.3 m/hr). The baseline value of the filter differential pressure (ΔP) was 50 to 60 inWG (125-149 mbar,g) in the stable operations. Other operating conditions are listed in table 3.18.1-1. The operating data are shown in figures 3.18.1-1 through -3.

Table 3.18.1-1

TC01D Run Statistics

Start Time	9/29/97 at 21:33
End Time	10/5/97 at 22:25
Coal Type	Calumet Alabama Bituminous
Hours on Coal	97.2
Sorbent Type	Plum Run Dolomite
Number of Filter Elements	86
Filter Element Layout No.	5 (see Figure 3.18.1-4)
Filtration Area	240.7 ft^2 (22.4 m^2)
Back-Pulse Valve Open Time	0.4 seconds
Back-Pulse Time Trigger	40 minutes
Back-Pulse Pressure	450 to 550 psig (31.0-37.9 bar,g) in normal operation
Back-Pulse DP Trigger	125 inWG (311 mbar,g)

Table 3.18.1-2

TC01D Major Events (Refer to Figures 3.18.1-1 through –3)

Event	Description	Time
A	Test started – main air compressor (MAC) started	9/29/97 at 21:30
B	Start-up burner lit	9/30/97 at 06:23
C	Back-pulse valve testing started	9/30/97 at 10:12
D	Coal feed started	9/30/97 at 13:40
E	Back-pulse valve testing started	10/1/97 at 08:00
F	Spheri valve on coal feeder failed	10/1/97 at 13:07
G	Coal feed started	10/2/97 at 02:50
H	Coal feeder failed	10/2/97 at 06:45
I	Coal feed started	10/2/97 at 12:57
J	Coal feeder failed	10/5/97 at 07:45
K	Start-up burner lit	10/5/97 at 09:25
L	Coal feed started	10/5/97 at 16:30
M	Coal feeder tripped	10/5/97 at 16:58
N	Coal feeder stopped	10/5/97 at 19:00
O	Spent fines transport system tripped	10/5/97 at 19:40
P	Test stopped – MAC stopped	10/5/97 at 22:25

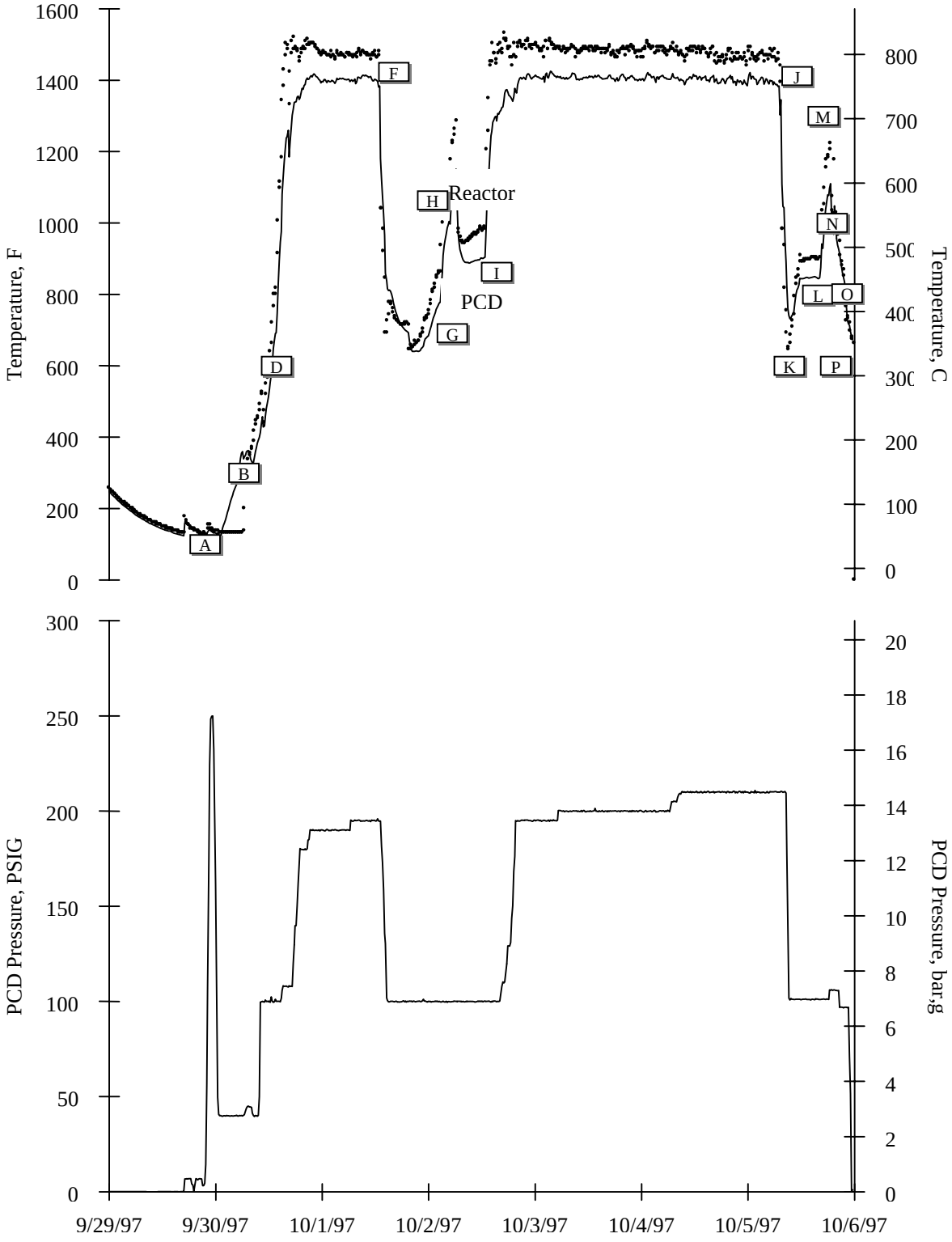


Figure 3.18.1-1 TC01D Temperature and Pressure for September 29 Through October 6

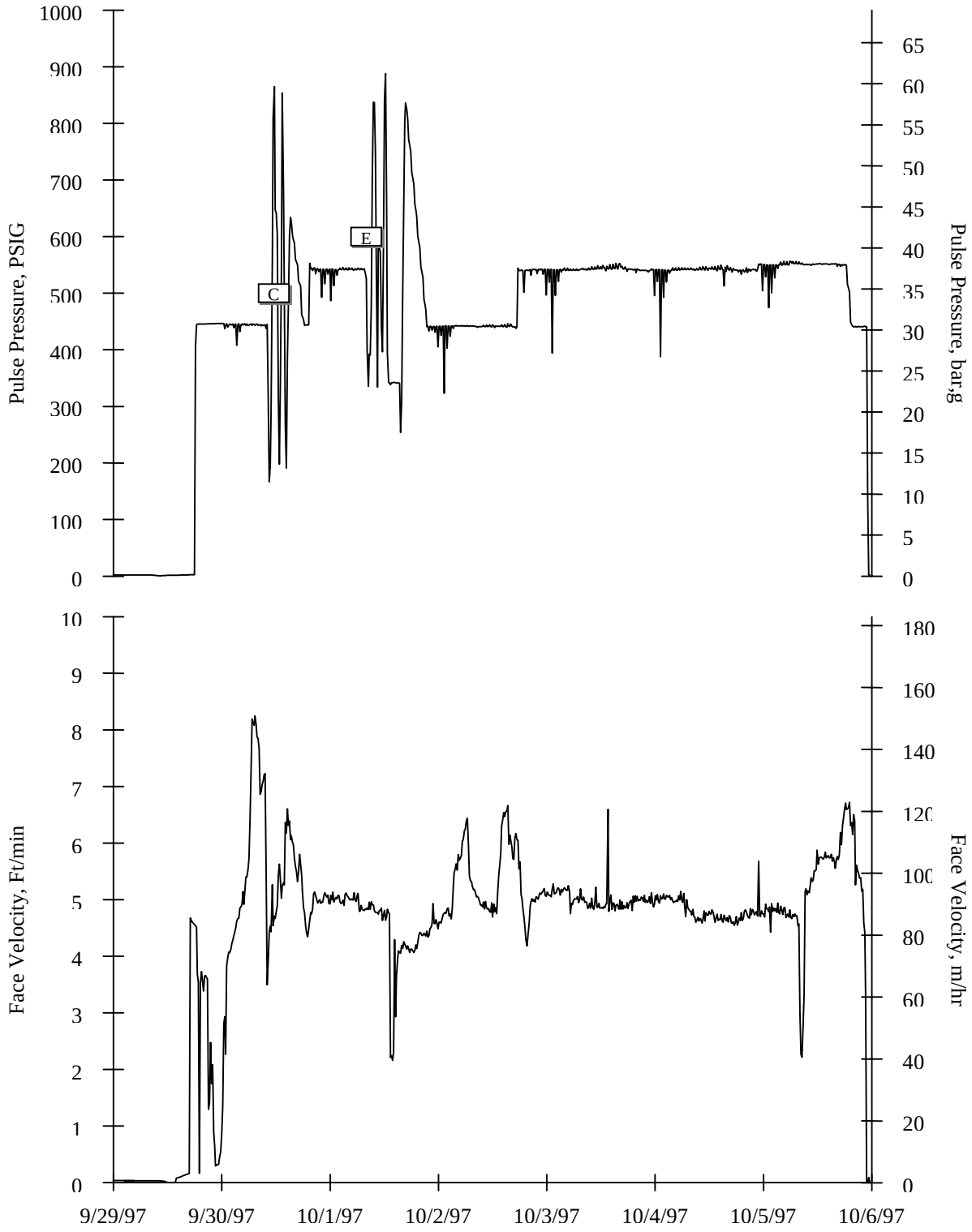


Figure 3.18.1-2 TC01D Back-Pulse Pressure and Face Velocity for September 29 Through October 6

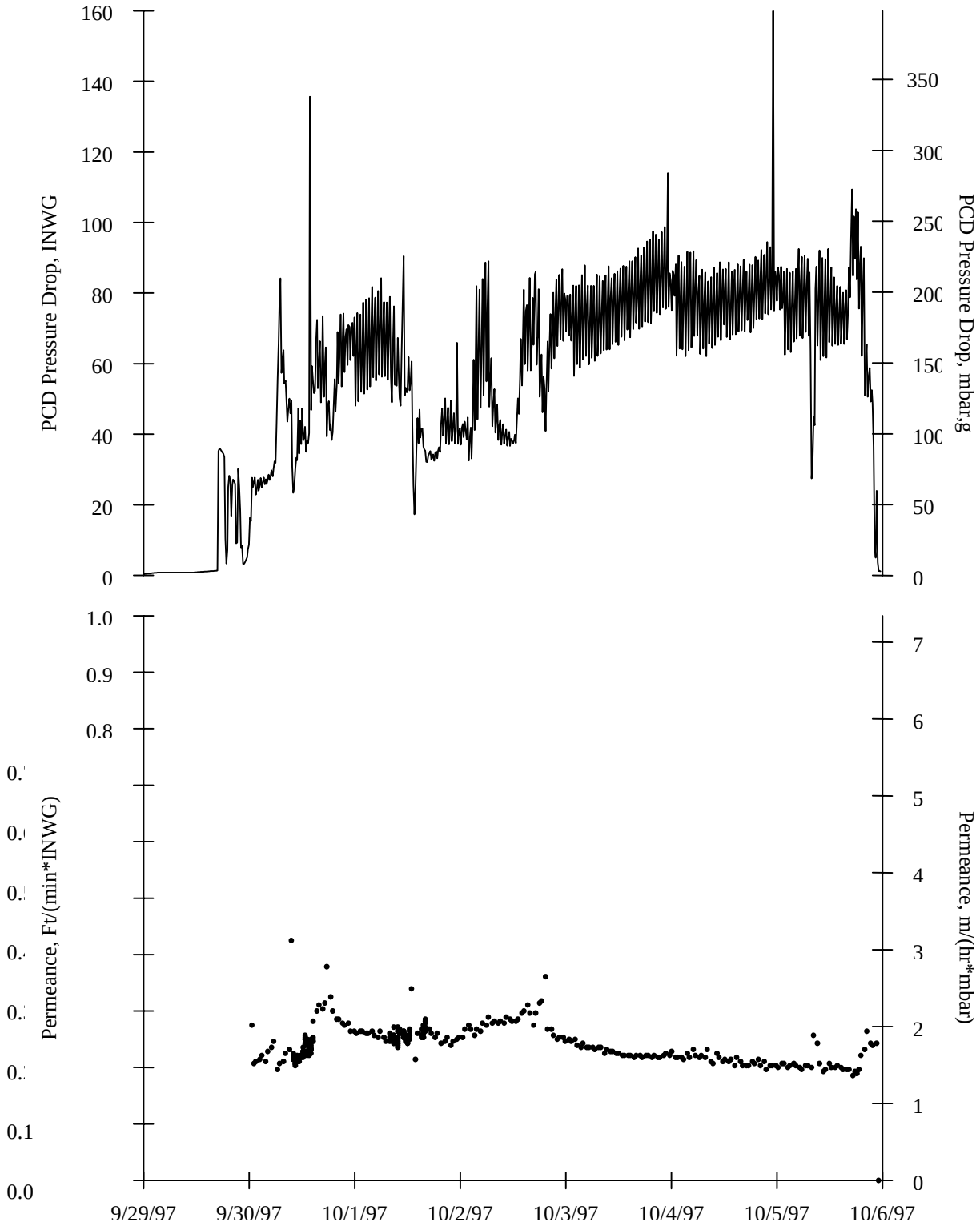


Figure 3.18.1-3 TC01D Pressure Drop and Permeance for September 29 Through October 6

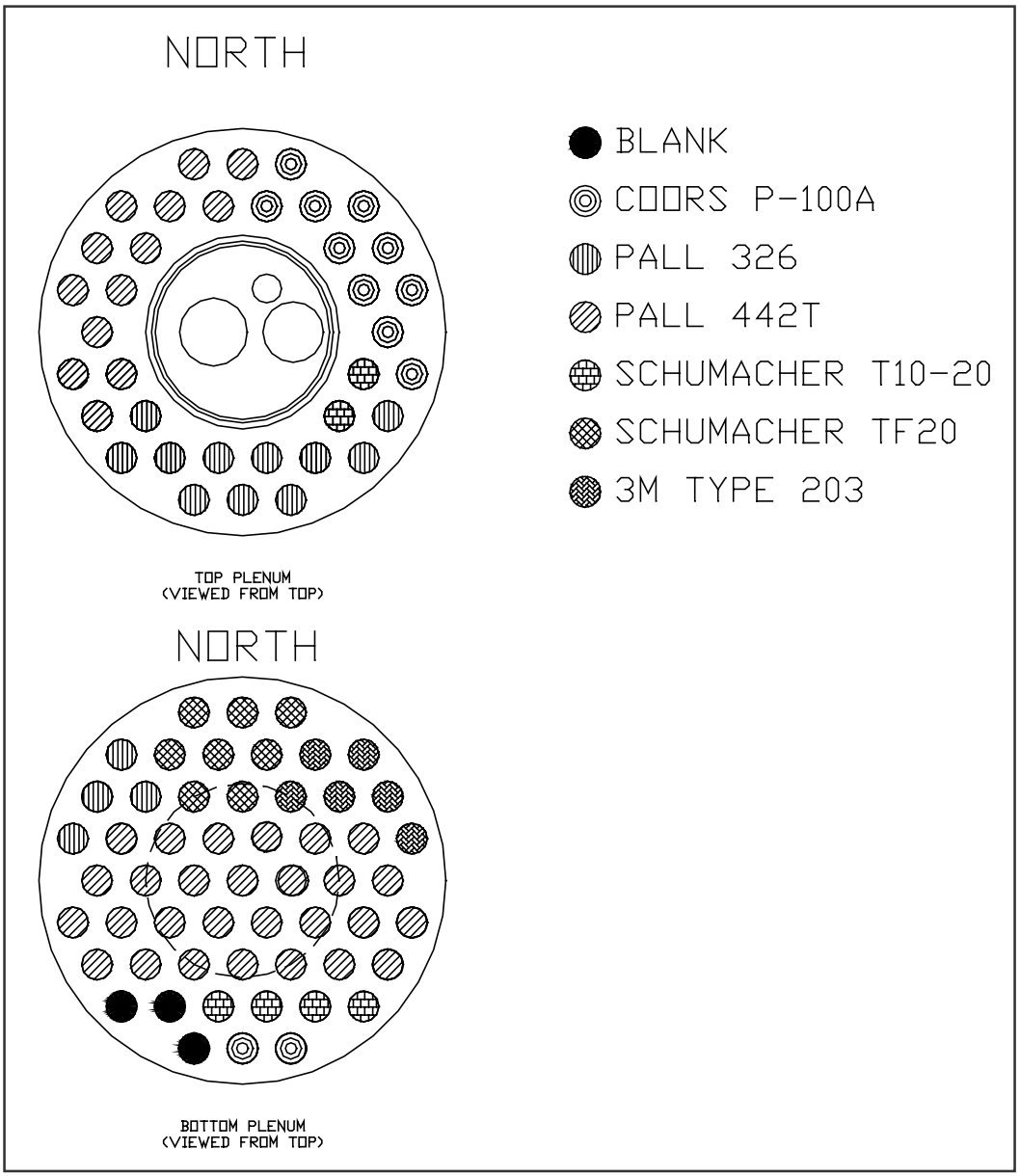


Figure 3.18.1-4 Filter Element Layout for TC01D (Layout No. 5)

3.18.2 Test Objectives

This test run was a continuation of the 1,000-hour test campaign TC01. The main objective for the PCD was to obtain 1,000 hours exposure time for the filter elements at temperatures above 1,350°F (732.2°C).

3.18.3 Observations/Events

A. Test Started–Main Air Compressor (MAC) Started – September 29 at 21:30.

B. Start-Up Burner Lit–September 30 at 06:23.

C. Back-Pulse Valve Testing Started–September 30 at 10:12. Back-pulse valve testing was performed on SV3112B from 10:12 to 15:02. The back-pulse pressure was varied from 200 to 850 psig (13.8 to 58.6 bar,g). The valve open time was 1.2 seconds and the pilot pressure was varied at 100, 120, and 140 psig (6.90, 8.27, and 9.65 bar,g).

D. Coal Feed Started–September 30 at 13:40.

E. Back-Pulse Valve Testing Started–October 1 at 08:00. Two back-pulse valve tests were performed on SV3112B from 08:00 to 16:40. The back-pulse pressure was varied from 250 to 900 psig (17.2 to 62.1 bar,g). The valve open times were 0.3 and 0.6 seconds, respectively, and the pilot pressure was varied at 100, 120, and 140 psig (6.90, 8.27, and 9.65 bar,g) in each test.

F. Spheri Valve on Coal Feeder Failed–October 1 at 13:07.

G. Coal Feed Started–October 2 at 02:50.

H. Coal Feeder Failed–October 2 at 06:45.

I. Coal Feed Started–October 2 at 12:57.

J. Coal Feeder Failed–October 5 at 07:45.

K. Start-Up Burner Lit–October 5 at 09:25.

L. Coal Feed Started–October 5 at 16:30.

M. Coal Feeder Tripped–October 5 at 16:58.

N. Coal Feeder Stopped–October 5 at 19:00.

O. Spent Fines Transport System Tripped–October 5 at 19:40. The bottom spheri valve seal was blown out.

P. Test Stopped. MAC Stopped–October 5 at 22:25.

3.18.4 Run Outcome

The on-coal time was 97.2 hours and the accumulative time for the PCD temperature above 1,350°F (732.2°C) was 335 hours 50 minutes from the beginning of TC01. The PCD and spent fines transport system worked fine except that the bottom spheri valve seal failed at the end of the run. The mechanical contact switch on the shuttle valves of the spent fines transport system presented a problem that caused improper spheri valve operation.

3.19 PCD OPERATION DURING TEST RUN TC01E

3.19.1 Run Summary

The bottom spheri valve on the spent fines transport system (FD0520) was tested before starting this run to correct mechanical problems with the valve closing. The contact switch was adjusted and the shuttle valves and valve seals were also replaced.

The TC01E run started on October 8, 1997, at 21:56 and ended on October 16, 1997, at 01:23. The run was terminated because the spheri valve on FD0520 failed. The PCD performed well during this run. There was no evidence of filter element breakage. The FD0520 system still had problems with the spheri valve closing caused by improper mechanical contact of the shuttle valves. Three back-pulse valve tests were conducted during the start-up period before feeding coal.

In the stable operating period the temperature of the PCD was above 1,350°F (732.2°C) and the pressure was 195 to 210 psig (13.4 to 14.5 bar,g). The face velocity averaged about 4.5 ft/min (82.3 m/hr). The baseline value of the filter differential pressure (ΔP) was 50 to 60 inWG (125 to 149 mbar,g). The back-pulse pressure was kept at about 350 psig (24.1 bar,g) above the PCD pressure. Other operating conditions are listed in table 3.19.1-1. The operating data are shown in figures 3.19.1-1 through -6.

Table 3.19.1-1

TC01E Run Statistics

Start Time	10/8/97 at 21:56
End Time	10/16/97 at 01:23
Coal Type	Calumet Alabama Bituminous
Hours on Coal	118.75
Sorbent Type	Plum Run Dolomite
Number of Filter Elements	86
Filter Element Layout No.	5 (See Figure 3.19.1-7)
Filtration Area	240.7 ft^2 (22.4 m^2)
Back-Pulse Valve Open Time	0.4 seconds
Back-Pulse Time Trigger	40 minutes
Back-Pulse Pressure	450 to 550 psig (31.0 to 37.9 bar,g) in normal operation
Back-Pulse DP Trigger	125 inWG (311 mbar,g)

Table 3.19.1-2

TC01E Major Events (Refer to Figures 3.19.1-1 through –6)

Event	Description	Time
A	Test started – main air compressor (MAC) started	10/8/97 at 21:56
B	Start-up burner lit	10/9/97 at 06:16
C	Back-pulse valve testing started	10/9/97 at 09:16
D	Thermal oxidizer ran out of propane	10/9/97 at 15:55
E	MAC started	10/10/97 at 03:43
F	Start-up burner lit	10/10/97 at 04:20
G	Coal feed started	10/10/97 at 16:55
H	Coal feed stopped	10/11/97 at 04:12
I	Coal feed started	10/11/97 at 09:15
J	Spheri valve on spent fines transport system failed	10/14/97 at 13:00
K	Pressure letdown valve failed	10/15/97 at 21:15
L	Spheri valve on spent fines transport system failed	10/15/97 at 22:50
M	Reactor shutdown	10/15/97 at 22:51
N	Test stopped – MAC stopped	10/16/97 at 01:23

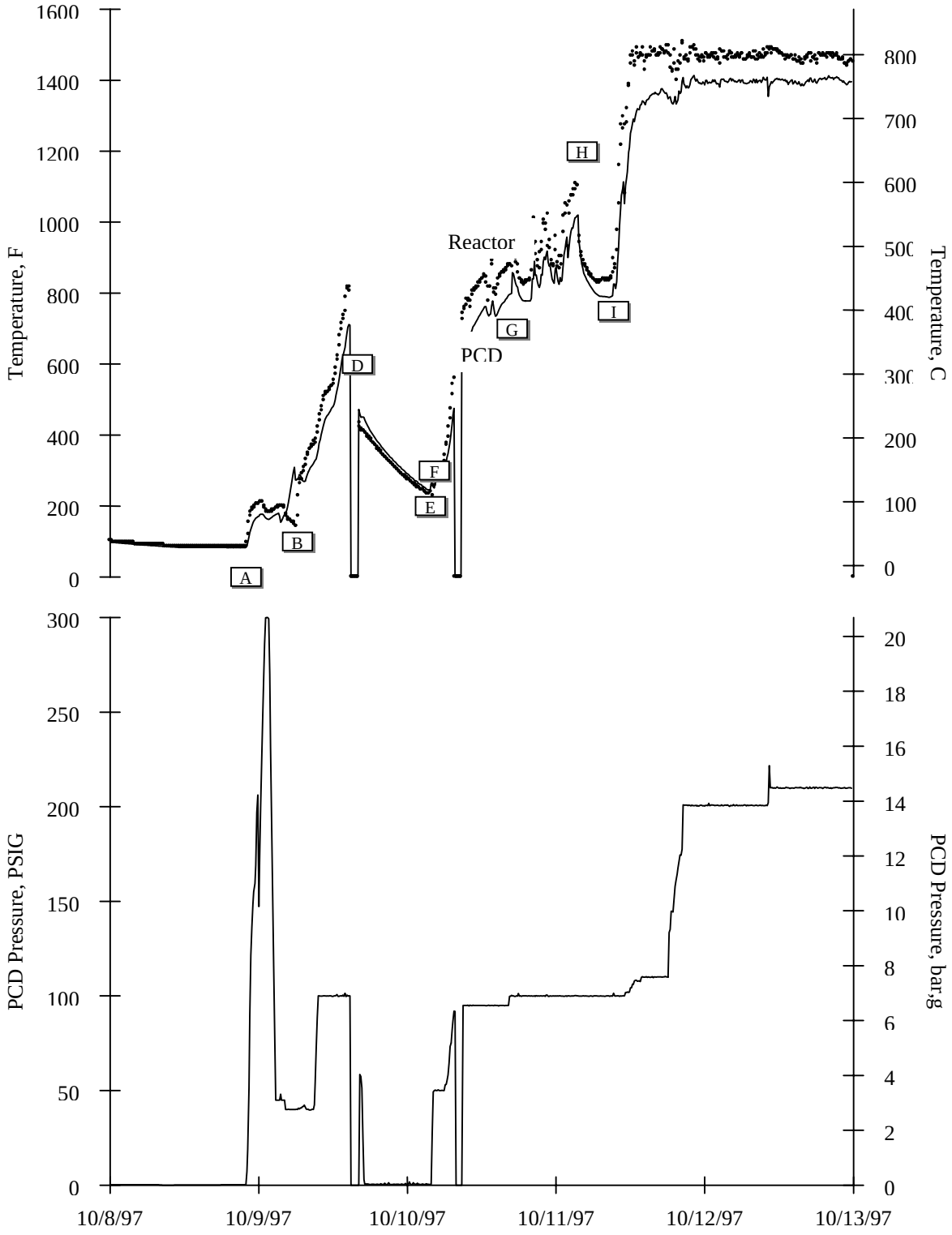


Figure 3.19.1-1 TC01E Temperature and Pressure for October 8 Through 13

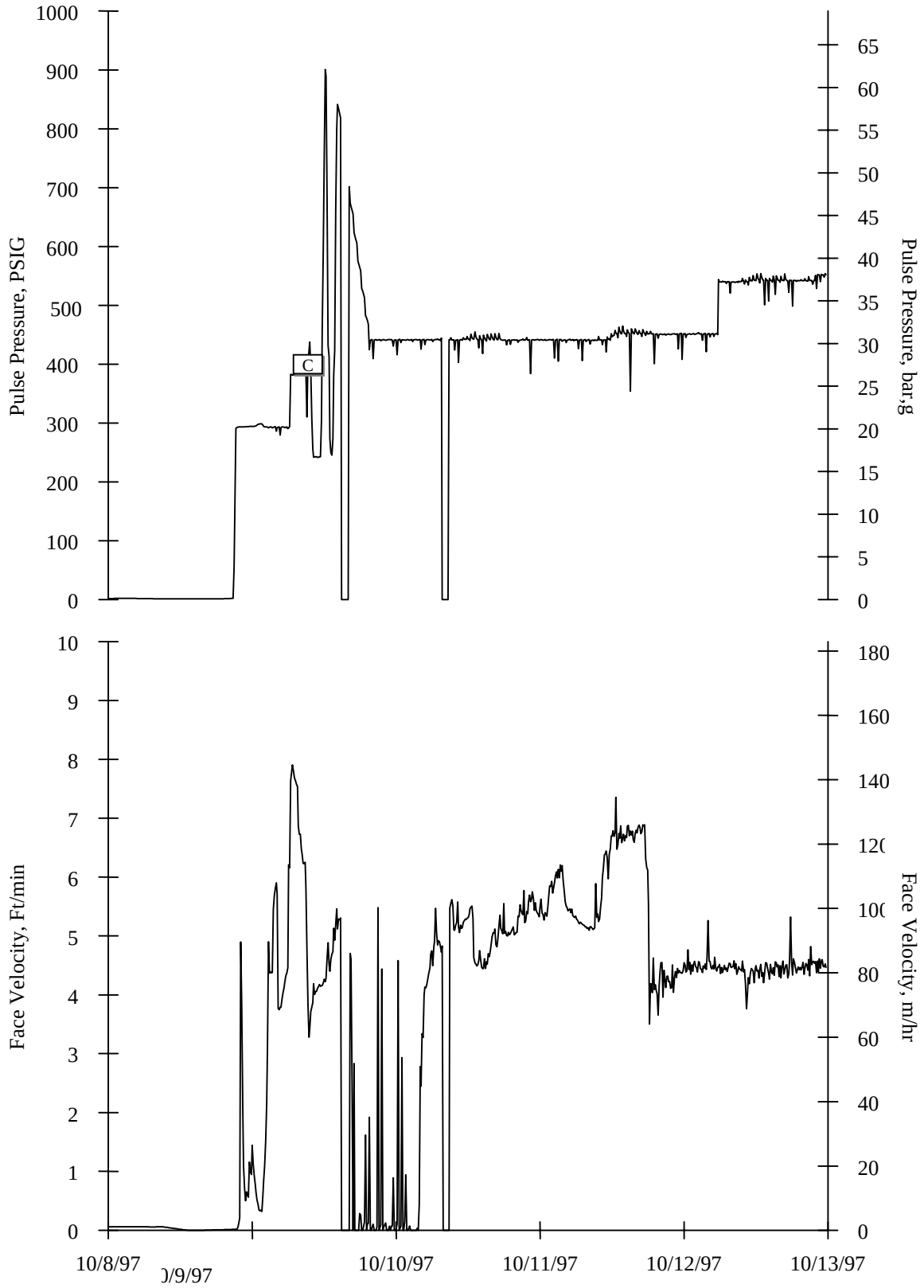


Figure 3.19.1-2 TC01E Back-Pulse Pressure and Face Velocity for October 8 Through 13

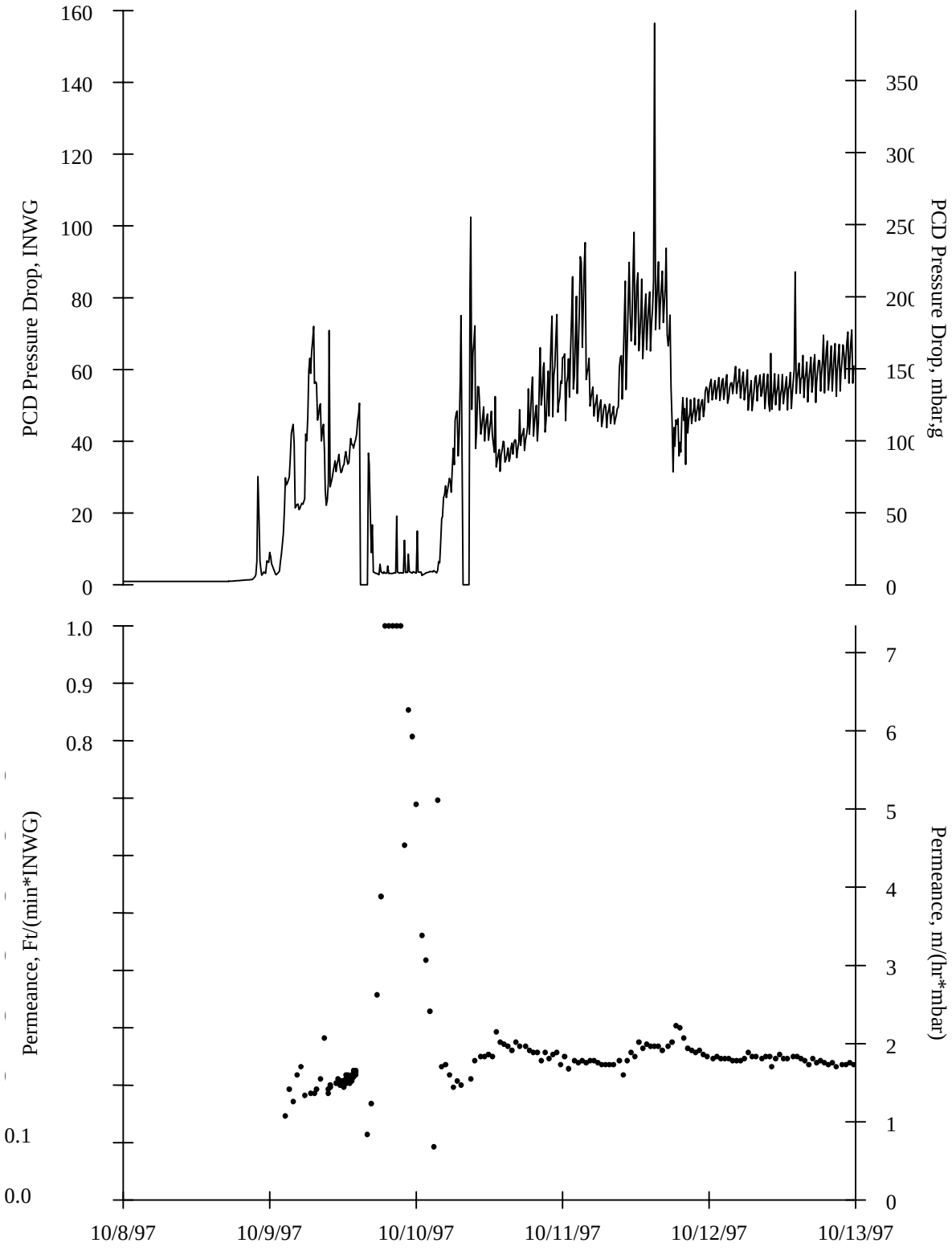


Figure 3.19.1-3 TC01E Pressure Drop and Permeance for October 8 Through 13

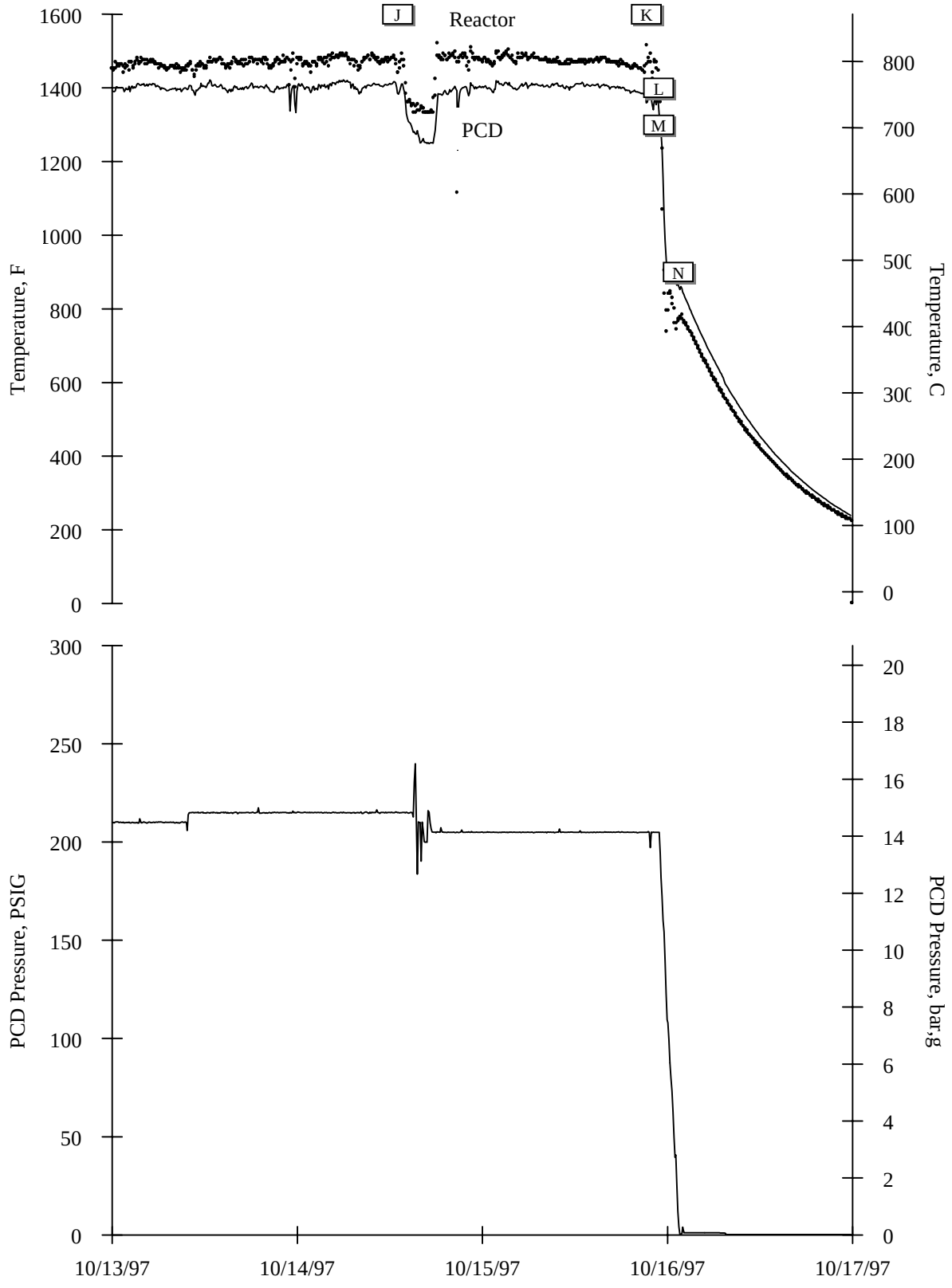


Figure 3.19.1-4 TC01E Temperature and Pressure for October 13 Through 17

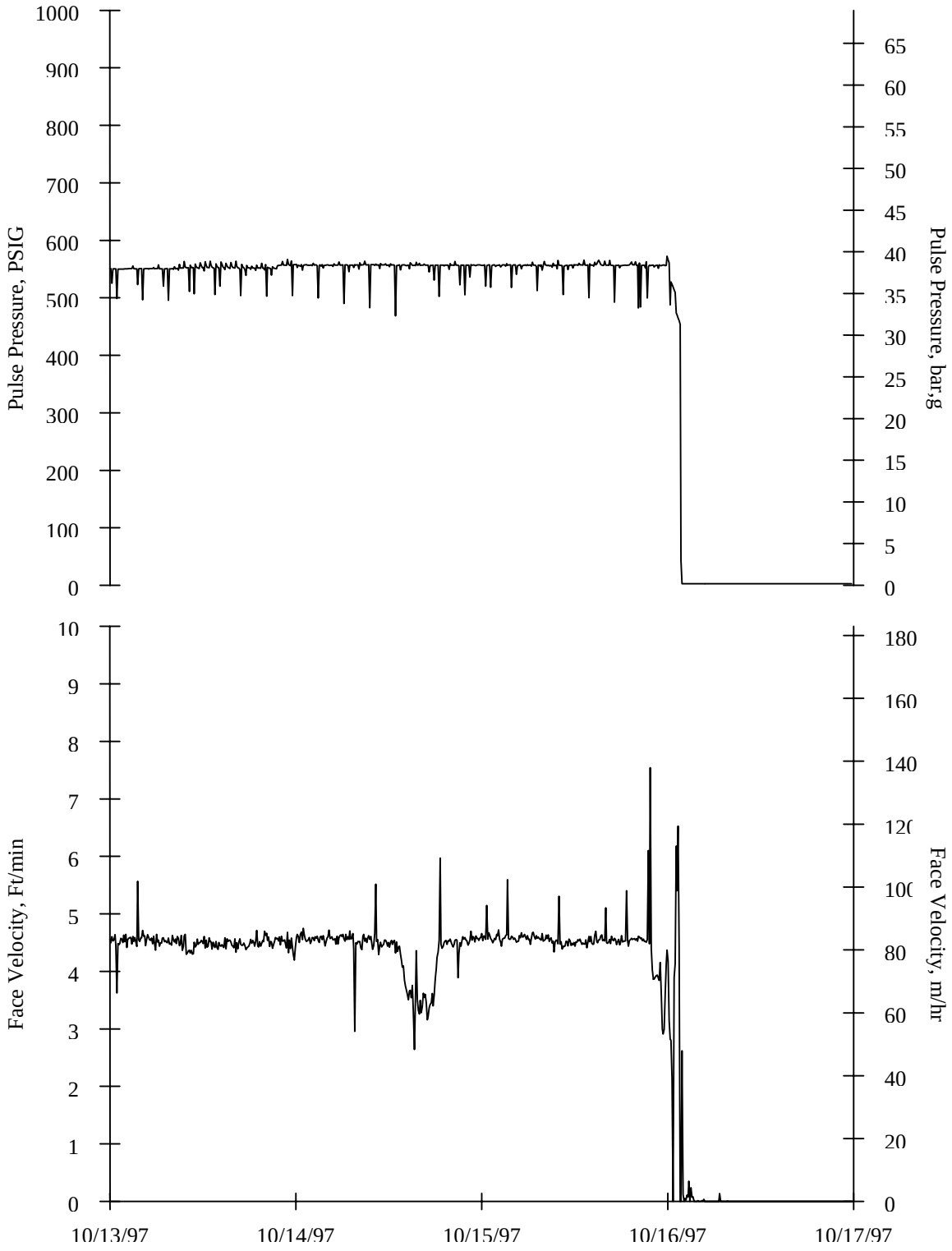


Figure 3.19.1-5 TC01E Pulse Pressure and Face Velocity for October 13 Through 17

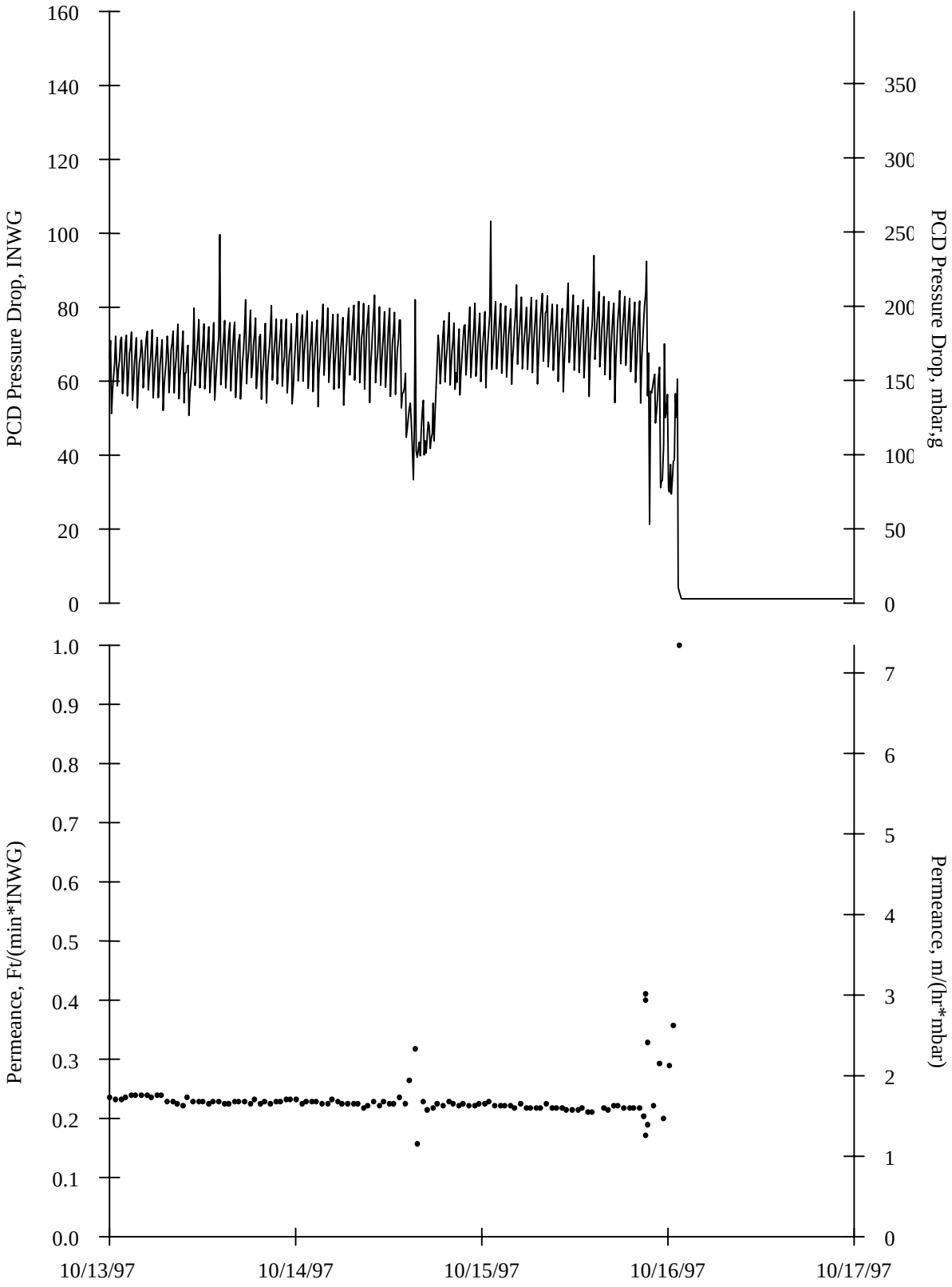


Figure 3.19.1-6 TC01E Pressure Drop and Permeance for October 13 Through 17

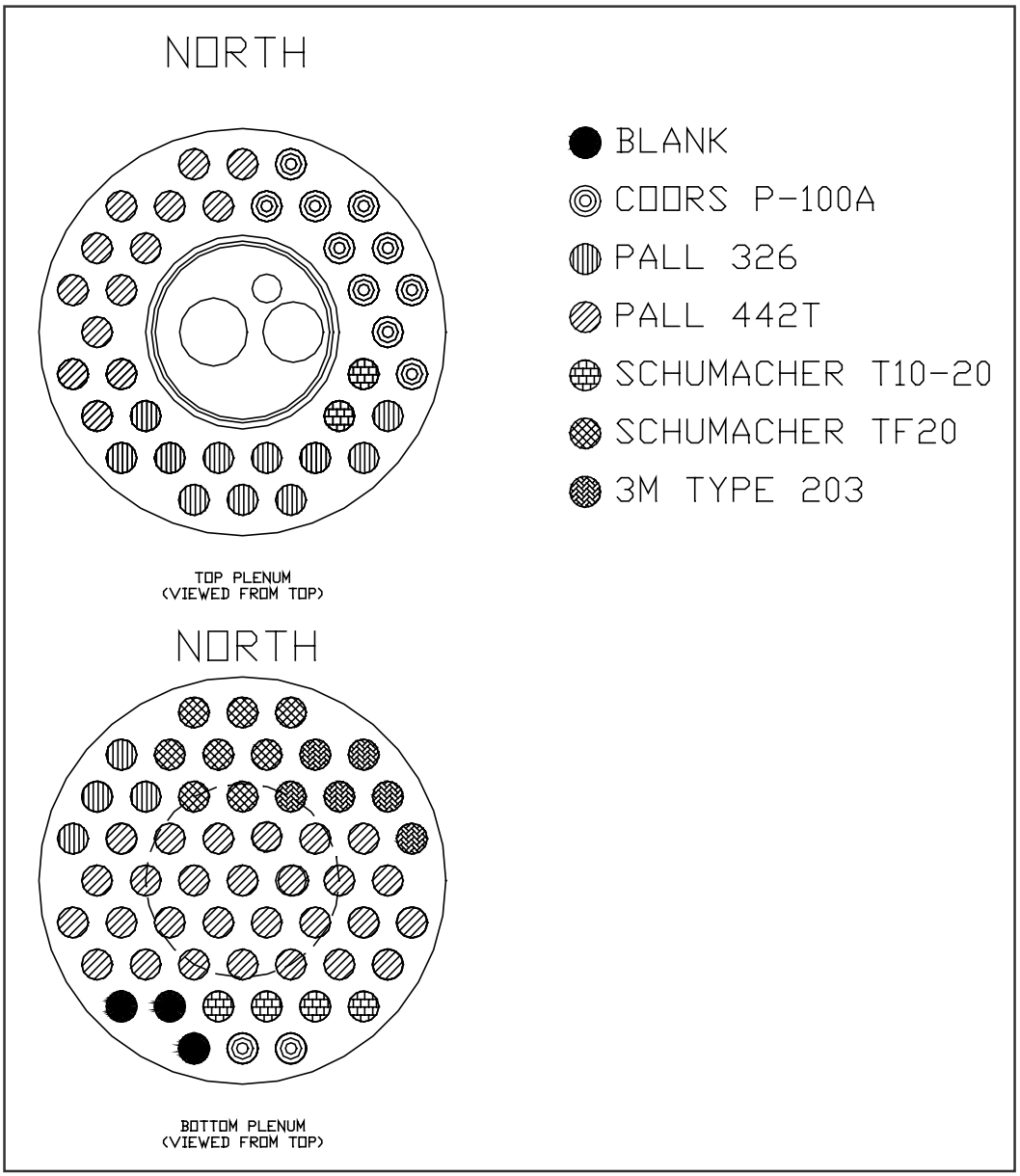


Figure 3.19.1-7 Filter Element Layout for TC01E (Layout No. 5)

3.19.2 Test Objectives

This test run was a continuation of the 1,000-hour test campaign TC01. The main objective for the PCD was to obtain 1,000 hours exposure time for the filter elements at temperatures above 1,350°F (732.2°C).

3.19.3 Observations/Events

A. Test Started–Main Air Compressor (MAC) Started – October 8 at 21:56.

B. Start-Up Burner Lit–October 9 at 06:16.

C. Back-Pulse Valve Testing Started–October 9 at 09:16. Back-pulse valve testing was performed on SV3112B from 09:16 to 14:13. The back-pulse pressure was varied from 250 to 900 psig (17.2 to 62.1 bar,g). The valve open time was 0.9 seconds and the pilot pressure was varied at the 3 levels of 100, 120, and 140 psig (6.90, 8.27, and 9.65 bar,g).

D. Thermal Oxidizer Ran Out of Propane–October 9 at 15:55.

E. MAC Started–October 10 at 03:43.

F. Start–Up Burner Lit–October 10 at 04:20.

G. Coal Feed Started–October 10 at 16:55.

H. Coal Feed Stopped–October 11 at 04:12.

I. Coal Feed Started–October 11 at 09:15.

J. Spheri Valve on Spent Fines Transport System Failed–October 14 at 13:00. The bottom spheri valve on the spent fines transport system (FD0520) did not function properly. There was a mechanical problem with the valve closing. This problem continued throughout the day.

K. Pressure Letdown Valve Failed–October 15 at 21:15. The pressure letdown valve (PV287) was vibrating. While the pressure and operating conditions were changed to eliminate the valve vibration, about 540 pounds (245 kg) solids were carried over to the PCD.

L. Spheri Valve on Spent Fines Transport System Failed–October 15 at 22:50. The seal on the bottom spheri valve of FD0520 had been ruptured.

M. Reactor Shutdown–October 15 at 22:51.

N. Test Stopped–MAC Stopped–October 16 at 01:23.

3.19.4 Run Outcome

This run had an on-coal time of 118.8 hours. The accumulative time for the PCD temperature above 1,350°F (732.2°C) reached 423 hours 50 minutes since the beginning of TC01 run. The PCD worked well without filter element damage. The FD0520 again became the cause of the system shutdown due to the seal problem.

3.20 PCD OPERATION DURING TEST RUN TC01F

3.20.1 Run Summary

Test campaign TC01F was started late in the evening on October 18, 1997, for the purpose of continuing the 1,000-hour test campaign. Problems with the spent fines transport system, FD0520, spheri valves from the previous TC01 runs were analyzed with hopes of understanding the failure mechanisms involved in the seal failures in order to avoid similar occurrences during TC01F.

Startup of the unit was completed successfully with only minor complications. The temperature of the particulate control device (PCD) attained 1,350°F (732.2°C) within the first 5 minutes of the morning of October 20, 1997. This temperature was maintained with only minor complications through late in the day of October 21, 1997, when coal feed was lost and the temperature in the PCD dropped 580°F (304.4°C) in 3 hours. Coal feed was reestablished early in the morning on October 22, 1997, and 1,350°F (732.2°C) was achieved by early afternoon. Problems with the lower spheri valve seal on FD0520 began interrupting operation of the unit late in the evening of October 22, 1997. Eventually, the seal failed to hold pressure and forced the unit to come down late in the night of October 23, 1997. Analysis of the seal showed that the o-ring seal had failed and allowed nitrogen to leak by and escape.

Table 3.20.1-1

TC01F Run Statistics

Start Time:	10/18/97 21:50
End Time:	10/24/97 00:00
Coal Type:	Calumet Alabama Bituminous
Hours on Coal:	97.25
Sorbent Type:	Plum Run Dolomite
Number of Filter Elements:	88 (two elements suspected of failure)
Filter Element Layout No.:	5 (figure 3.20.1-1 through -4)
Filtration Area:	240.7 ft^2 (22.4 m^2)
Pulse Valve Open Time:	0.4 sec.
Pulse Time Trigger:	40 min.
Pulse Pressure:	440 to 600 psig (30.3 to 41.4 bar,g)
Pulse DP Trigger:	112 inWG (278.7 mbar,g)

Table 3.20.1-2

TC01F Major Events

Event	Description	Date at Time
A	Test Started	October 18 at 21:50
B	Coal Feeder Tripped	October 21 at 21:45
C	Spheri Valve Seal Leak	October 22 at 17:40
D	Spheri Valve Seal Failure	October 23 at 21:45
E	Test Ended	October 24 at 00:00

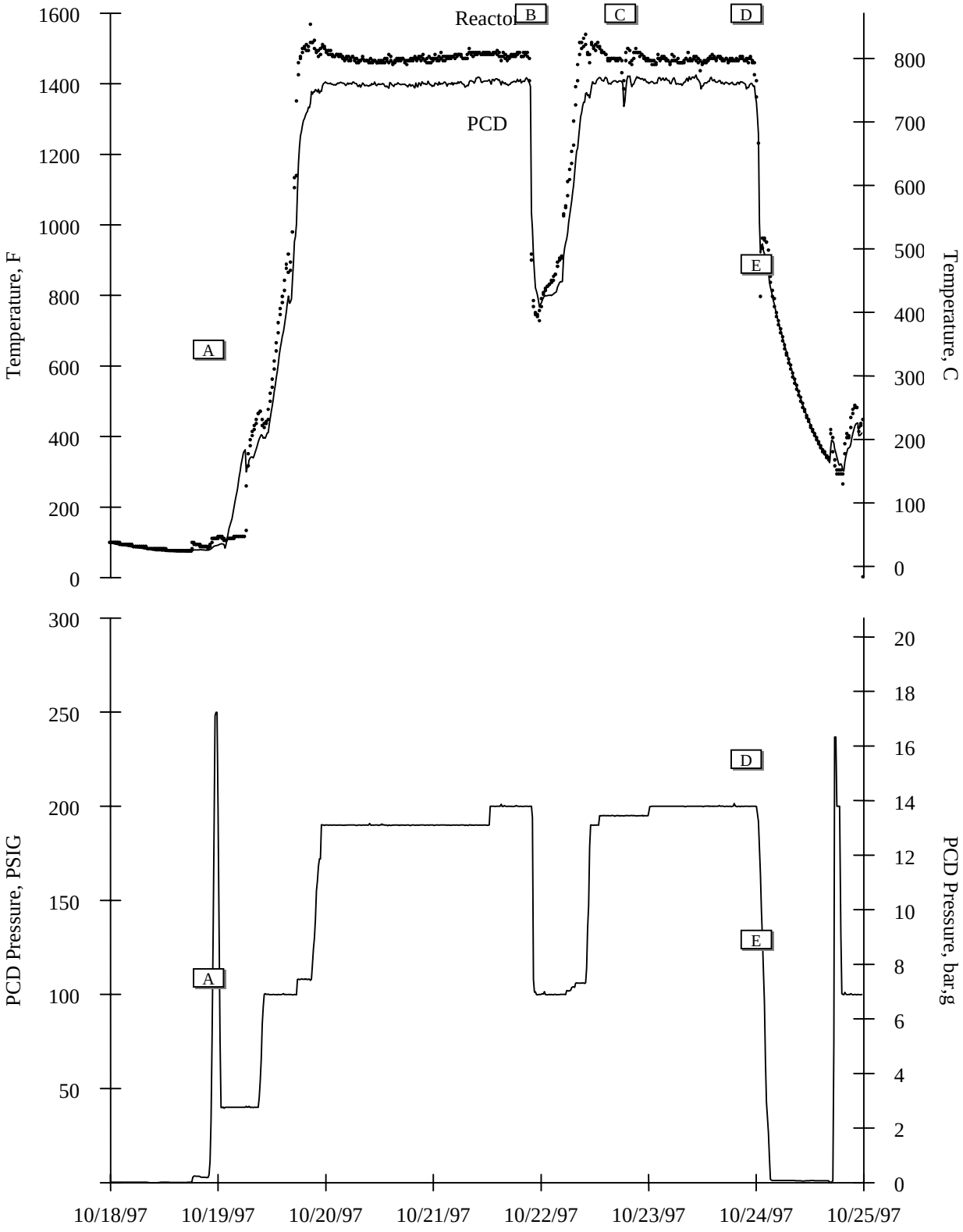


Figure 3.20.1-1 TC01F Temperature and Pressure for October 18 Through 25

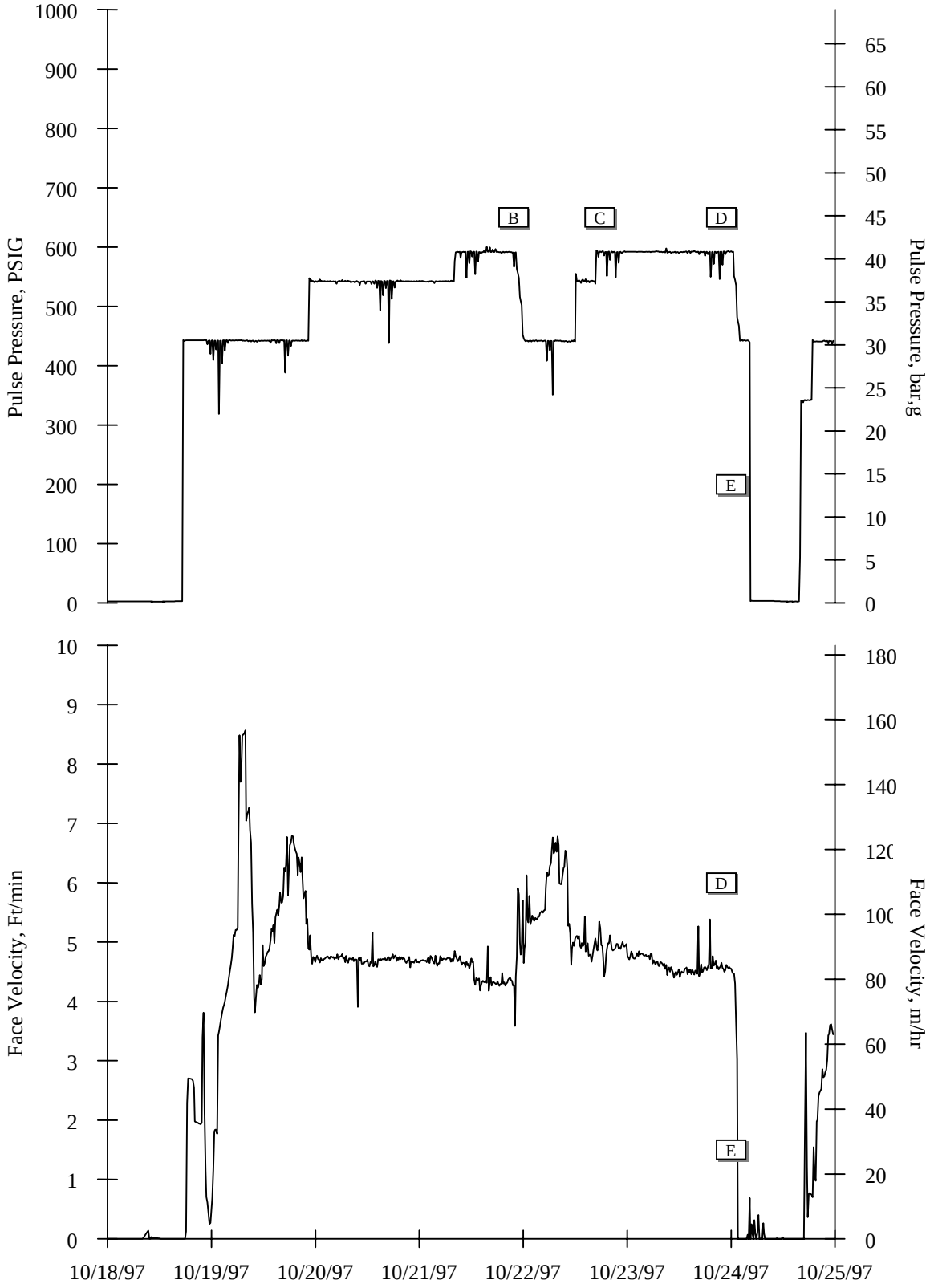


Figure 3.20.1-2 TC01F Pulse Pressure and Face Velocity for October 18 Through 25

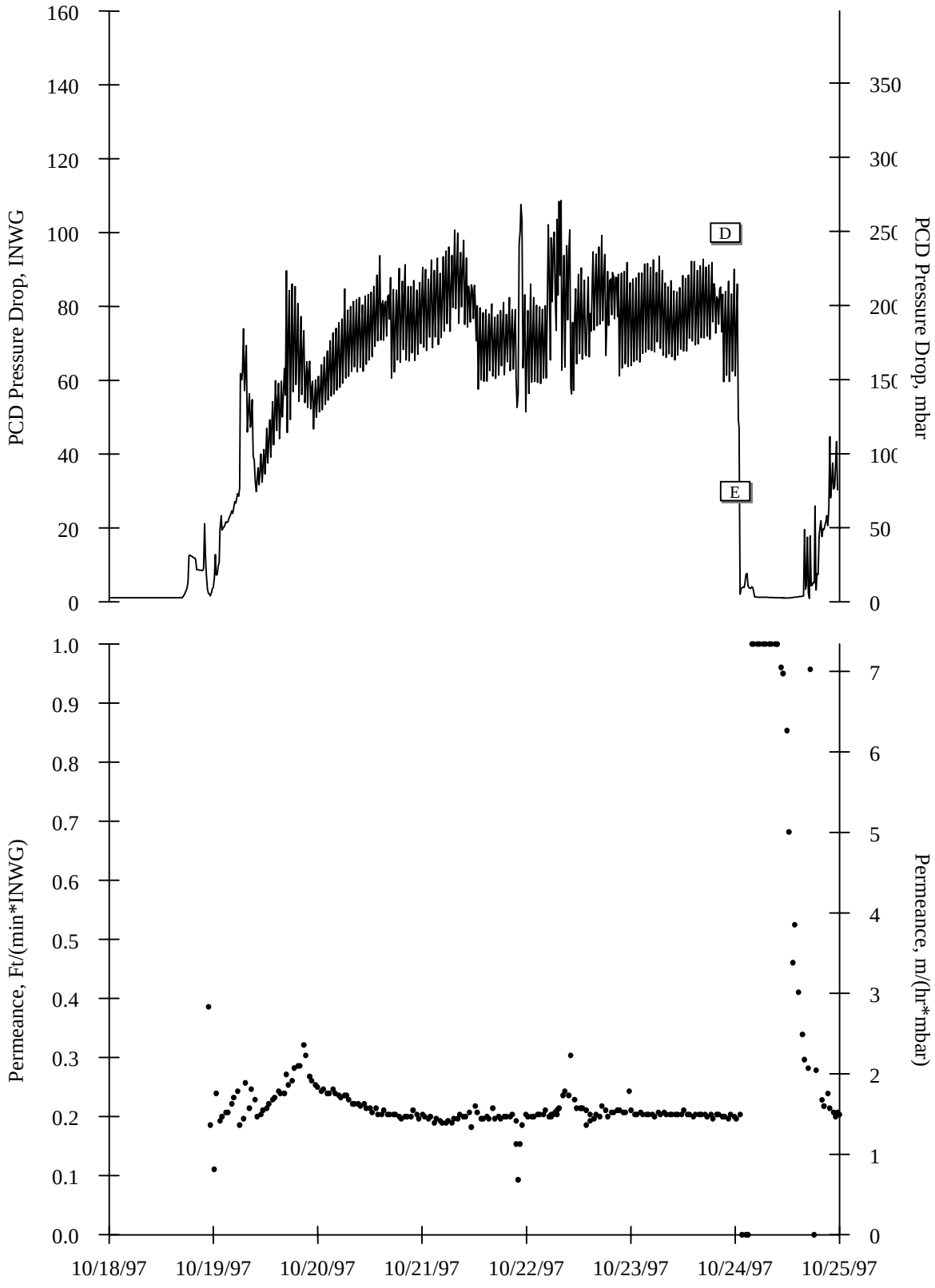


Figure 3.20.1-3 TC01F Pressure Drop and Permeance for October 18 Through 25

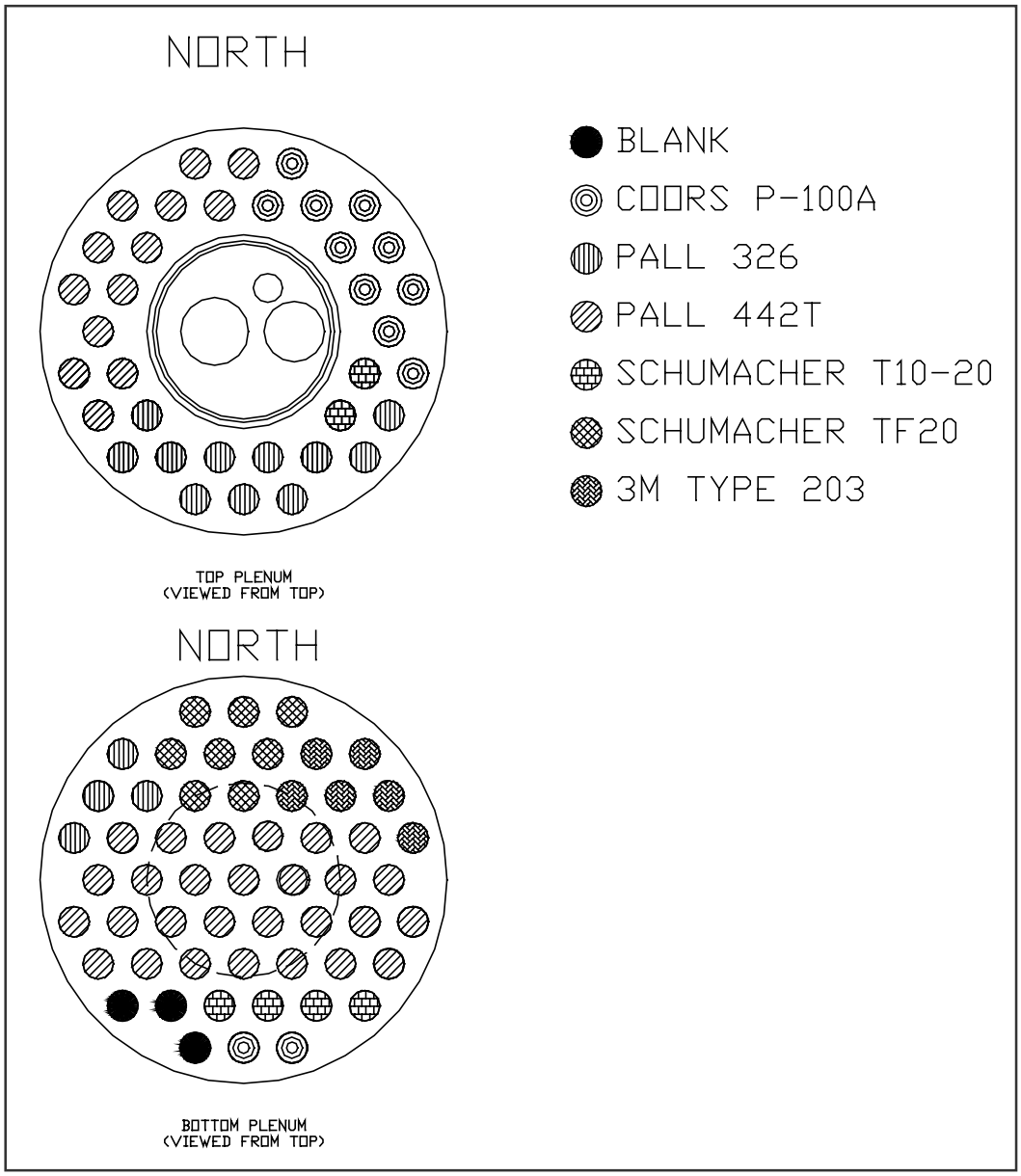


Figure 3.20.1-4 Filter Element Layout for TC01F (Layout No. 5)

3.20.2 Test Objectives

This test segment was a continuation of the 1,000-hour test run TC01. The main objective for the PCD was to obtain 1,000 hours exposure time for the filter elements above 1,350°F (732.2°C).

3.20.3 Observations/Events

A. Test Started–October 18 at 21:50. The main air compressor (MAC) was started late on October 18, 1997, to begin TC01F.

B. Coal Feeder Tripped–October 21 at 21:45. The tubing to the piston actuator to close the top spheri valve on the coal feeder (FD0210) was loose and leaking. The tubing was reconnected and the valve began functioning normally.

C. Spheri Valve Seal Leak–October 22 at 17:40. The o-ring seal on FD0520 bottom spheri valve was leaking nitrogen. The valve on the nitrogen header was fluctuating between closed and fully open. The leaking o-ring recovered and the run continued.

D. Spheri Valve Seal Failure–October 23 at 21:45. The o-ring on FD0520 began leaking again and forced the end of the run.

E. Test Ended–October 24 at 00:00.

3.20.4 Run Outcome

PCD Ash Removal System

Take down of the middle spheri valve showed the to o-ring to have been damaged. Whether or not it was damaged during installation could not be determined during the inspection, but it was confirmed as the cause of the leak. The o-ring was replaced and the seal material was replaced with neoprene. The temperature limit of the neoprene is only 212°F (100°C) so the screw cooler had to maintain proper cooling in order to avoid damaging the seal material. Previously, the silicone seals were extruding and wearing excessively from the additional friction with the dome valve. In tests conducted on site by Southern Company Services and Clyde Pneumatic Conveying (manufacturer of FD0520) employees, silicone was shown to extrude at ambient temperatures and only 200 psig(13.8 bar,g). Neoprene showed no extrusion at ambient temperature and 200 psig (13.8 bar,g). Additionally, as recommended by Clyde Pneumatic Conveying, the seal pressures were reduced to maintain the seal pressure approximately 30 psi (~2 bar) above system pressure. The pressure to the seals was reduced to 250 psig (17.2 bar,g). This should aid in avoiding extrusion. A detailed report for FD0520 can be found in section 3.30.

Westinghouse PCD

The plenum assembly was not pulled. No filter element failures were suspected of failure during the run; however, two filter elements were suspected to have failed during run TC01B.

3.21 PCD OPERATION DURING TEST RUN TC01G

3.21.1 Run Summary

Test campaign TC01G was started late in the evening on October 24, 1997, to continue the 1,000-hour test campaign. The seals in the spent fines transport system FD0520 spheri valves were replaced with neoprene in hopes of avoiding past complications during TC01G.

Startup of the unit was completed successfully with only minor complications. The temperature of the particulate control device (PCD) attained 1,350°F (732.2°C) late in the afternoon of October 25, 1997. This temperature was maintained with only minor complications through late in the day of October 26, 1997, when coal feed was lost due to problems with the coal feeder (FD0210). Coal feed was intermittent for the next full day due to continued problems with the feeder system. These problems were resolved and the run was uninterrupted for approximately 5 full days before the coal feed problems resurfaced on November 1, 1997. While trying to repair FD0210 on November 2, 1997, a large amount of coal was inadvertently fed to the reactor causing a severe thermal event through the particulate control device (PCD). It became apparent that elements had failed since the spent fines transport system plugged immediately after the thermal event. The run was ended to inspect the damage to the filter elements.

Table 3.21.1-1

TC01G Run Statistics

Start Time:	10/24/97 18:50
End Time:	11/2/97 22:10
Coal Type:	Calumet Alabama Bituminous
Hours on Coal:	174.75
Sorbent Type:	Plum Run Dolomite
Number of Filter Elements:	88 (two elements suspected of failure)
Filter Element Layout No.:	5 (Figure 3.21.1 through -8)
Filtration Area:	240.7 ft^2 (22.4 m^2)
Pulse Valve Open Time:	0.4 seconds
Pulse Time Trigger:	40 minutes
Pulse Pressure:	440 to 600 psig (30.3 to 41.4 bar,g)
Pulse DP Trigger:	112 inWG (278.7 mbar,g)

Table 3.21-2

TC01G Major Events

Event	Description	Date at Time
A	Test Started	October 24 at 18:50
B	Lost PI System	October 26 at 02:00
C	Lost Coal Feed	October 26 at 14:00
D	Lost Coal Feed	November 1 at 22:10
E	Unexpected Coal Transfer and Candle Failure	November 2 at 13:10
F	Test Ended	November 2 at 22:10

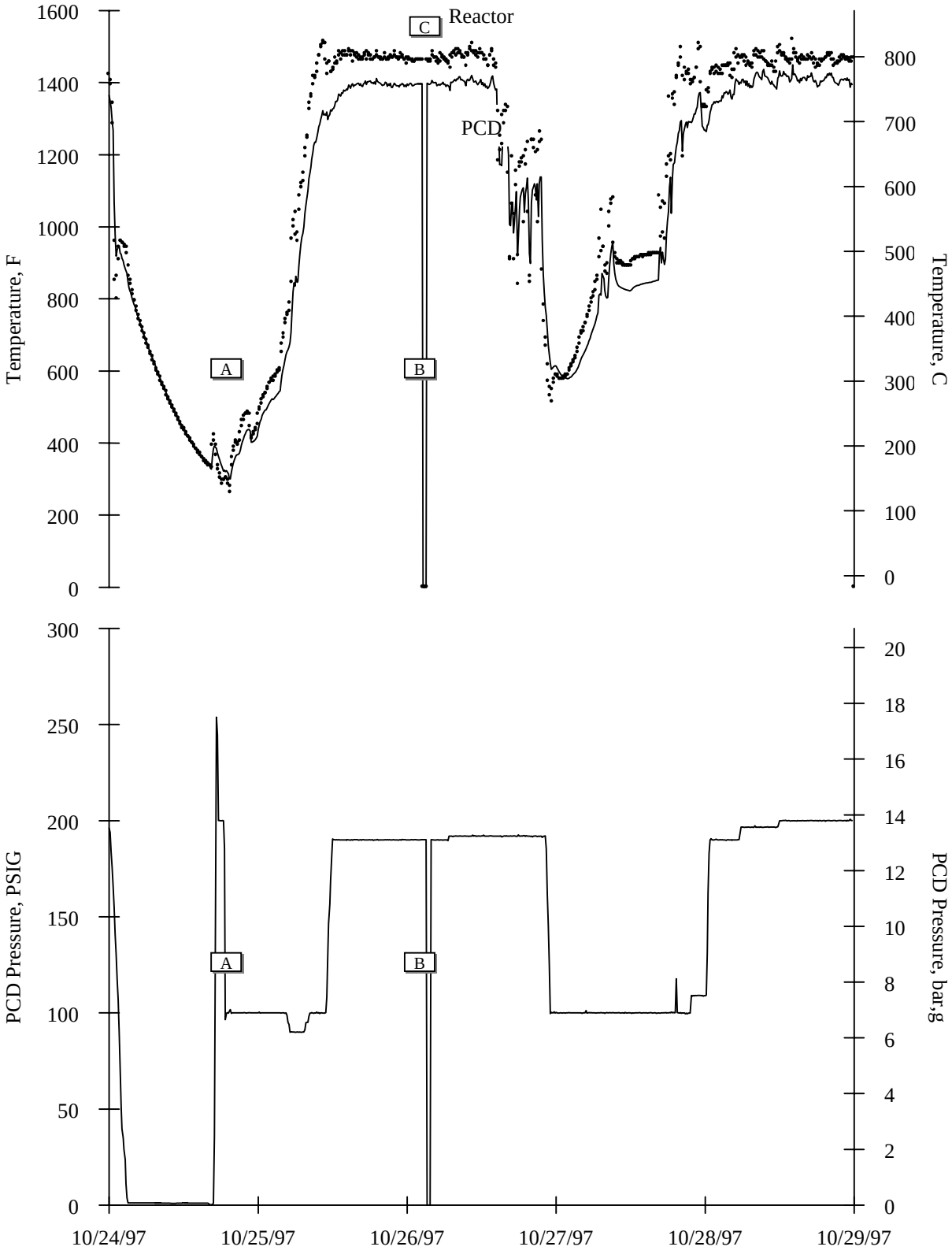


Figure 3.21.1-1 TC01G Temperature and Pressure for October 24 Through 29

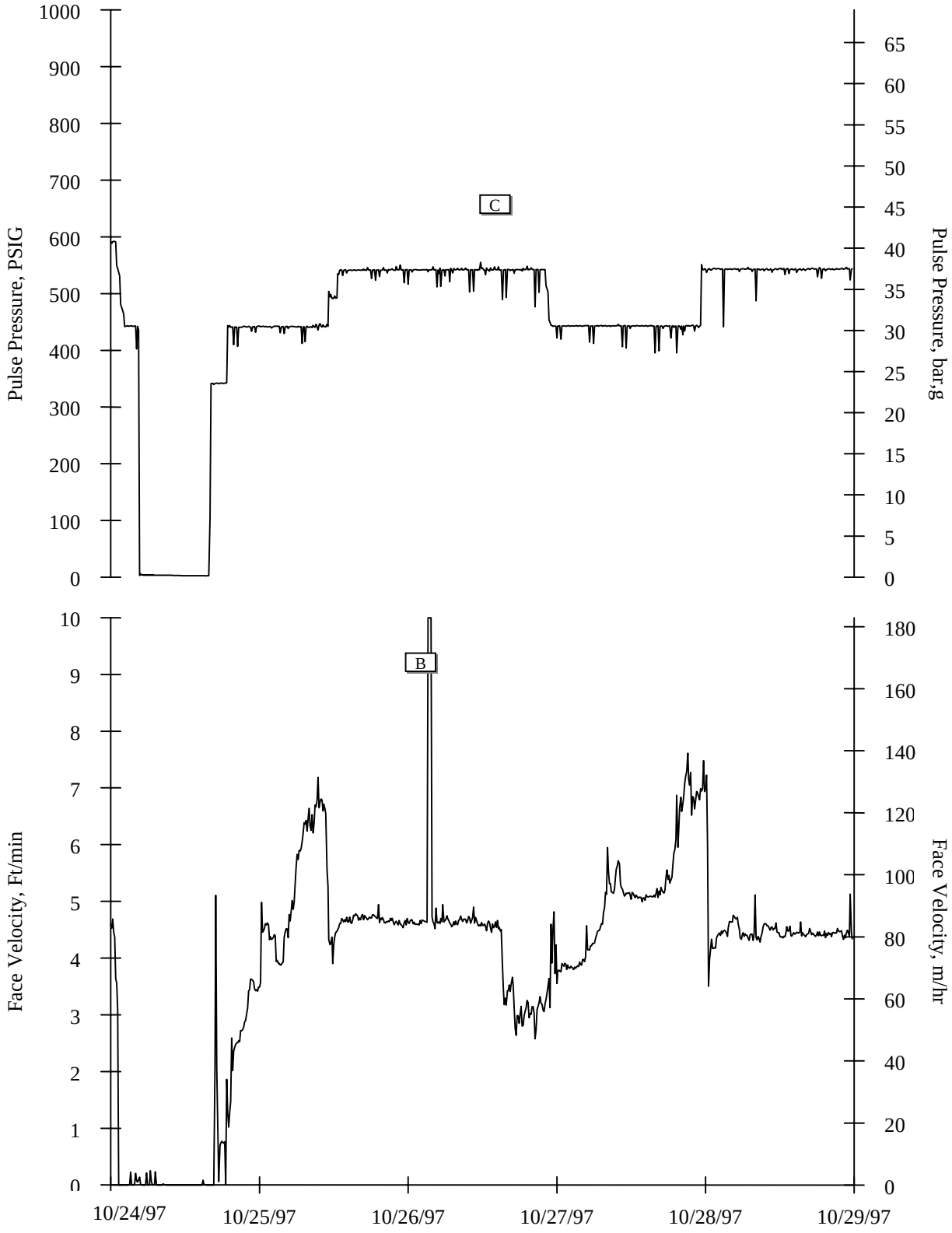


Figure 3.21.1-2 TC01G Pulse Pressure and Face Velocity for October 24 Through 29

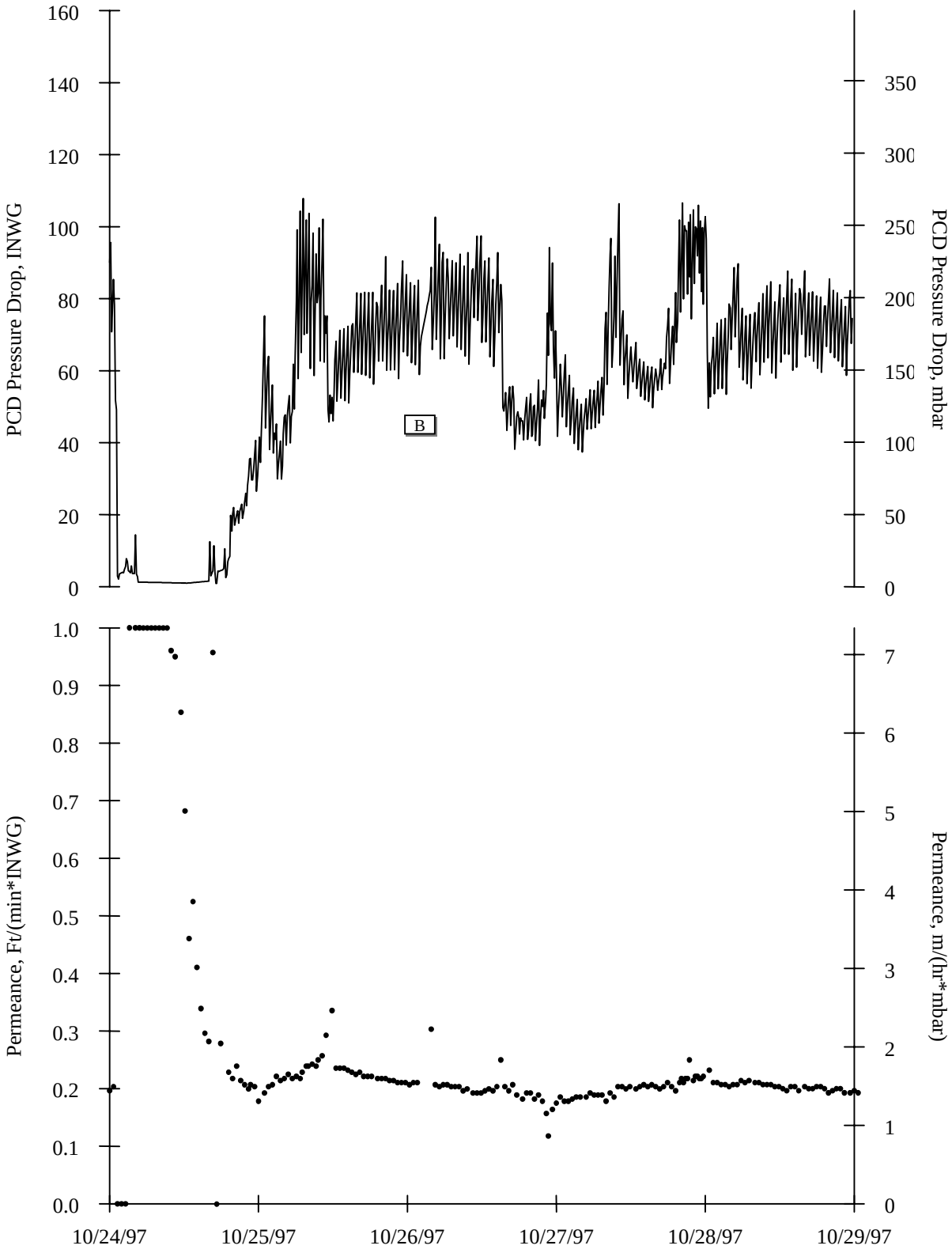


Figure 3.21.1-3 TC01G Pressure Drop and Permeance for October 24 Through 29

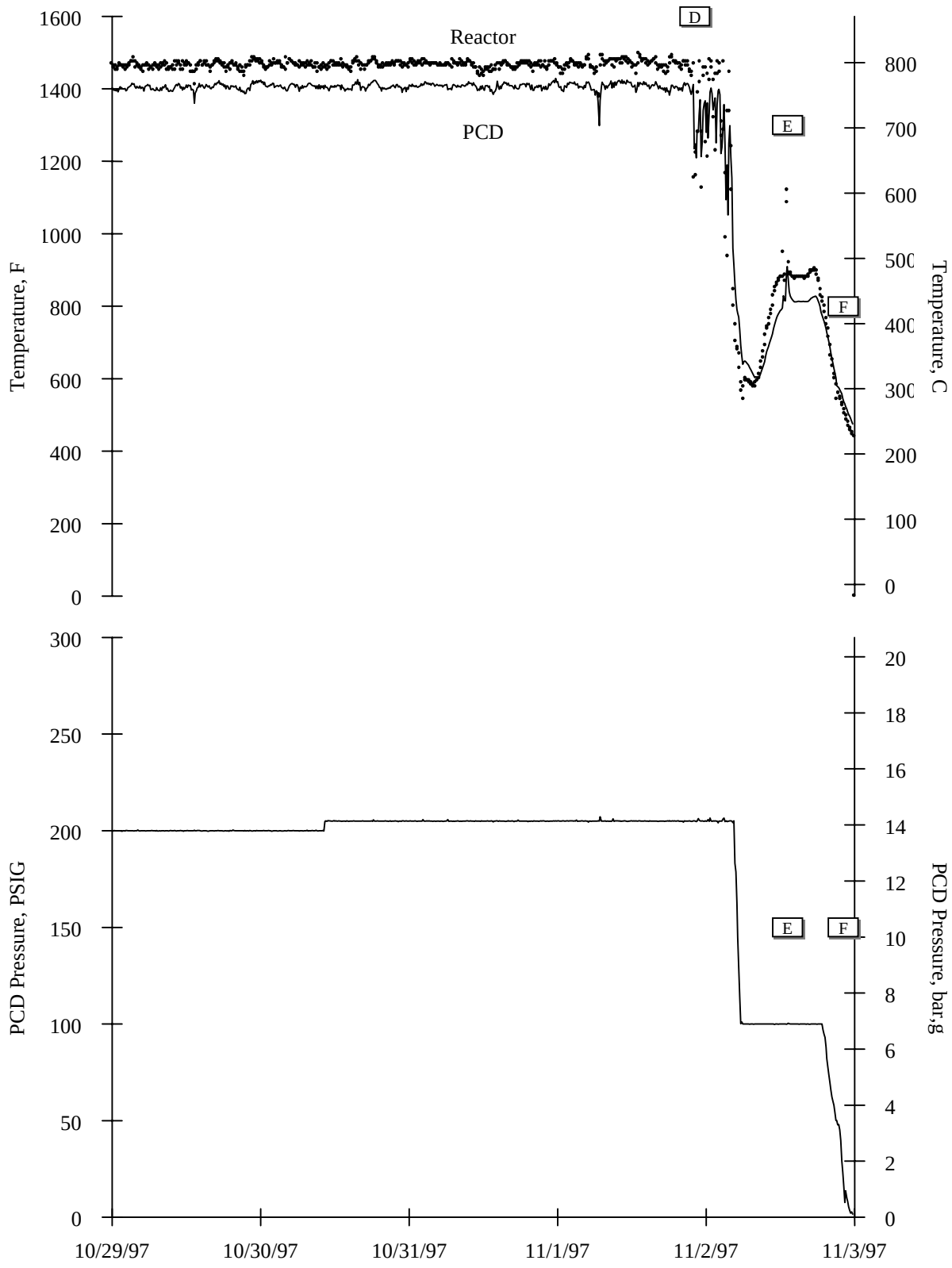


Figure 3.21.1-4 TC01G Temperature and Pressure for October 29 Through November 3

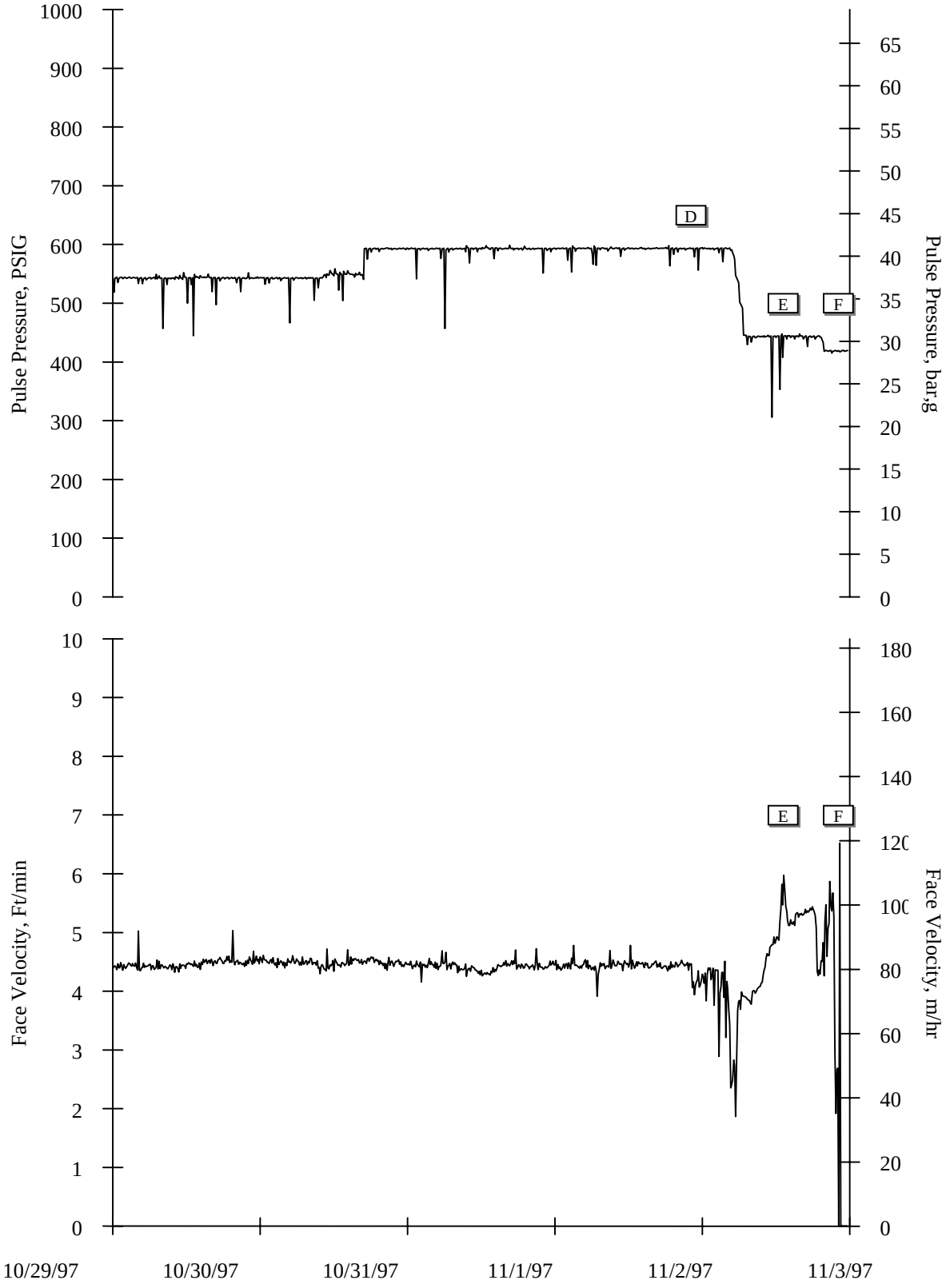


Figure 3.21.1-5 TC01G Pulse Pressure and Face Velocity for October 29 Through November 3

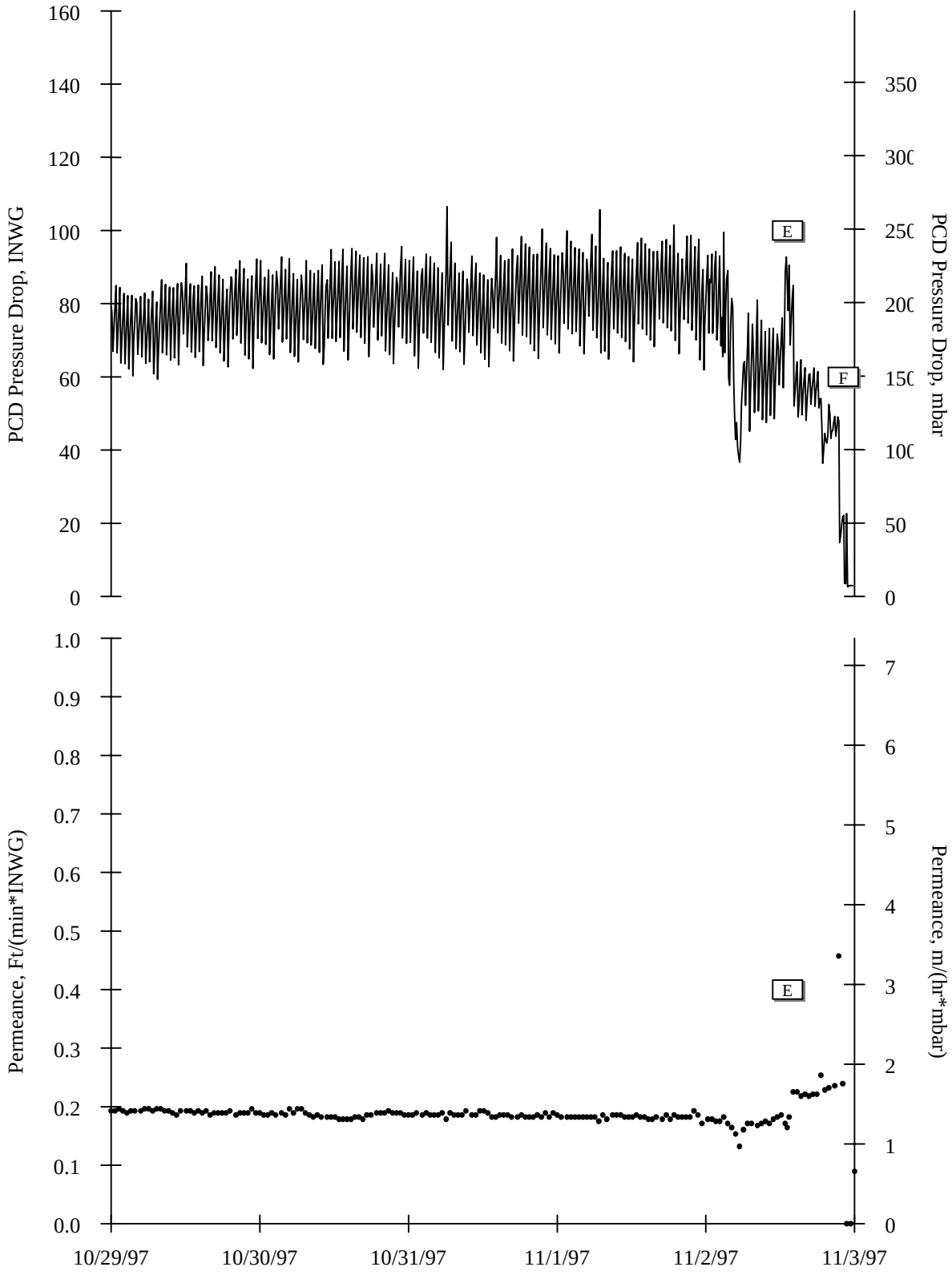


Figure 3.21.1-6 TC01G Pressure Drop and Permeance for October 29 Through November 3

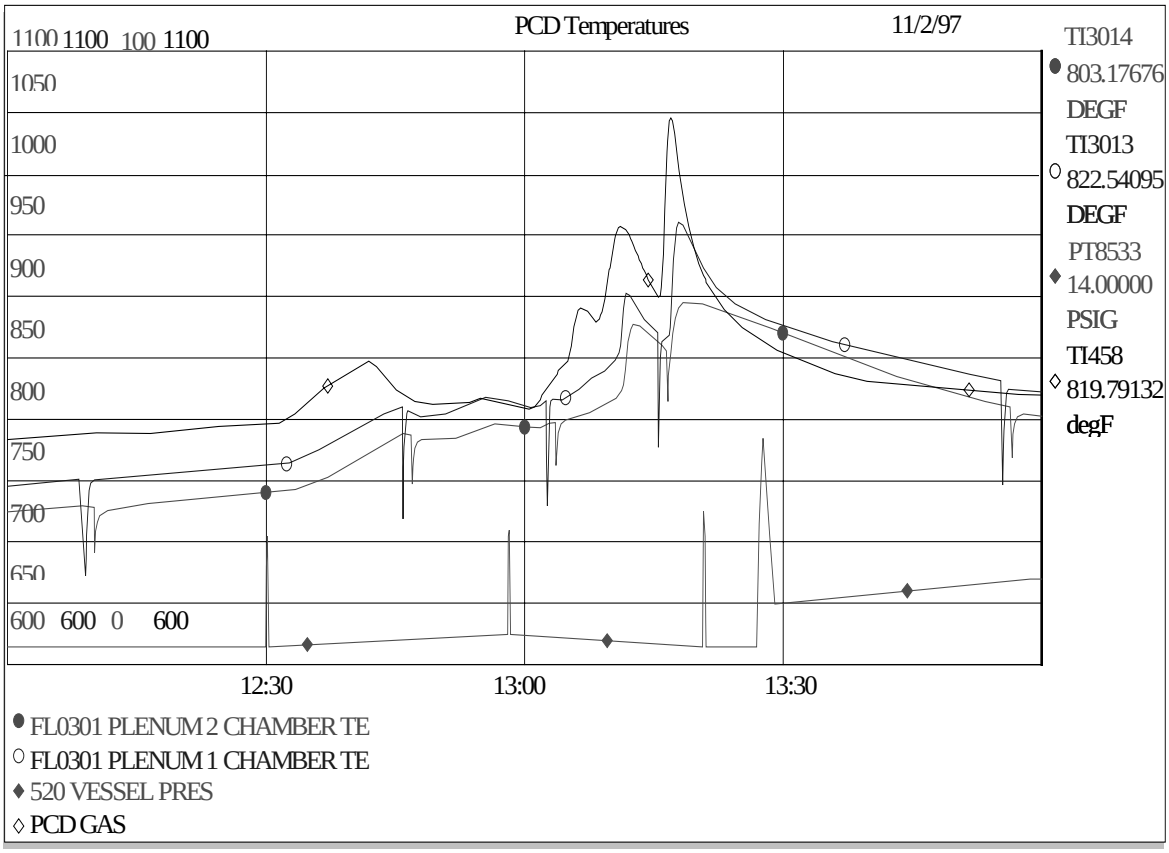


Figure 3.21.1-7 Thermal Event on November 2, 1997

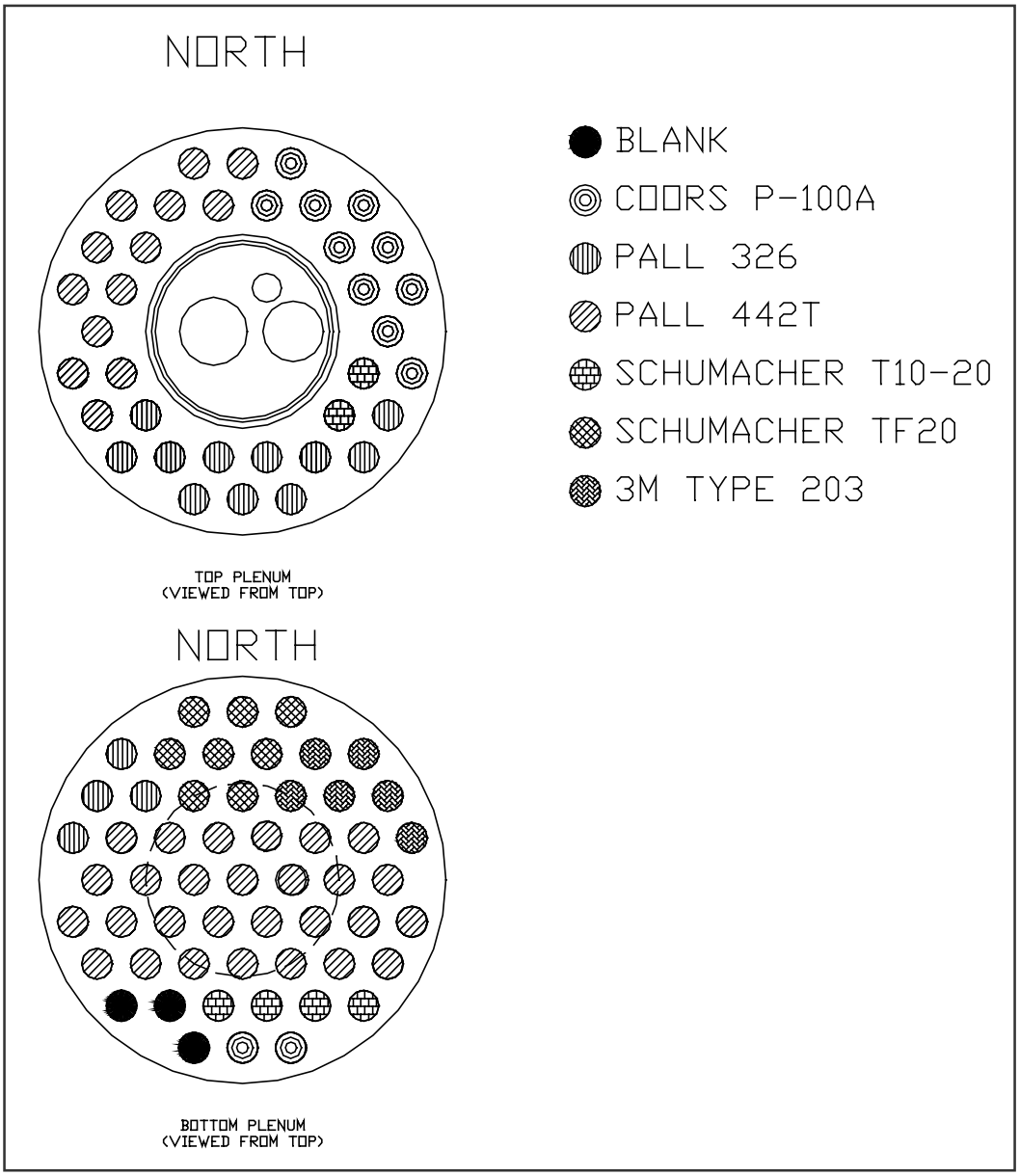


Figure 3.21.1-8 Filter Element Layout for TC01G (Layout No. 5)

3.21.2 Test Objectives

This test segment was a continuation of the 1,000-hour test run (TC01). The main objective for the PCD was to obtain 1,000 hours of exposure time for the filter elements at the temperature above 1,350°F (732.2°C).

3.21.3 Observations/Events

A. Test Started–October 24 at 18:50. The main air compressor (MAC) was started late on October 24, 1997, to begin TC01G.

B. Lost PI System–October 26 at 02:00. The clocks were set back 1 hour due the end of daylight savings time. This caused the PI system to malfunction, but it was recovered shortly thereafter.

C. Lost Coal Feed–October 26 at 14:00. This was the first in a series of problems with the coal feed unit (FD0210).

D. Lost Coal Feed–November 1 at 22:10.

E. Unexpected Coal Transfer and Element Failure–November 2 at 13:10. While attempting to repair the problems with FD0210, approximately 400 lb (181.4 kg) of coal was transferred to the transport reactor causing a severe thermal event in the PCD. The PCD experienced both a rapid rise and decline in temperature. All of the Coors P100A elements failed as well as one 3M Type 203 filter. Several minutes after the thermal event the fines transport system (FD0520) plugged with element pieces indicating that elements had failed. This forced the run to end.

F. Test Ended–November 2 at 22:10.

3.21.4 Run Outcome

Element Failure

The thermal event in the PCD caused a significant element failure. Figure 3.21-7 shows the temperatures experienced by the PCD. As many as 12 Coors P100A elements failed as a result of the thermal shock. Additionally, two 3M Type 203 elements and three Schumacher elements also failed either directly or indirectly from the thermal episode. It is speculated that some of the other elements failed after being struck by Coors P100A elements falling from the top plenum. Additionally, others failed during the removal and cleaning process. On the whole, the majority of the failures involved Coors P100A elements. The exact reason that the other elements failed has not been conclusively proven. At the time this report was drafted the failure mechanism was still under investigation. A detailed report of this failure episode can be found in the Inspection Report for TC01G (section 3.22).

FD0520

The neoprene seal was removed and inspected after this run was finished. No noticeable wear was present. The seal saw only 471 cycles with one cycle being defined as 1) starting with no pressure in the seal, 2) inflating the seal, and 3) deflating the seal. This was an improvement over the previous runs with silicone. Additional detail about the spent fines transport system, including FD0520, can be found in section 3.28.

FD0502

The shaft of FD0502 was worn as well as the ceramic bushing at the ash inlet end. The housing also showed visible signs of wear from the flights. It is suspected that the wear of the bushing and shaft allowed the flights to contact the housing. The shaft was reworked and the bushing was replaced. The housing was not seriously damaged enough to compromise its structural integrity. A detailed report of FD0502 can be found in section 3.28.

3.22 INSPECTION REPORT FOR TC01G

3.22.1 Run Summary

Test campaign TC01G was suspended on November 2, 1997, after numerous pieces of ceramic filter elements were found in the PCD fines transport system. Since several elements appeared to be involved the transport reactor (RX0201) was shut down and the PCD was allowed to cool to permit removal of the internals. On November 5, the PCD head and the attached tubesheets and elements were lifted from the vessel and placed into the maintenance bay for inspection. The purposes of this removal were to inspect and replace the damaged and broken elements after the failure event of November 2, 1997, during the TC01G run. The inspection revealed that all 12 of the Coors P100A elements had been completely broken off near the flanged end of the elements. One of the 3-M elements had been broken off, apparently, when it was struck by a falling Coors P100A element. All of the other elements were intact, although a closer inspection revealed a fraying of one of the 3M elements. Some of the cracked elements that were intact after the shutdown failed during removal from the tubesheet. All of the Pall elements survived intact with no failures during operation or removal. The Schumacher filters were removed intact, but two failed later during handling.

3.22.2 Thermal Event

While attempting to repair the problems with FD0210 approximately 400 lb (181.4 kg) of coal was transferred to the transport reactor causing a severe thermal event in the PCD. The PCD experienced both a rapid rise and decline in temperature (see figure 3.22.2-1). Several minutes after the thermal event the fines transport system (FD0520) plugged with element pieces, indicating that elements had failed.

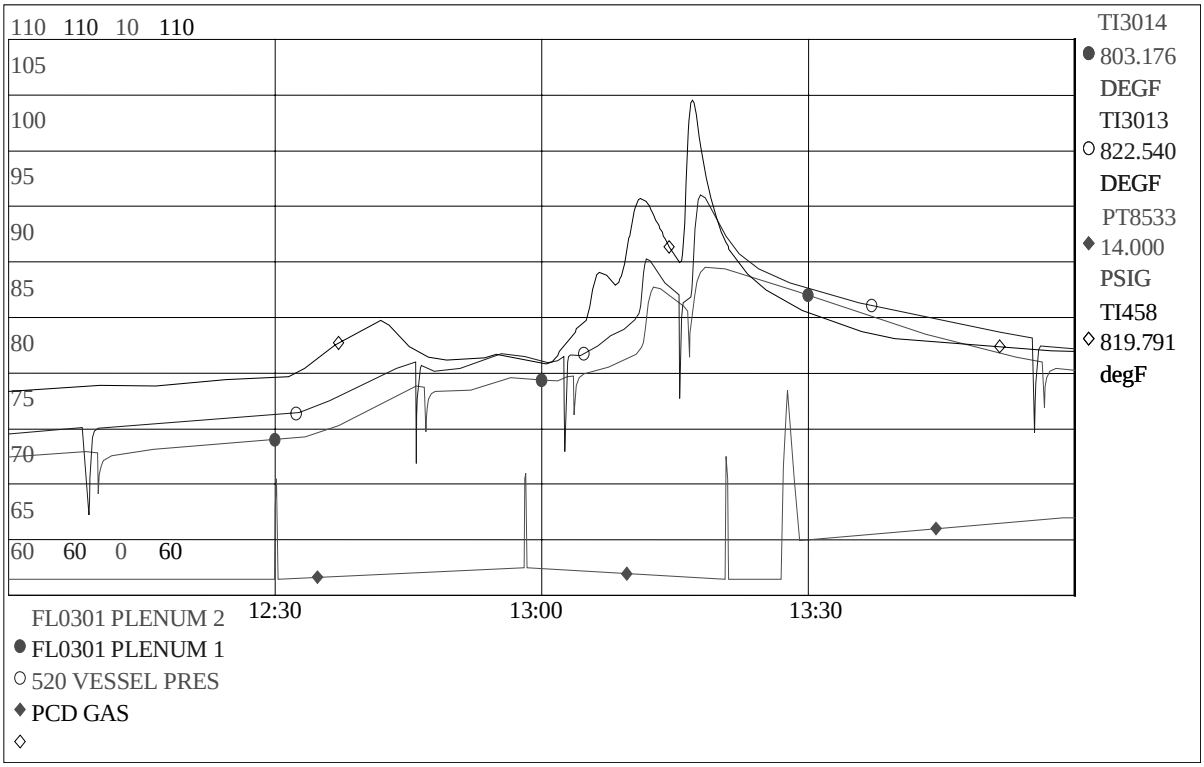


Figure 3.22.2-1 Thermal Event on November 2, 1997

3.22.3 PCD Inspection and Dustcake Observations

It was found that 10 Coors P100A filter elements had failed during operation on the top plenum. Two Coors P100A and one 3M type 203 failed in the bottom plenum during operation and one 3M type 203 showed signs that it had been damaged during operation. Additionally, on the bottom plenum one Schumacher T10-20 and two Schumacher TF20s failed during the removal and cleaning process. The damaged elements were removed and inspected. Several surrounding elements were also removed, cleaned, and inspected. Fail-safes were also examined.

To reference the locations of the failed and damaged elements in the plenum assembly, an element layout showing the damaged elements and a location map are shown in figures 3.22.3-1 and -2, respectively. Those elements numbered with a preceding letter T were on the top plenum and those with letter B were on the bottom plenum.

Figure 3.22.3-3 shows the upper plenum prior to removal of the broken elements. Figure 3.22.3-4 shows a close-up of the broken elements. Many of the elements showed additional cracking in a "spider web" fashion. Most of the breaks were of a V shape indicating that the failure was a result of the joining of the two cracks. Figure 3.22.3-5 shows a close-up of the V break. A representative from Coors was present during the removal process. Samples of the elements were taken for further study.

Additional elements failed during the removal process. One failed while secured to the plenum and simply cracked and fell free. This failure event prompted the removal of the additional elements for damage inspection. Consequently, two failed during transit from the structure to the cleaning shop or while cleaning. Figure 3.22.3-5 shows the test elements that were removed.

Compared to the residual dustcake from the July inspection the residual dustcake observed in November was relatively thin, with the measured cake thickness varying from 0.02 to 0.1 in. The dustcake was so thin that the surface texture of the 3M elements was immediately apparent through the cake. Many of the cracks in the Coors P100A elements were also apparent through the dustcake. The dustcake was again light tan in color with a speckled surface that resembled the surface of a textured ceiling. The swirl pattern that was evident on the PCD shroud in July after CCT6 was again evident during the November inspection, but there was no evidence of heavier deposits on the windward side of the elements. The absence of the windward deposits suggests that the ash particles that were entering the PCD in September and October were small enough to flow around the elements without impacting on the windward side. The effects of this inertial impaction were obvious during the July inspection, presumably because relatively large particles were being carried out of the transport reactor system prior to the July shutdown. This difference in particle size reflects the successes of efforts to eliminate upsets in the cyclone dipleg and reduce particulate carryover from the transport reactor system.

The affected fail-safes were also removed and the pressure drop was measured. Figure 3.22.3-6 details the significant pressure drops of the fail-safes tested. As expected the fail-safes showed

visible ash accumulation on the inlet screens. The graph shows that B9 and B10 experience a higher pressure drop, meaning each had been exposed to more ash. Such high-pressure drops lead to the assumption that these elements had broken earlier than the November 2, 1997, episode. Of more critical concern was the pressure drop for B11, B12, and B29. These had been placed behind blanks. Such high-pressure drop and visible ash accumulation lead to the speculation that the blanks were leaking.

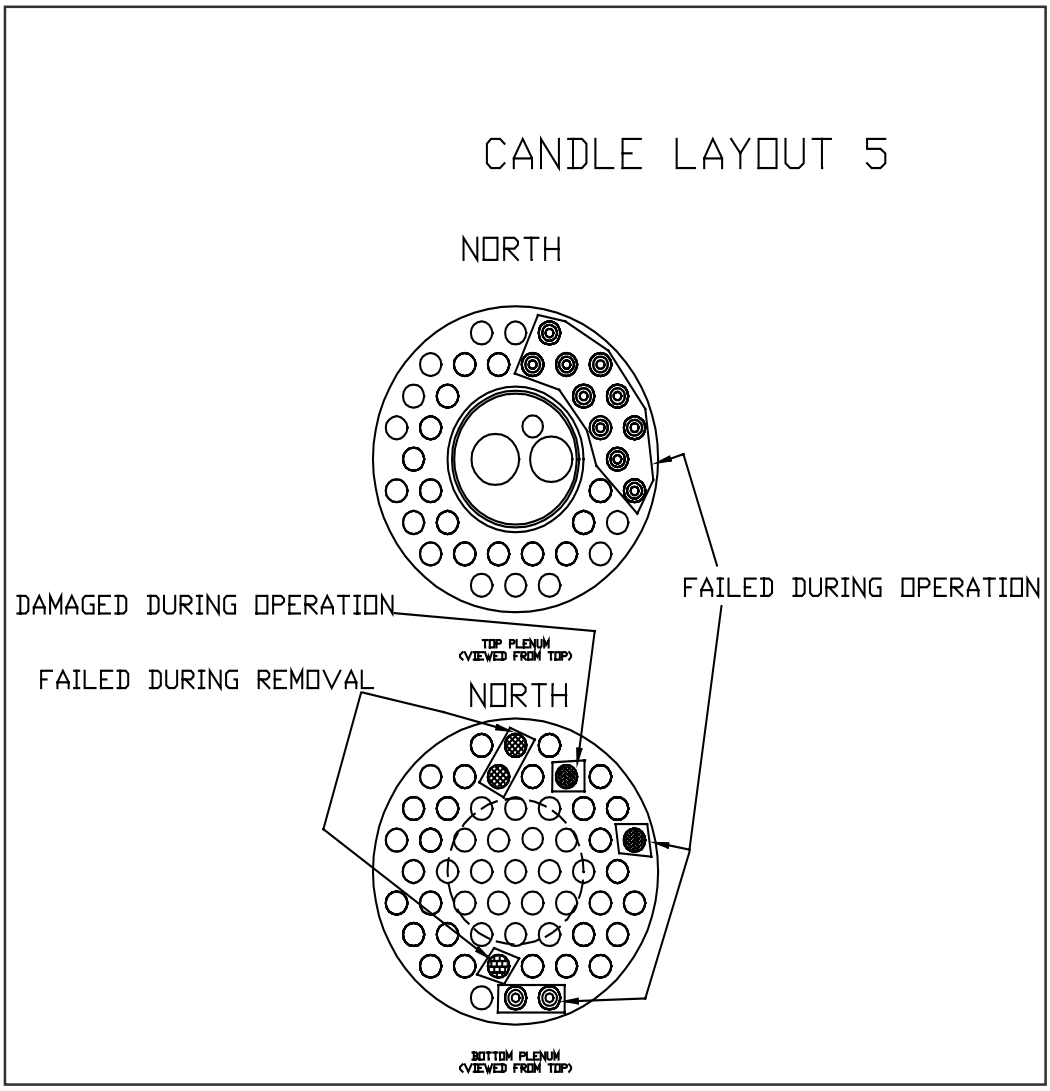


Figure 3.22.3-1 Damaged Elements on November 2, 1997

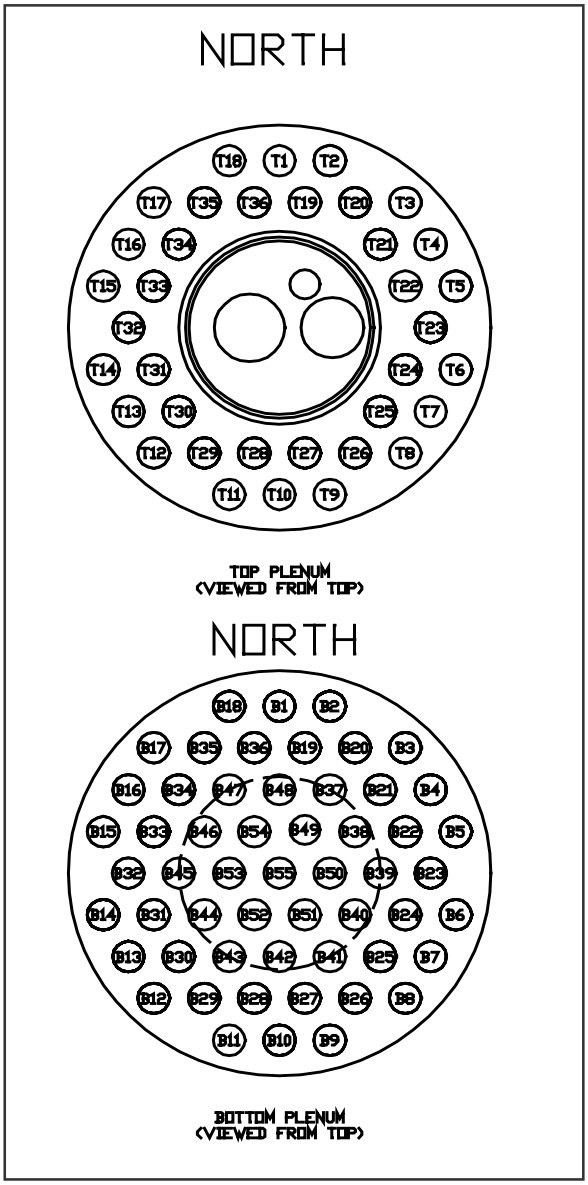


Figure 3.22.3-2 Element Layout

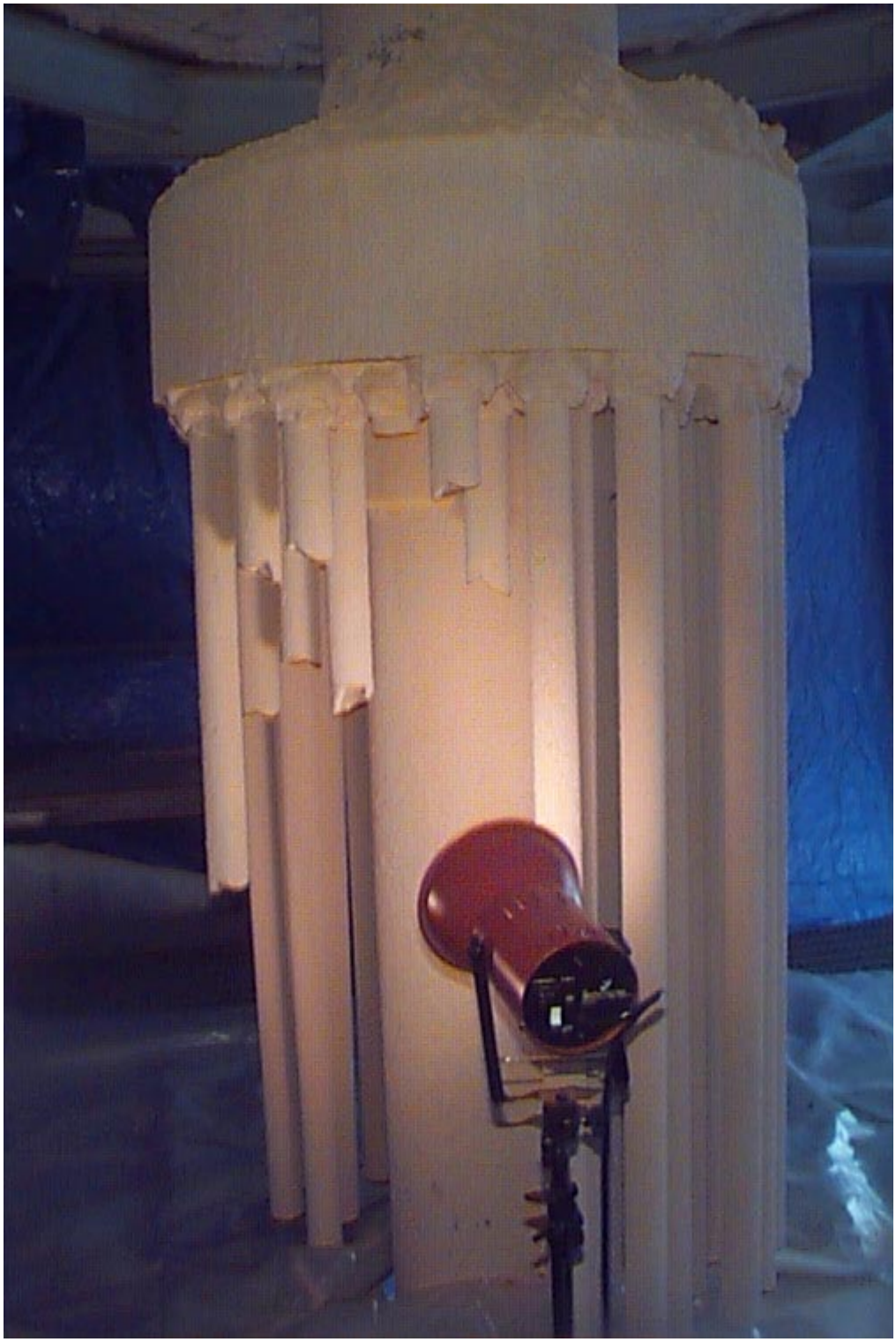


Figure 3.22.3-3 Top Plenum Broken Candles

Figure 3.22.3-4 Top Plenum Broken Candle Close-Up

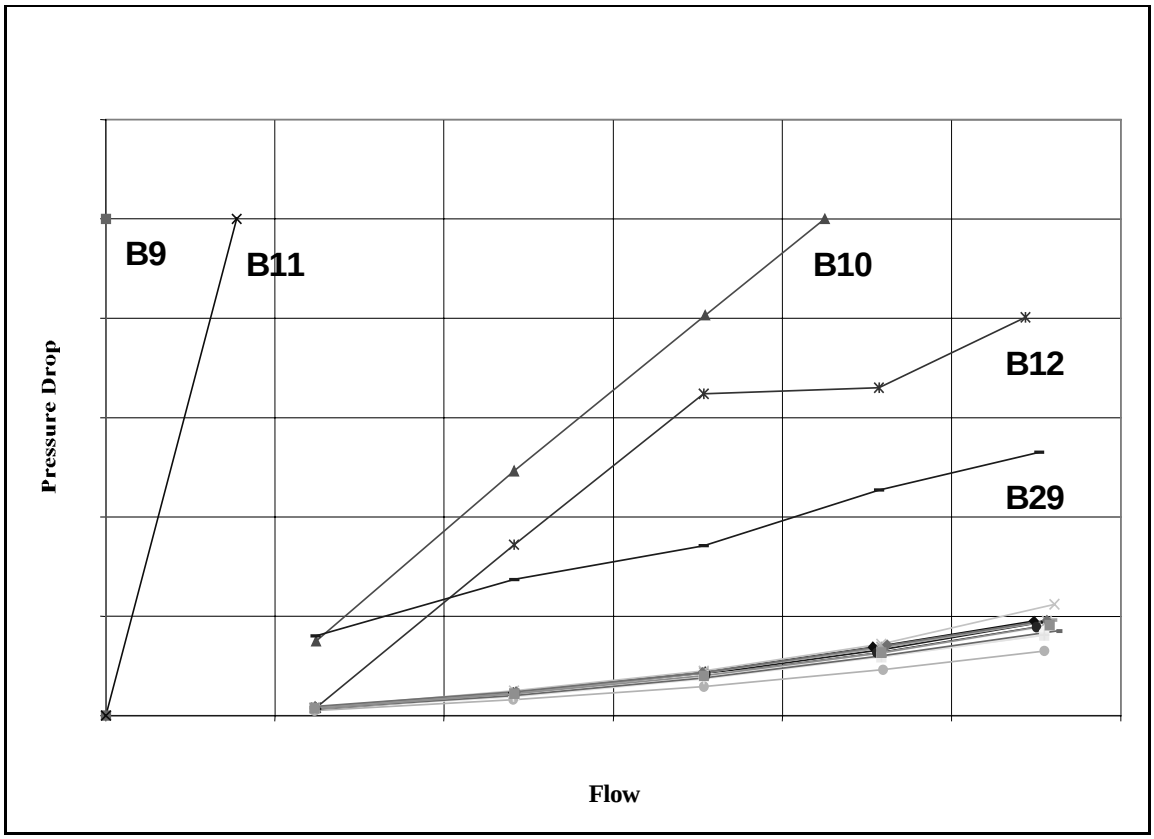


Figure 3.22.3-5 Pressure Drop in Fail-safes after TC01G Run

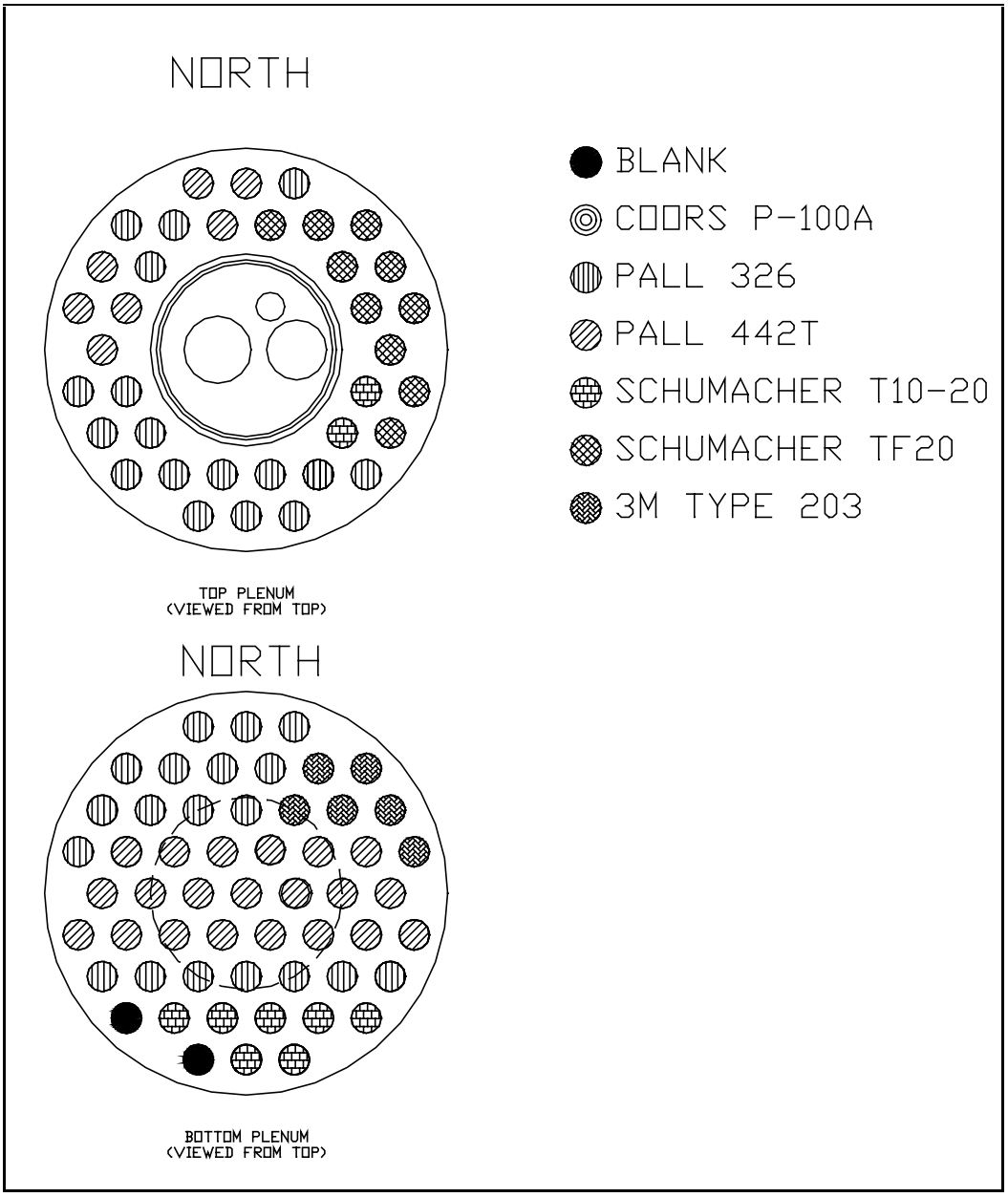


Figure 3.22.3-6 Filter Element Layout for TC01H (Layout No. 6) (See also Figure 3.23.1-7)

3.22.4 Inspection Outcome

Figure 3.22.3-4 shows the test elements that were removed and reinstalled for run TC01H. The failure of the two Schumacher TF20 prompted the removal of all of these TF20 elements from the bottom plenum. These were the elements immediately surrounding the two that failed during removal. Due to the past failures of Coors P100A elements there were none reinstalled for the next run. Additionally, three Pall 442Ts and three Pall 326s were removed from the top plenum for analysis. All other elements on the top plenum were reinstalled and the Coors P100A were replaced with Schumacher TF20s and one Pall 326. Figure 3.22.3-6 shows the final arrangement as installed for TC01H.

3.23 PCD OPERATION DURING TEST RUN TC01H

3.23.1 Run Summary

Test campaign TC01H was started late in the evening on November 16, 1997, to continue the 1,000-hour test campaign.

Start-up of the unit was completed successfully with only minor complications. The temperature of the particulate control device (PCD) attained 1,350°F (732.2°C) early in the morning of November 18, 1997. Shortly after, however, a malfunction in the back-pulse system upset the dipleg and sent a large mass of solids to the PCD. It took over 8 hours to remove all the solids from the PCD before coal feed could be resumed. This length of time was primarily because of the neoprene seals temperature limitations in the spent fines transport system (FD0520). The problem with the back-pulse system was traced to a malfunctioning solenoid valve that allowed the back-pulse valve to remain open. Bridging in the coal feed system (FD0210) hindered regulated coal feeds to the transport reactor (RX0201). Subsequently, the temperature in the PCD varied when the coal feeder was experiencing difficulty. A leaking quick dump valve on the lower spheri valve caused the nitrogen header system to lose pressure. Adjustments were made to the position switch that remedied the problem.

Table 3.23.1-1

TC01H Run Statistics

Start Time:	11/16/97 11:55
End Time:	11/23/97 22:27
Coal Type:	Calumet Alabama Bituminous
Hours on Coal:	122.3
Sorbent Type:	Plum Run Dolomite
Number of Filter Elements:	89
Filter Element Layout No.:	6 (figure 3.23-7)
Filtration Area:	249.1 ft^2 (23.1 m^2)
Pulse Valve Open Time:	0.4 seconds
Pulse Time Trigger:	40 minutes
Pulse Pressure:	420 to 530 psig (29 to 36.5 bar,g)
Pulse DP Trigger:	112 inWG (278.7 mbar,g)

Table 3.23.1-2

TC01H Major Events

Event	Description	Date at Time
A	Test Started	November 16 at 11:55
B	Lost PI System	November 17 at 9:40
C	Back-pulse System Malfunction	November 18 at 2:30
D	Coal Feed Resumed	November 18 at 13:33
E	PCD Filling with Ash	November 18 at 20:15
F	Raised Back-pulse Pressure to 500 psig (34.5 bar,g)	November 19 at 8:22
G	Coal Feeder (FD0210) Packing with Fine Coal	November 20 at 4:10
H	Coal Feeder Tripped	November 20 at 8:44
I	Coal Feed Resumed	November 20 at 8:47
J	FD0520 Bottom Spheri Valve Quick Dump Valve Failure; Coal Feeder Tripped	November 21 at 13:16
K	Coal Feed Resumed	November 21 at 13:26
L	Coal Feeder Bridging; Coal Feeder Tripped	November 22 at 16:13
M	Start-up Burner Failure	November 23 at 4:00
N	Main Compressor Off	November 23 at 9:55
O	Replace Start-up Burner	November 23 at 15:00
P	Main Compressor On	November 23 at 16:30
Q	Start-up Burner Failure	November 23 at 21:25
R	Main Compressor Off	November 23 at 22:27

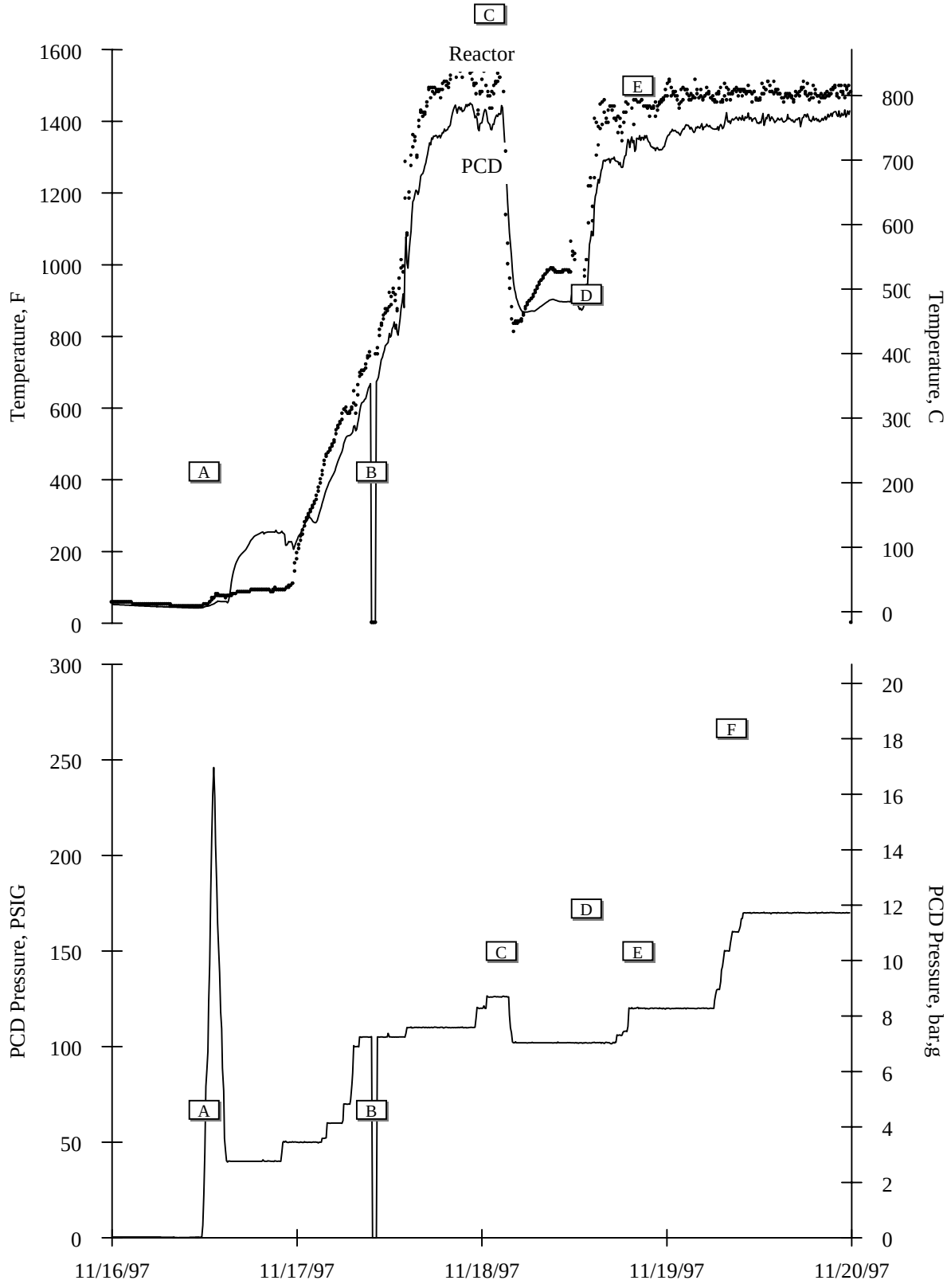


Figure 3.23.1-1 TC01H Temperature and Pressure for November 16 Through 20

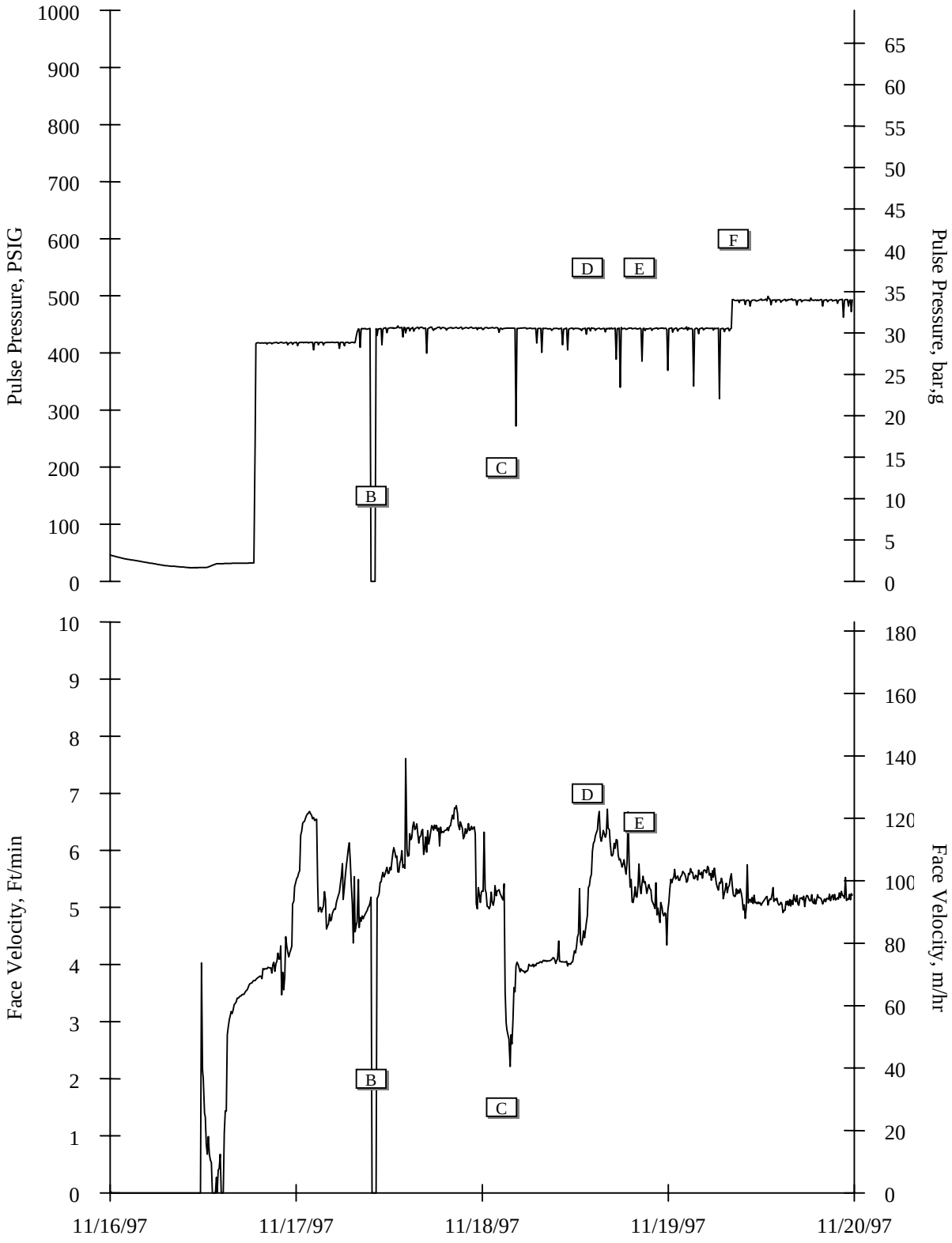


Figure 3.23.1-2 TC01H Pulse Pressure and Face Velocity for November 16 Through 20

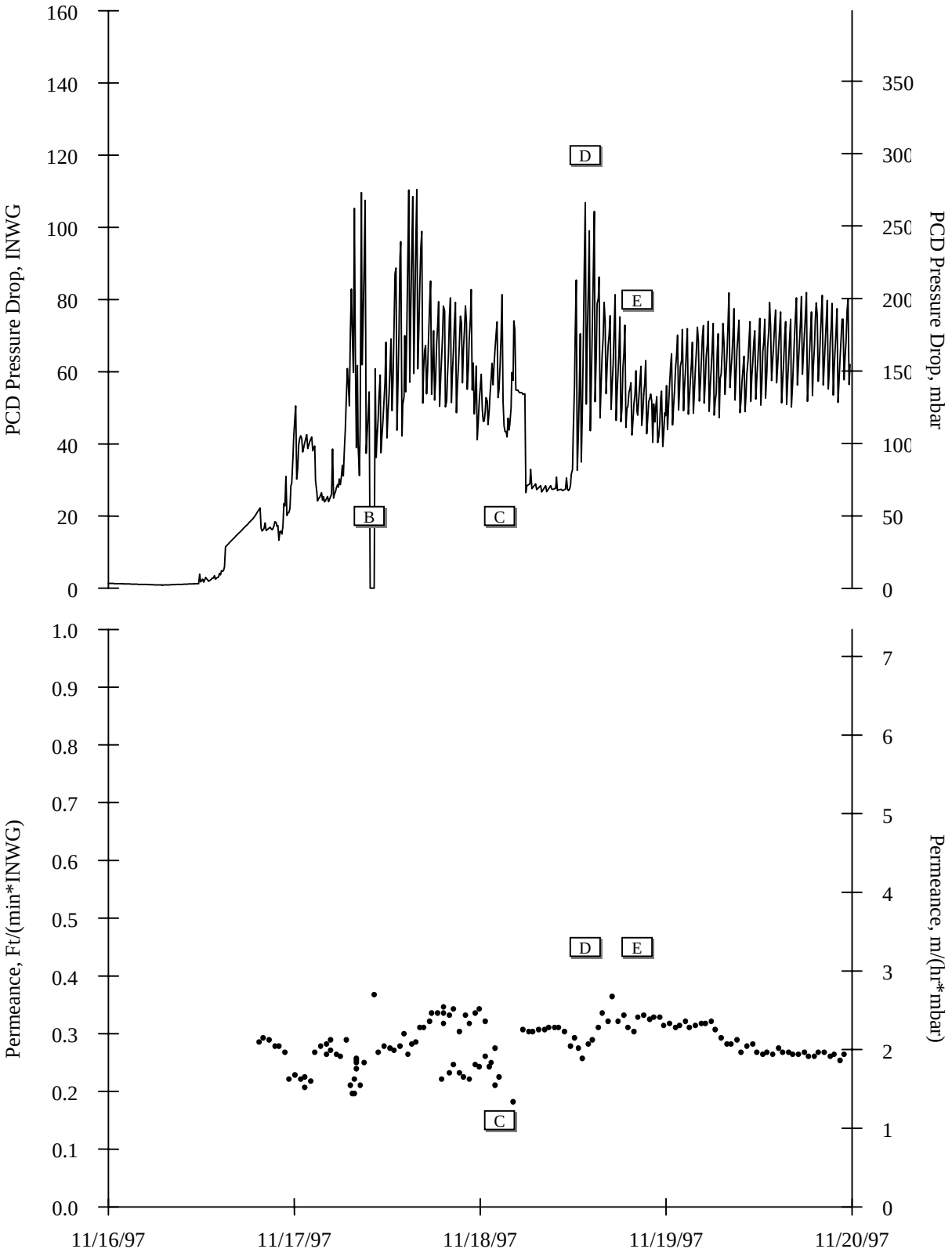


Figure 3.23.1-3 TC01H Pressure Drop and Permeance for November 16 Through 20

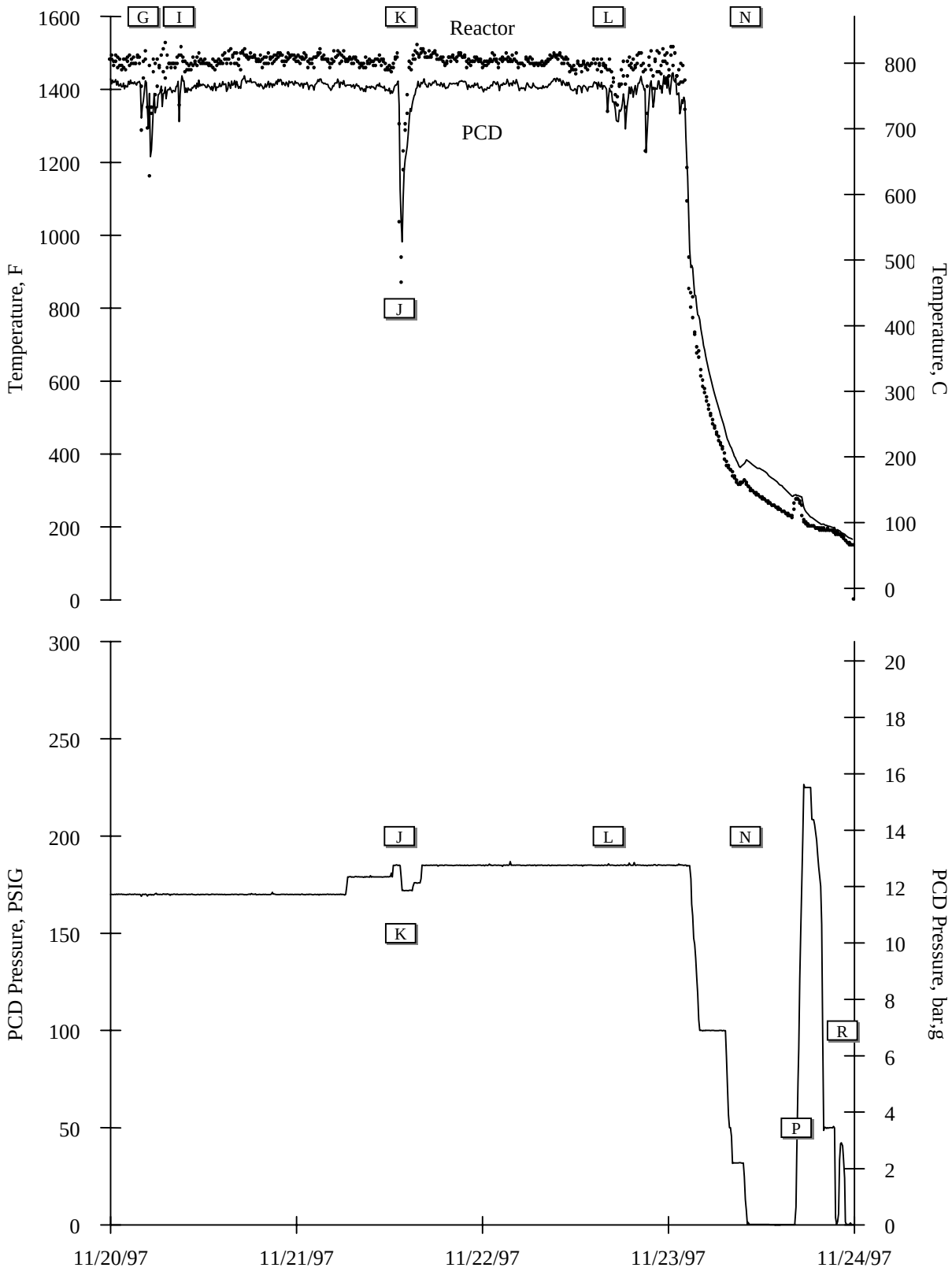


Figure 3.23.1-4 TC01H Temperature and Pressure for November 20 Through 24

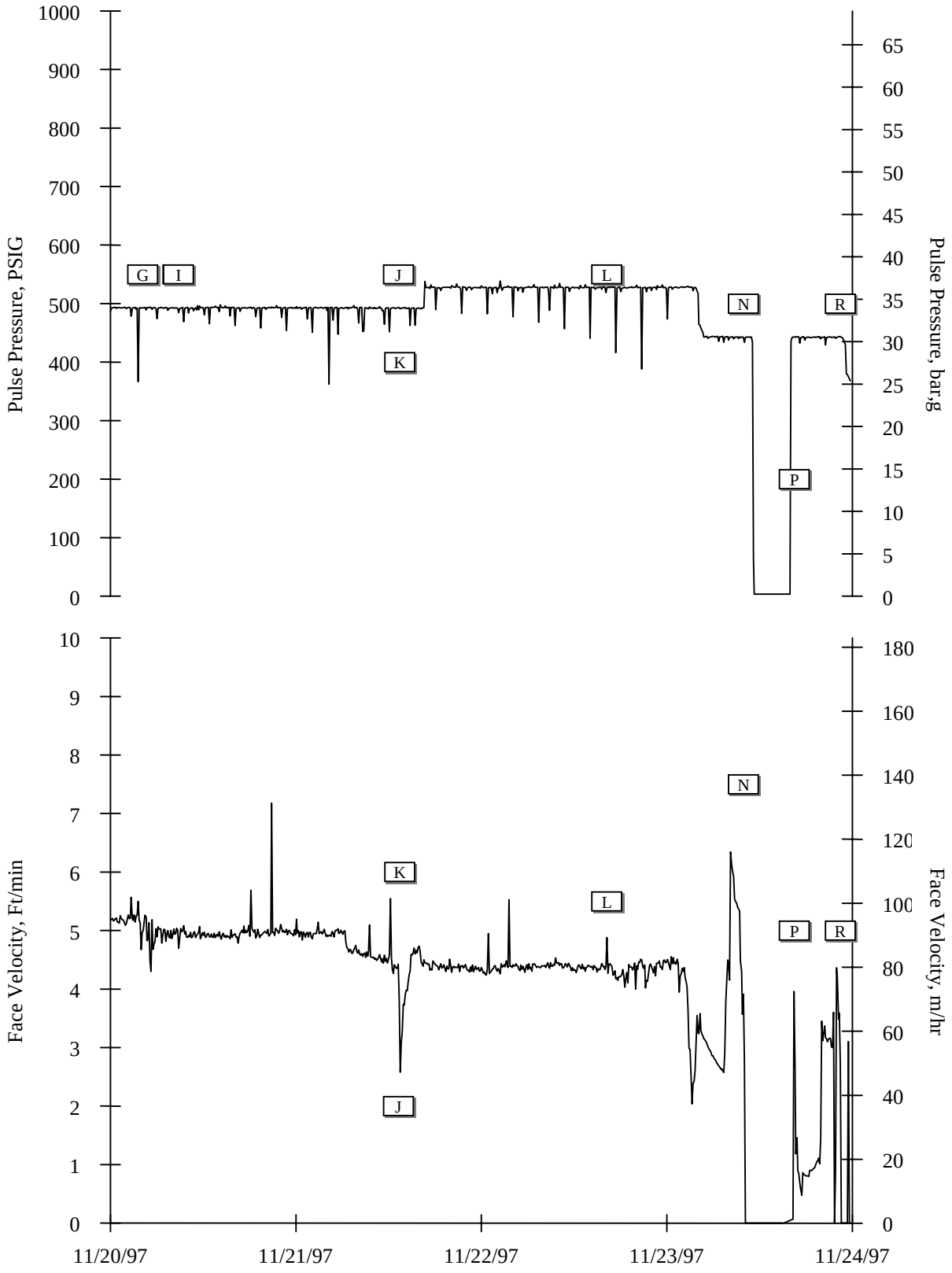


Figure 3.23.1-5 TC01H Pulse Pressure and Face Velocity for November 20 Through 24

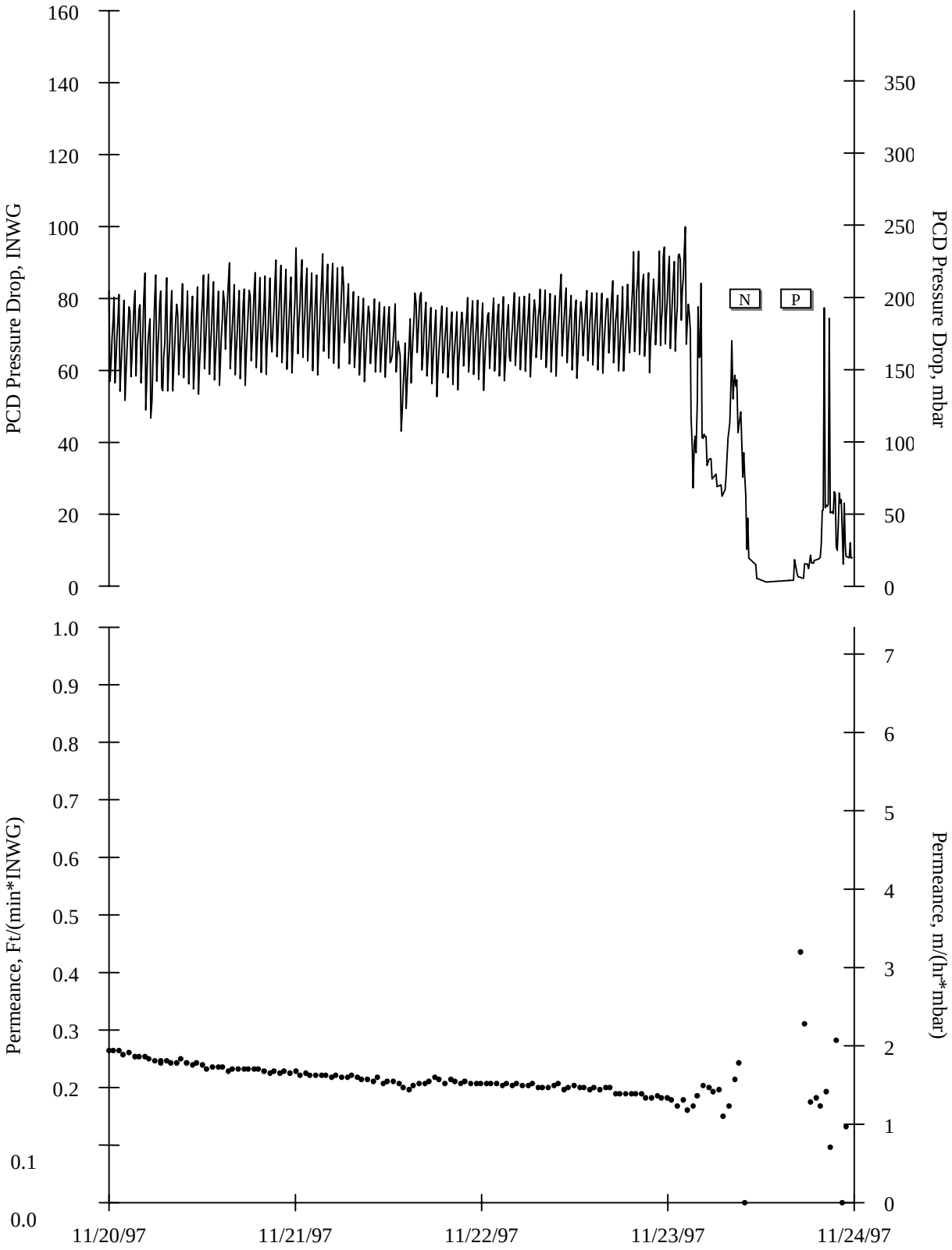


Figure 3.23.1-6 TC01H Pressure Drop and Permeance for November 20 Through 24

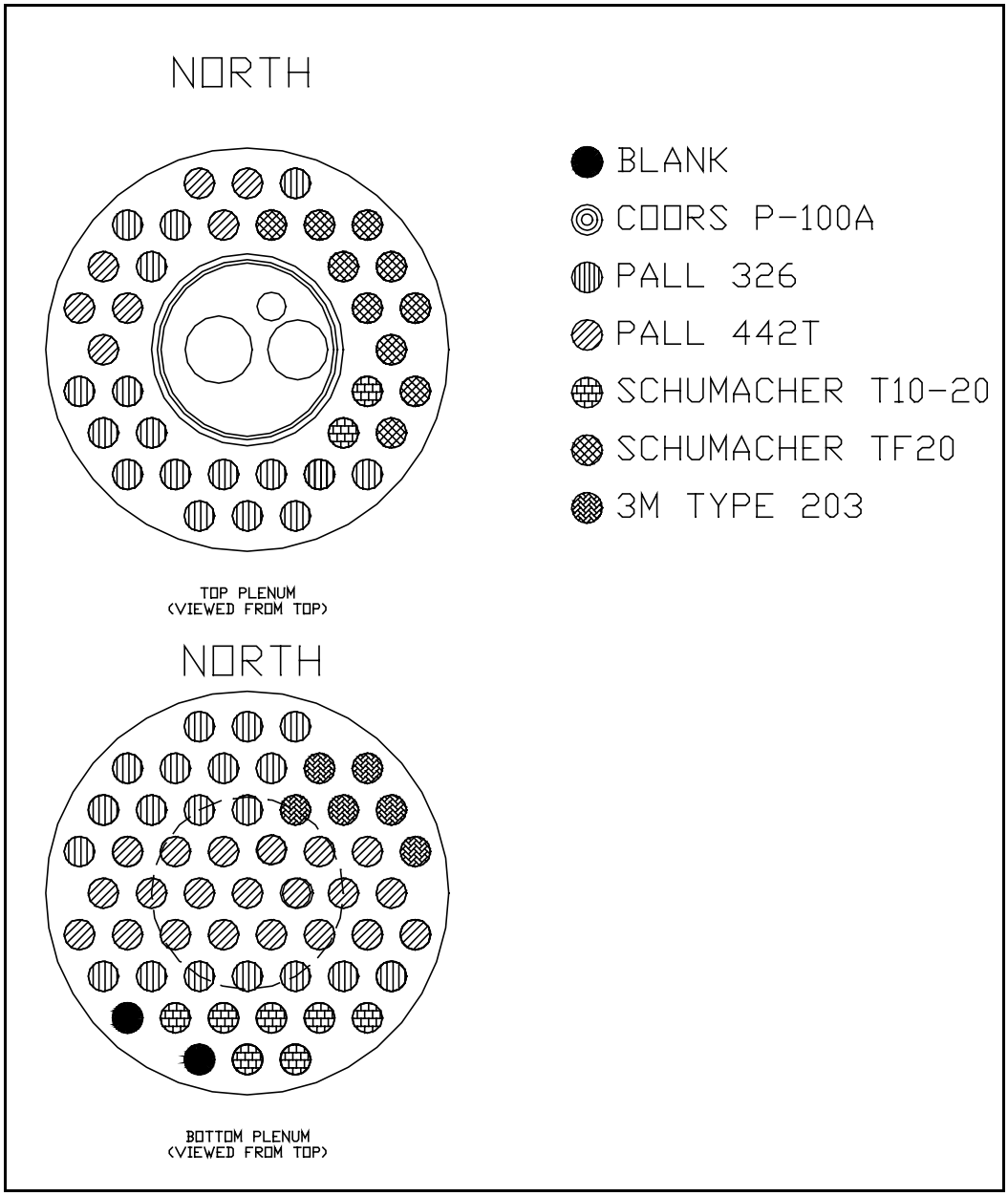


Figure 3.23.1-7 Filter Element Layout for TC01H (Layout No. 6) (See also Figure 3.22.3-6)

3.23.2 Test Objectives

This test segment was a continuation of the 1,000-hour test run TC01. The main objective for the PCD was to obtain 1,000 hours exposure time for the filter elements above 1,350°F (732.2°C).

3.23.3 Observations/Events

A. Test Started–November 16 at 11:55. The main air compressor (MAC) was started late in the morning of November 16, 1997, to begin TC01H.

B. Lost PI System–November 17 at 9:40. The plant information (PI) system malfunctioned and was not collecting data for approximately 30 minutes, but it recovered.

C. Back-pulse System Malfunction–November 18 at 2:30. The solenoid valve (SV3104A) on the back-pulse skid malfunctioned. This valve controls the back-pulse of the bottom PCD plenum. Apparently, it remained open for a longer period of time than it should, allowing the back-pulse valve (one of the two duplicate valves) to open longer than the specified 0.4 seconds. Consequently, the accumulator tank pressure decreased from 445 psig (30.7 bar,g) to 130 psig (9 bar,g). This was very close to the 126 psig (8.7 bar,g) transport reactor pressure at the time. Normally the tank pressure decreases from 445 to 300 psig (30.7 to 20.7 bar,g) during back-pulse. Additionally, for the next 1.5 minutes, the top plenum back-pulse valve continued to back-pulse. The transport reactor pressure increased by about 6.8 psig (0.5 bar,g) due to the large quantity of nitrogen entering the filter vessel. The increased pressure caused a back flow to the transport reactor. The dipleg was upset, sending about 1,000 lb (453.6 kg) of solids to the PCD. Removing the solids from the PCD took over 8 hours due to temperature constraints with the neoprene seal in the middle FD0520 spheri valve.

   Upon inspection, SV3104A was found to have a loose screw and a missing o-ring. The back-pulse system was switched to use the back-up valves.

D. Coal Feed Resumed–November 18 at 13:33. The PCD was emptied of solids and coal feed was resumed to the transport reactor.

E. PCD Filling with Ash–November 18 at 20:15. The temperature elements in the PCD cone showed it was filling with ash. The transport reactor circulation rate was reduced to allow the PCD to empty.

F. Raised Back-pulse Pressure to 500 psig (34.5 bar,g)–November 19 at 8:22. Because the transport reactor pressure was increased the back-pulse pressure was also increased to maintain the proper differential pressure.

G. Coal Feeder (FD0210) Packing with Fine Coal–November 20 at 4:10. The discharge line from the coal feeder was packing with fine coal and preventing proper discharge.

H. Coal Feeder Tripped–November 29 at 8:44. The plugged discharge line forced the unit to trip. Operators struck the elbow and line to break the plugged coal free.

I. Coal Feed Resumed–November 20 at 8:47.

J. FD0520 Bottom Spheri Valve Quick Dump Valve Failure; Coal Feeder Tripped–November 21 at 13:16. The quick-dump valve on the bottom spheri valve failed to close and allowed for continuous bleed of nitrogen from the header. Consequently, all Clyde Pneumatics Systems using nitrogen, which includes the coal feeder, lost pressure to the seals. The coal feeder was tripped to reduce solid feed to the PCD since the initial fear was that the seal had failed. Upon inspection, the nut on the position switch on the bottom spheri valve was turned one turn to facilitate closing the switch. The movement of the actuator arm housing was speculated as the cause. The housing to which the position switch was attached flexed with each movement of the arm. A portion of the housing had been removed to allow easier access to the components. Additionally, some of the bolts had loosened over time. The portion of the housing that had been removed was returned and the other bolts were tightened.

K. Coal Feed Resumed–November 21 at 13:26.

L. Coal Feeder Bridging; Coal Feeder Tripped–November 22 at 16:13. Significant bridging in the coal feeder (FD0210) caused inefficient coal transfers. Constant attention to the coal feeder began at this time and continued for the remainder of the day.

M. Start-up Burner Failure–November 23 at 4:00. Trying to isolate FD0210 for repair work, the transport reactor pressure was reduced and the start-up burner failed. Consequently, the temperature dropped.

N. Main Compressor Off–November 23 at 9:55. The compressor was turned off to try to repair the start-up burner.

O. Replace Start-up Burner–November 23 at 15:00. Start-up burner was replaced.

P. Main Compressor On–November 23 at 16:30.

Q. Start-up Burner Failure–November 23 at 21:25. The new burner failed to ignite.

R. Main Compressor Off–November 23 at 22:27. The TC01H run ended.

3.23.4 Run Outcome

Due to the short duration of the run there were no filter problems. No filter breakage was suspected. There was not an inspection of the PCD after the run because the outage was so short. A majority of the complications during the run involved the coal feeder system (FD0210). It was determined that the coal feeder was experiencing bridging problems. The lock hopper of the vessel was full with approximately 100 lb (45.4 kg) of coal. The level probe for the coal feeder was also pulled and inspected.

3.24 PCD OPERATION DURING TEST RUN TC01I

3.24.1 Run Summary

Test campaign TC01I was started late in the afternoon of November 24, 1997, to continue the 1,000-hour test campaign.

Startup of the unit was completed successfully with only a few software complications. The temperature of the particulate control device (PCD) attained 1,350°F (732.2°C) on the afternoon of November 25, 1997. A majority of the problems during the run centered on the coal feeder (FD0210). Problems with nitrogen seal pressure forced FD0210 to stop coal feed several times during the run, causing temperature fluctuations in the PCD. A malfunctioning dump valve on the FD0520 unit caused part of the complication. Late in the evening of November 25, 1997, an upset in the transport reactor dipleg sent 2,000 lbs (907 kg) of solids over to the PCD. Removing the solids took approximately one full day. Overall, this run amassed the longest amount of time of the TC01 runs. The spent fines transport system functioned well and was not a cause for shut down.

Table 3.24.1-1

TC01H Run Statistics

Start Time:	11/24/97 16:30
End Time:	12/9/97 15:30
Coal Type:	Calumet Alabama Bituminous
Hours on Coal:	313.5
Sorbent Type:	Plum Run Dolomite
Number of Filter Elements:	89
Filter Element Layout No.:	6 (Figure 3.24.1-10)
Filtration Area:	249.1 ft^2 (23.1 m^2)
Pulse Valve Open Time:	0.4 seconds
Pulse Time Trigger:	40 minutes
Pulse Pressure:	400 to 550 psig (27.6-37.9 bar, g)
Pulse DP Trigger:	112 inWG (278.7 mbar, g)

Table 3.24.1-2

TC01H Major Events

Event	Description	Date at Time
A	Test Started	November 24 at 16:30
B	Coal Feed Started	November 25 at 09:27
C	Clyde Software Problem; Coal Feed Stopped	November 25 at 13:56
D	FD0520 Middle Spheri Valve Quick Dump Valve Failure	November 25 at 21:10
E	Increased Back-pulse Pressure to 535 psig (36.9 bar,g)	November 26 at 01:07
F	Poppet Valve Failure on FD0520	November 26/97 06:58
G	Coal Feeder Tripped	November 26 at 07:15
H	Dipleg upset; 2000 lbs (907 kg) of solids sent to PCD	November 26 at 07:17
I	Coal Feed Resumed	November 26 at 07:19
J	Coal Feed Reduced	November 26 at 07:45
K	Coal Feed Stopped	November 26 at 09:54
L	Main Compressor Off	November 26 at 11:30
M	Main Compressor On	November 26 at 16:25
N	Coal Feed Resumed	November 27 at 05:20
O	Coal Feeder Transfer Problems	November 27 at 21:00
P	Coal Feeder Tripped	November 28 at 12:50
Q	Increased Cycling of FD0520 to every 5 minutes	November 28 at 18:40
R	PLC Computer accidentally placed in test mode; Coal Feed (and all Clyde Systems) Stopped	December 2 at 09:20
S	Coal Feed Resumed	December 2 at 09:37
T	Main Air Compressor Tripped; Coal Feed Stopped	December 5 at 05:03
U	Main Air Compressor Back On-Line	December 5 at 05:38
V	Coal Feed Resumed	December 5 at 05:41
W	FD0520 Middle Spheri Valve Quick Dump Valve Failure (Repeatedly)	December 8 at 02:37
X	Coal Feeder Transfer Problems	December 8 at 16:10
Y	Coal Feed Stopped	December 9 at 06:20
Z	Main Air Compressor Tripped	December 9 at 15:30

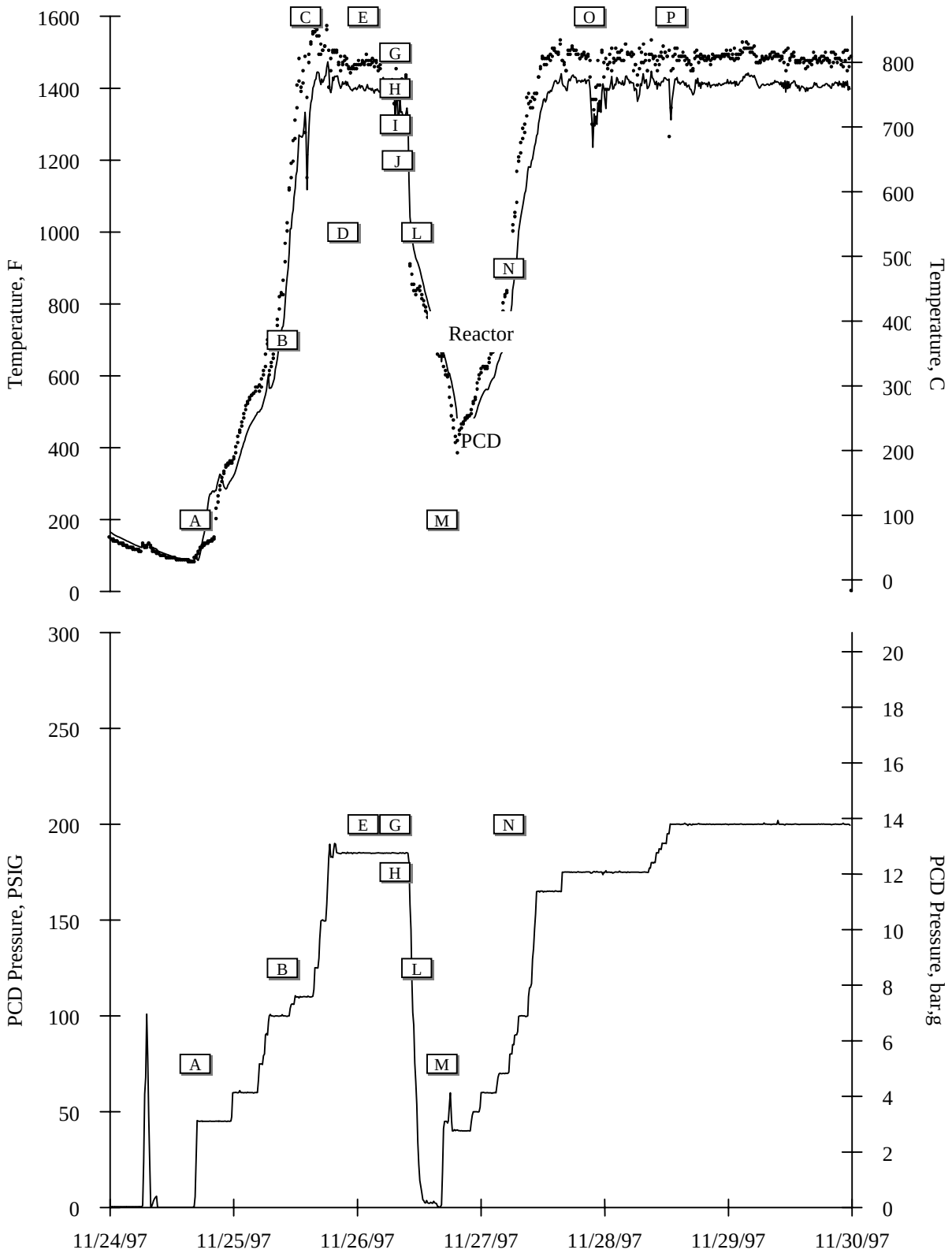


Figure 3.24.1-1 TC01I Temperature and Pressure for November 24 Through 30

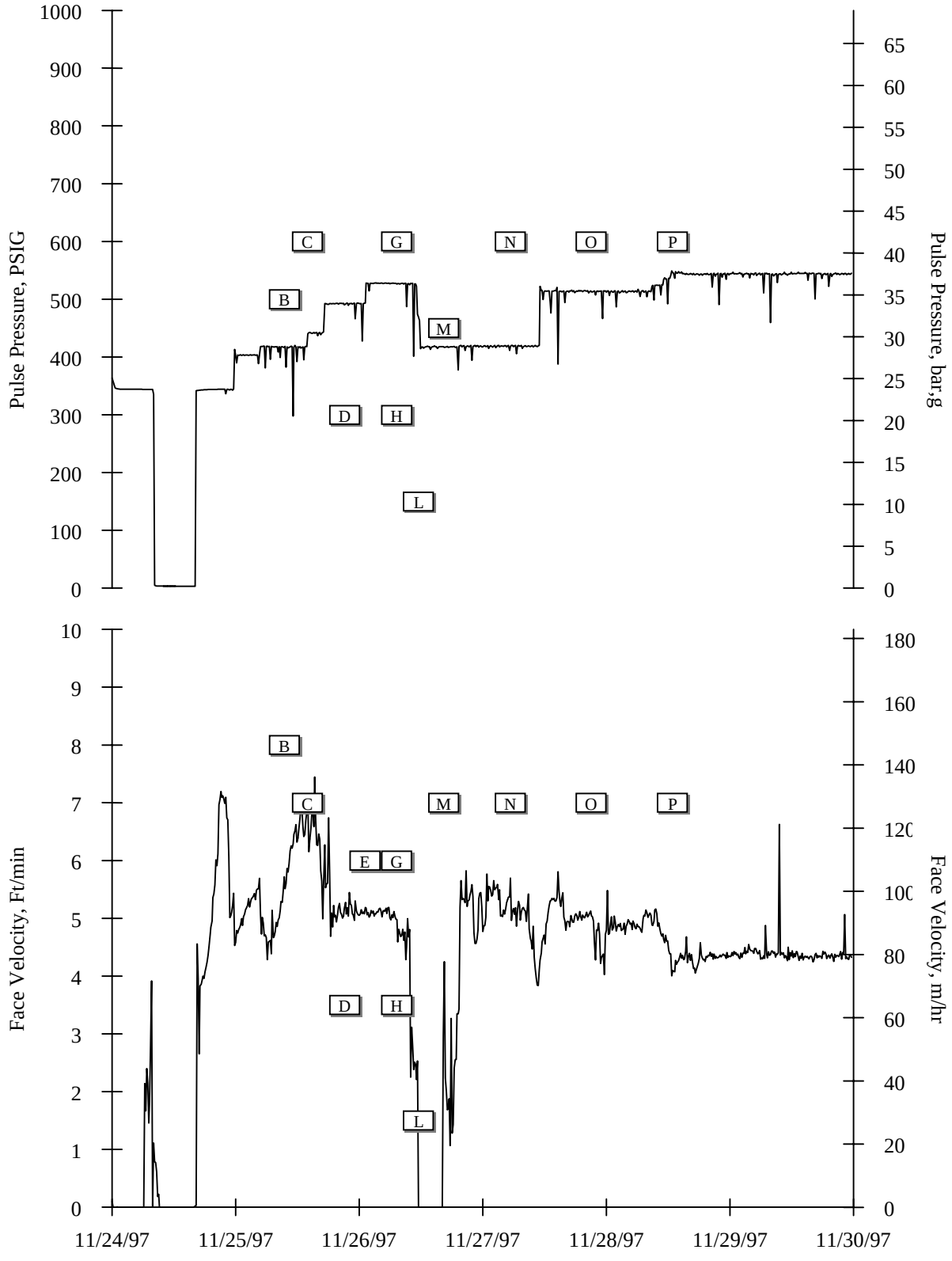


Figure 3.24.1-2 TC01I Pulse Pressure and Face Velocity for November 24 Through 30

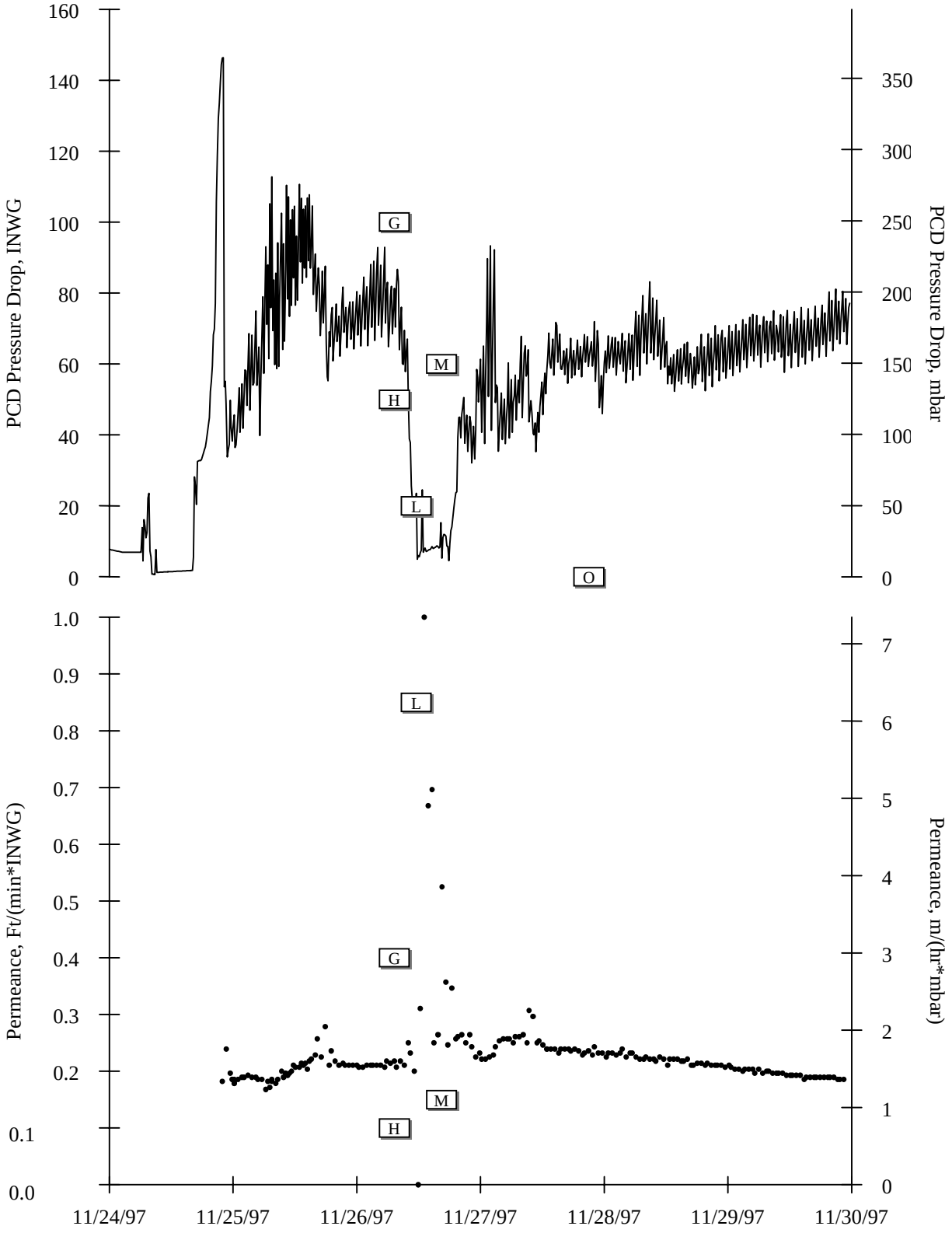


Figure 3.24.1-3 TC01I Pressure Drop and Permeance for November 24 Through 30

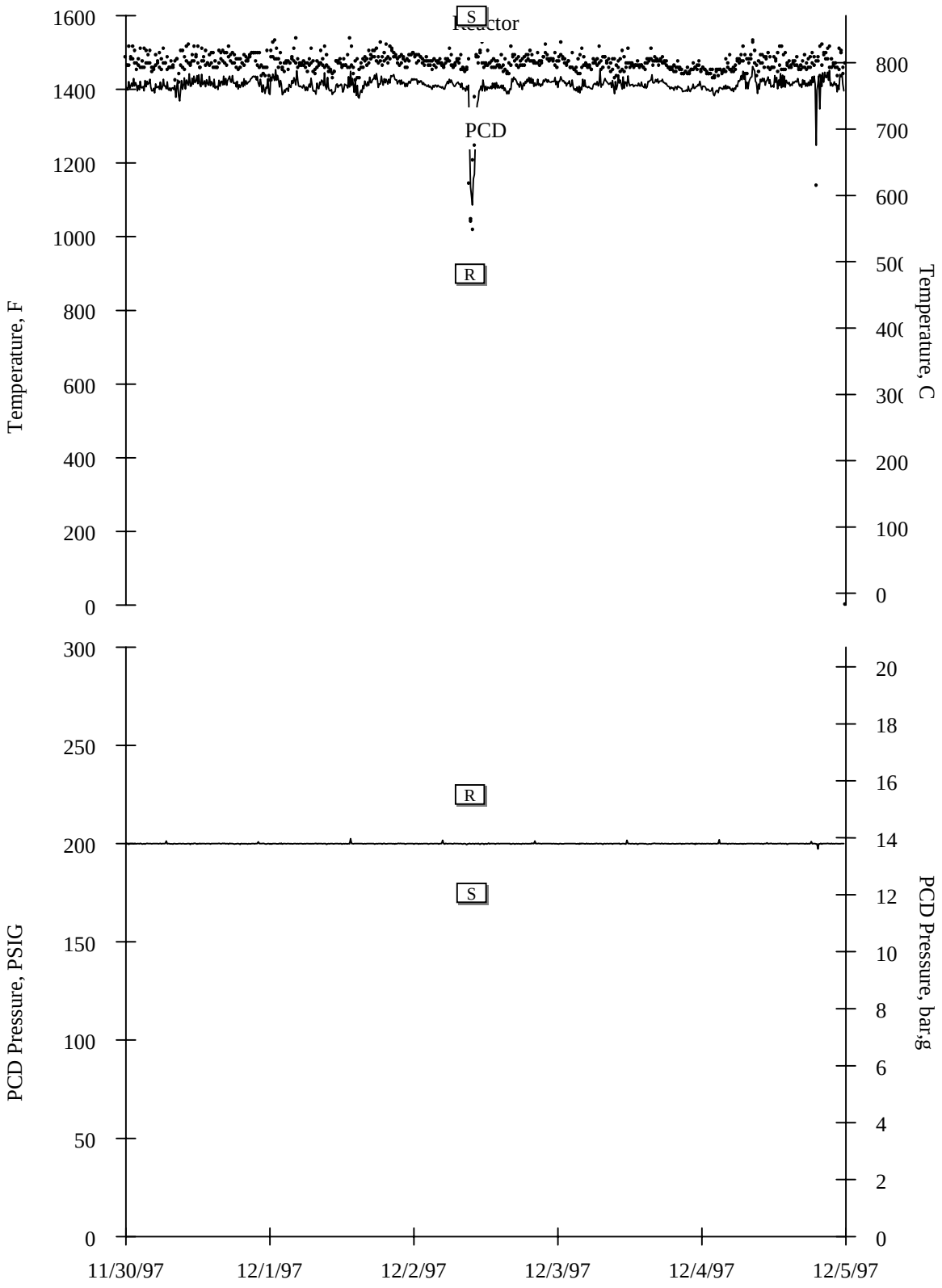


Figure 3.24.1-4 TC01I Temperature and Pressure for November 30 Through December 5

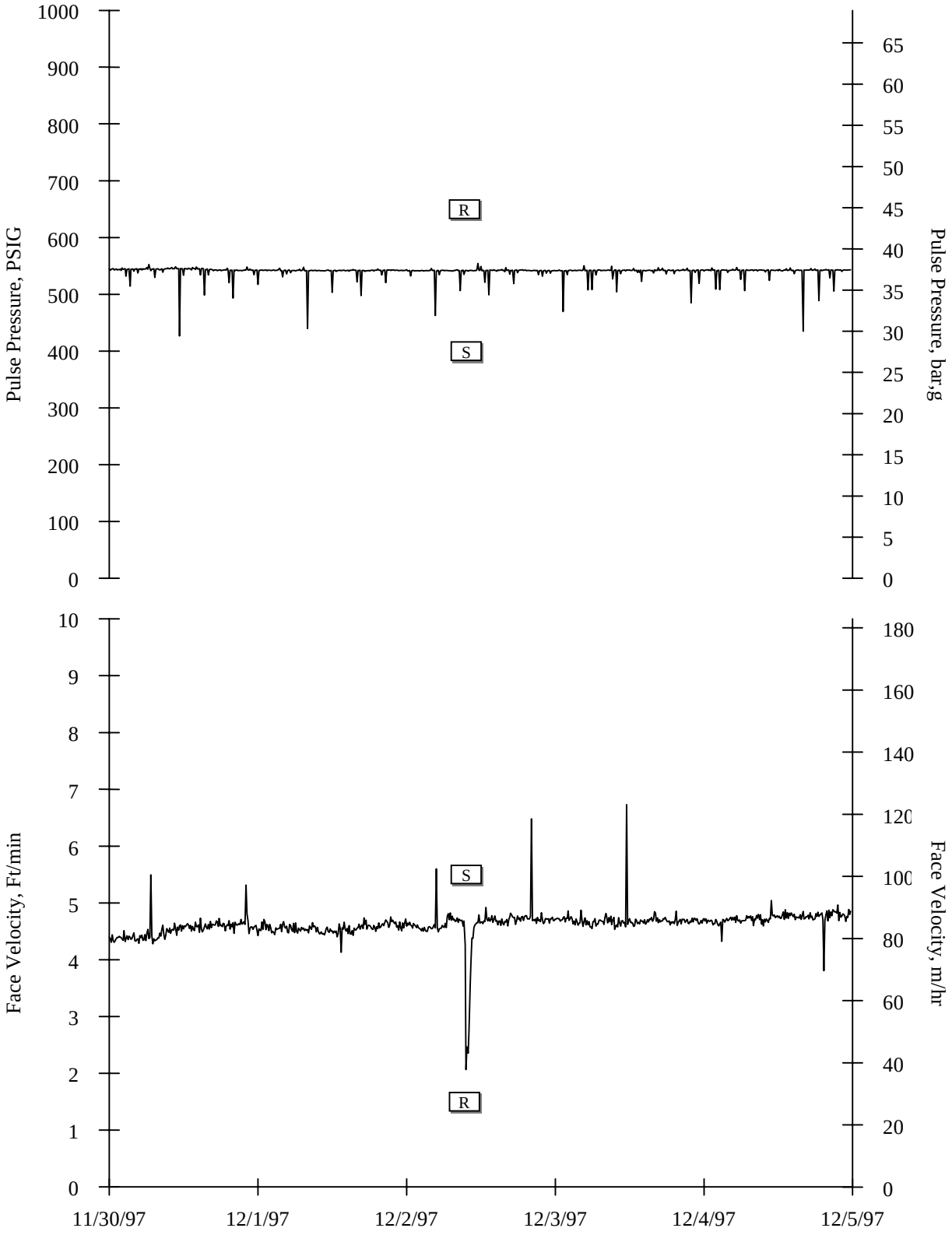


Figure 3.24.1-5 TC01I Pulse Pressure and Face Velocity for November 30 Through December 5

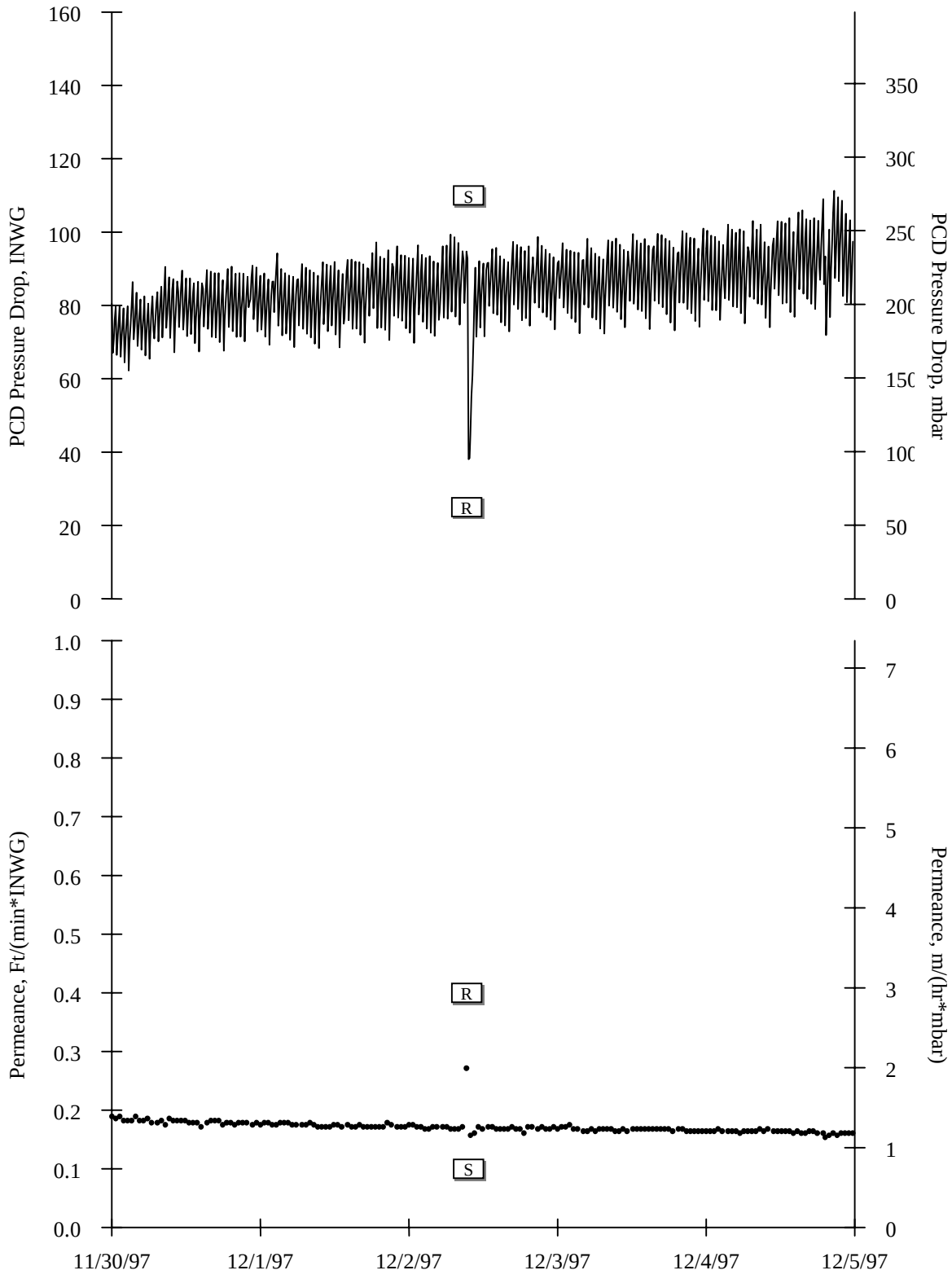


Figure 3.24.1-6 TC01I Pressure Drop and Permeance for November 30 Through December 5

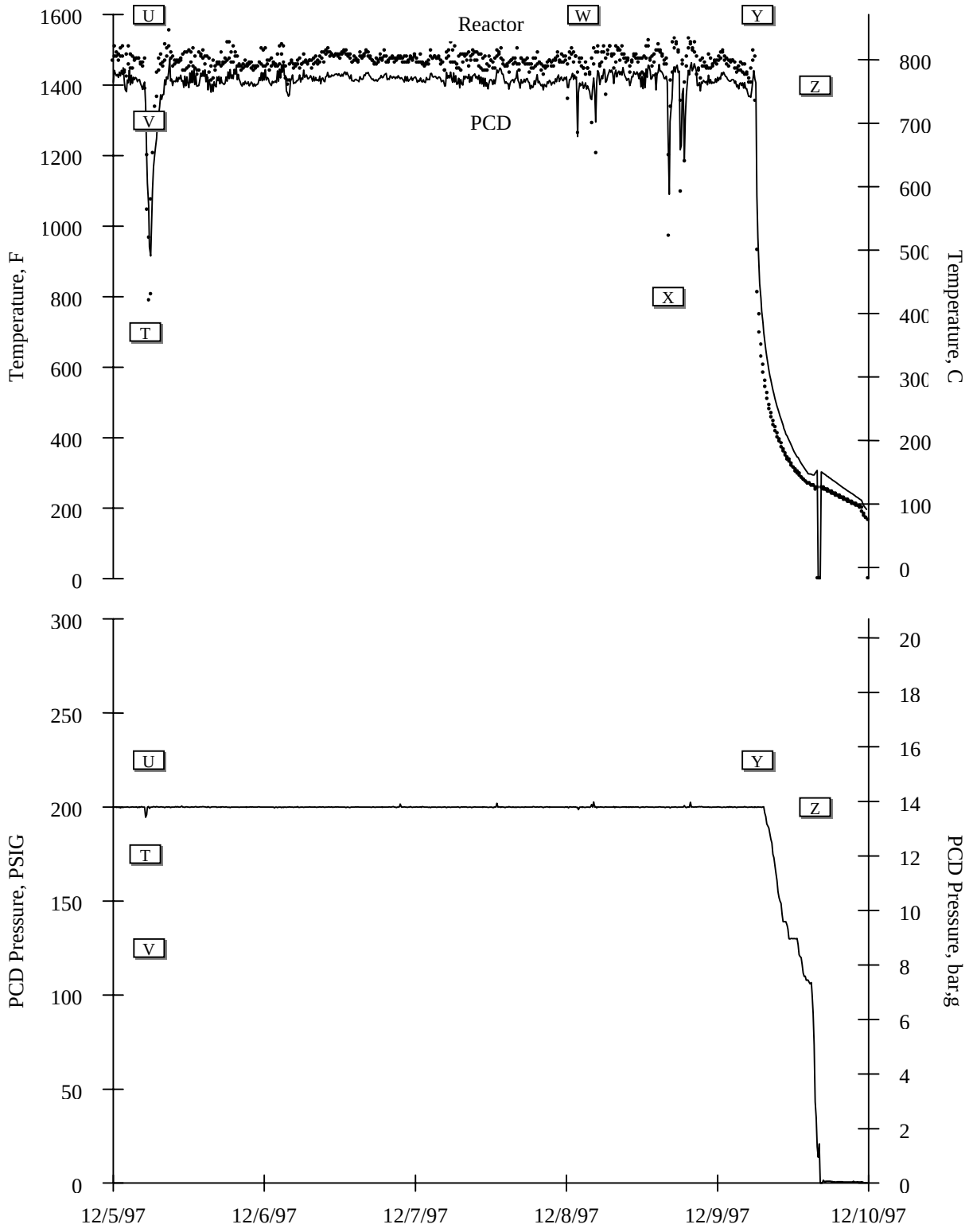


Figure 3.24.1-7 TC01I Temperature and Pressure for December 5 Through 10

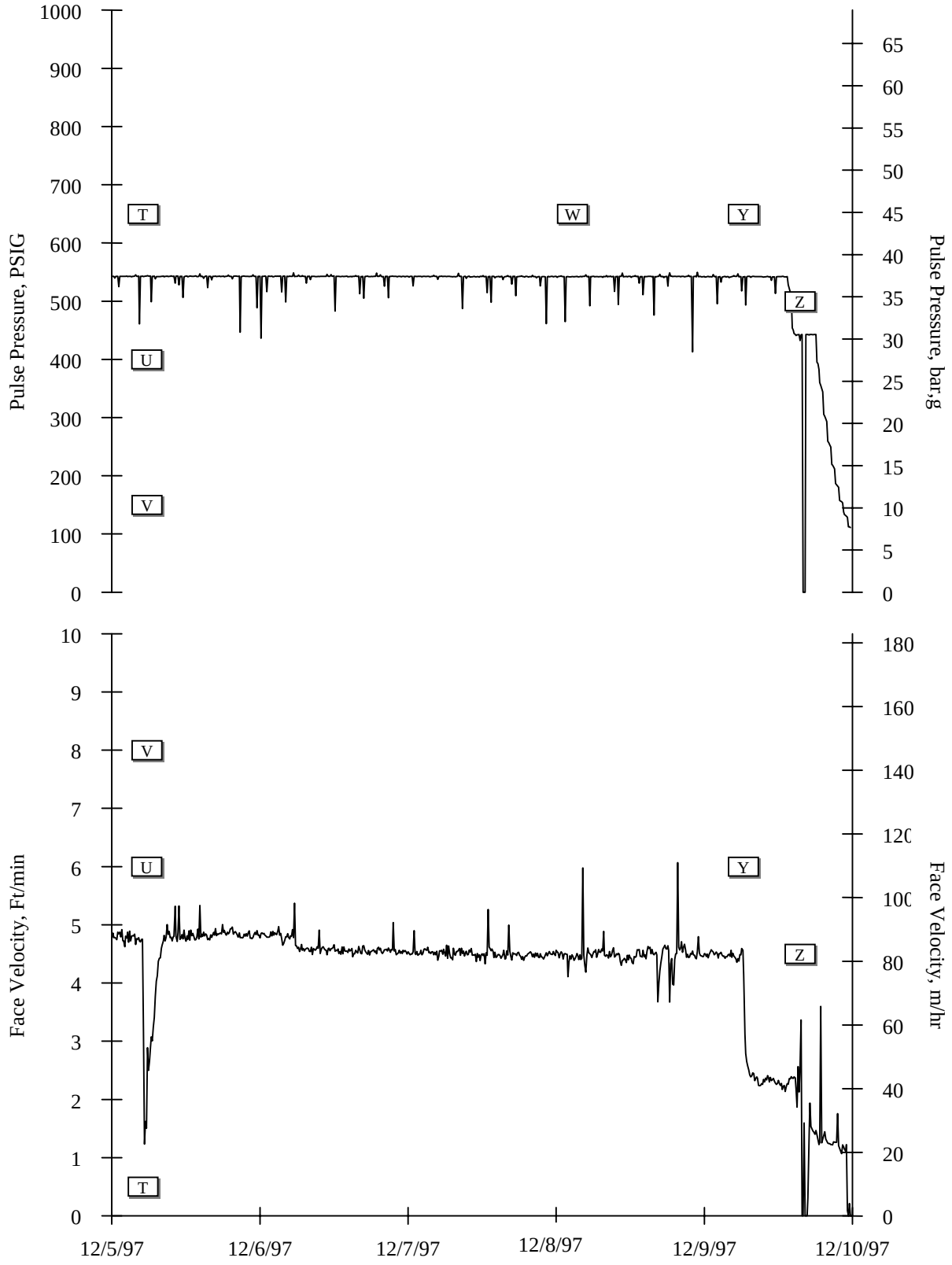


Figure 3.24.1-8 TC01I Pulse Pressure and Face Velocity for December 5 Through 10

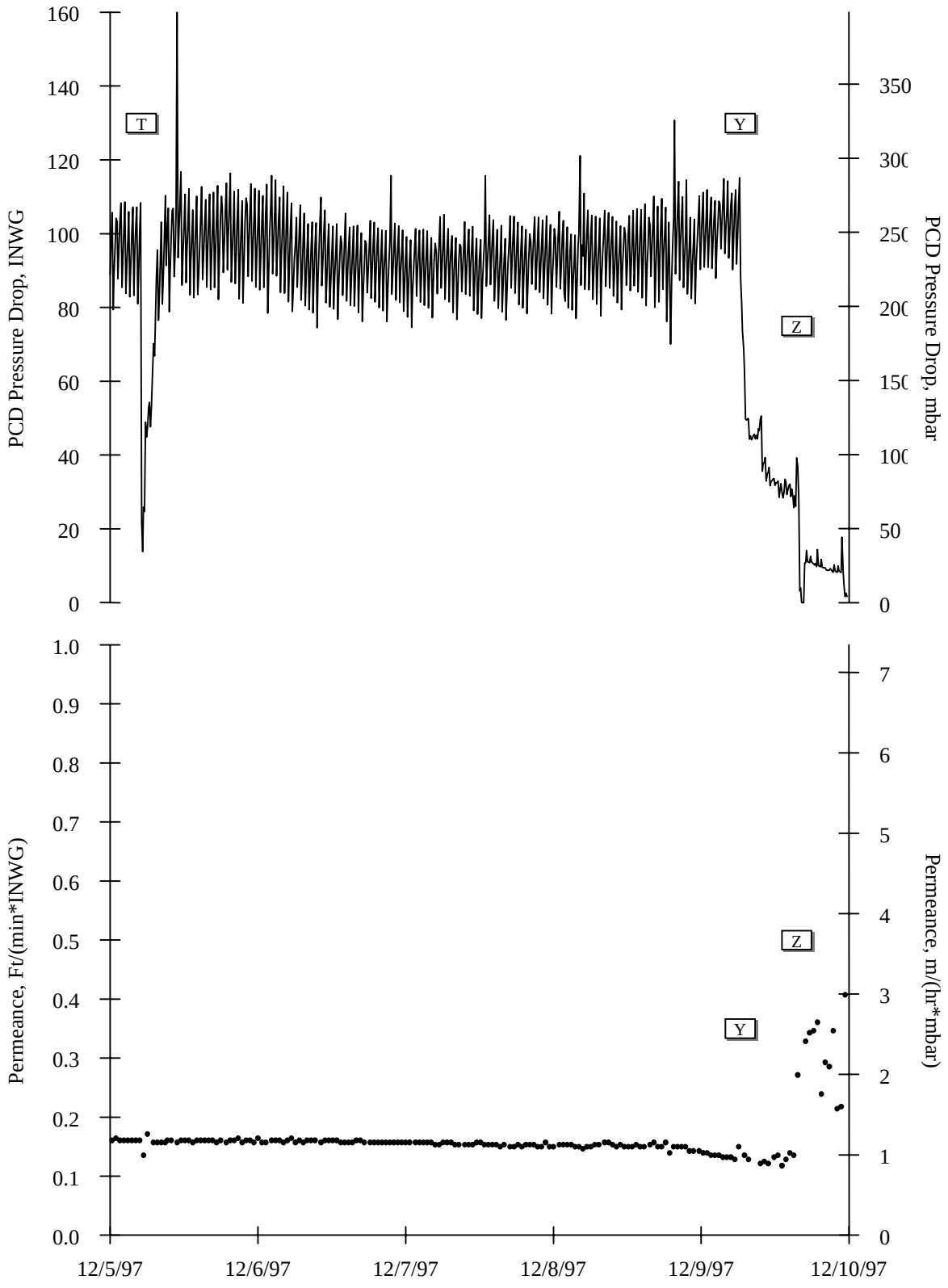


Figure 3.24.1-9 TC01I Pressure Drop and Permeance for December 5 Through 10

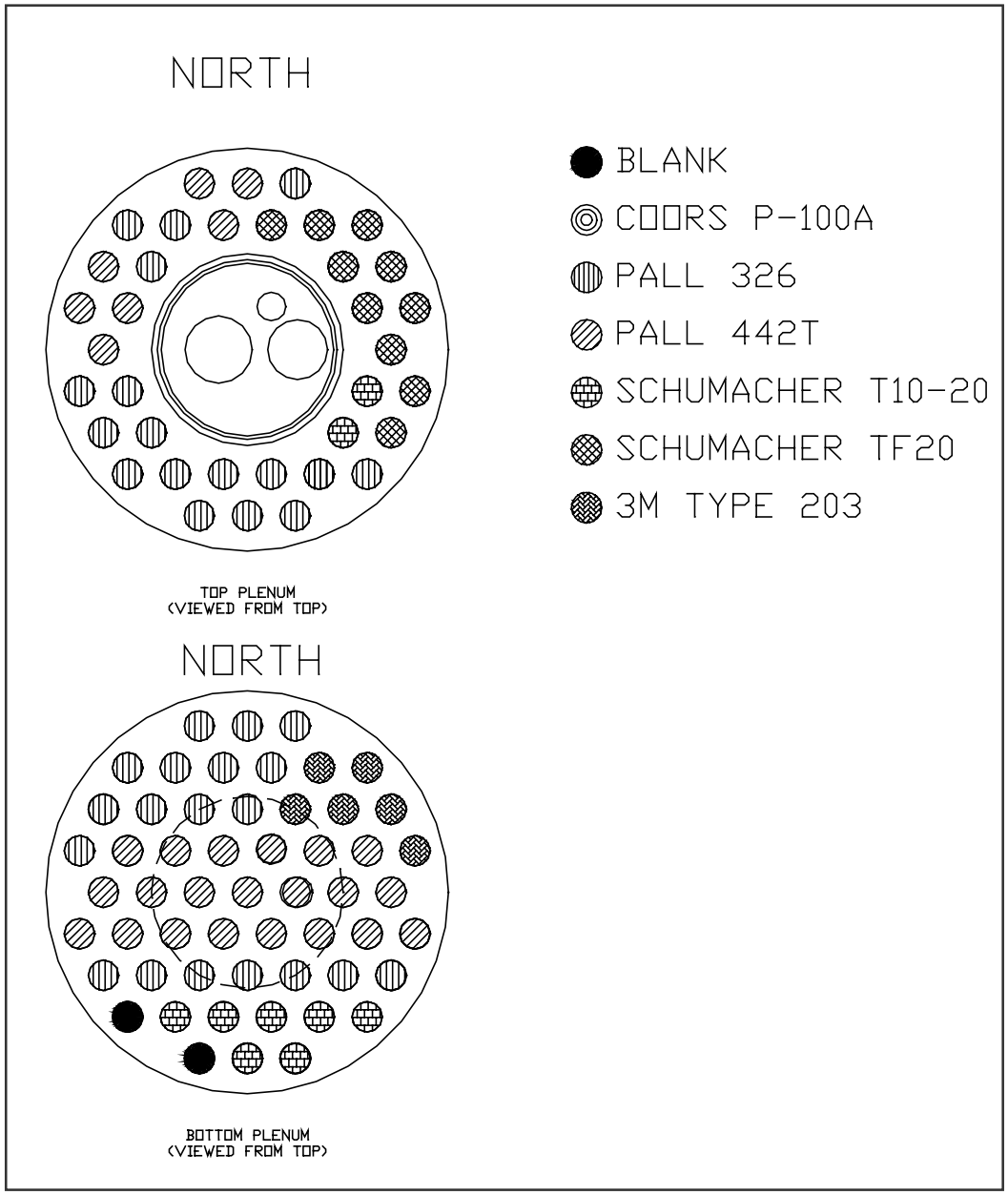


Figure 3.24.1-10 Filter Element Layout for TC01I (Layout No. 6)

3.24.2 Test Objectives

This test segment was a continuation of the 1000-hour test run TC01. The main objective for the PCD was to obtain 1,000 hours exposure time for the filter elements at temperatures above 1,350°F (732.2°C).

3.24.3 Observations/Events

A. Test Started–November 24 at 16:30. The main air compressor (MAC) was started late in the afternoon of November 24, 1997, to begin TC01I.

B. Coal Feed Started–November 25 at 9:27.

C. Clyde Software Problem; Coal Feed Stopped-November 25 at 13:56. Problems with the weigh cells on the coal feeder (FD0210) required that the software for all Clyde systems be reloaded. This included the spent fines transport system (FD0520). To do this, all of the Clyde systems were stopped.

D. FD0520 Middle Spheri Valve Quick Dump Valve Failure–November 25 at 21:10. The actuator arm was not making contact with the position switch to close the quick-dump valve. Replacing the cover plate for the mechanical switch helped solve the problem, and the switch engaged. The most likely cause was movement in the housing of the actuator.

E. Increased Back-pulse Pressure to 535 psig (36.9 bar, g)–November 26 at 1:07.

F. Poppet Valve Failure on FD0520–November 26 at 6:58. A failed poppet valve on the middle spheri valve seal allowed for nitrogen to escape. Enough nitrogen escaped to cause the header to lose pressure.

G. Coal Feeder Tripped–November 26 at 7:15. Declining nitrogen header pressure tripped the coal feeder.

H. Dipleg Upset; 2,000 lbs (907 kg) of solids sent to PCD–November 26 at 7:17. A back-pulse in the PCD while the coal feed was lost upset the dipleg; 2,000 lb (907 kg) of solids were sent to the PCD in just 11 minutes.

I. Coal Feed Resumed–November 26 at 7:19.

J. Coal Feed Reduced–November 26 at 7:45. The coal feed was reduced to avoid further complications in removing the 2,000 lbs (907 kg) of solids in the PCD cone. It took close to a full day to remove the solids from the PCD cone. The screw cooler was limited to 212°F (100°C) because of the neoprene spheri valve seal in FD0520.

K. Coal Feed Stopped–November 26 at 9:54.

L. Main Compressor Off –November 26 at 11:30. The compressor was stopped to aid in repair work on FD0520.

M. Main Compressor On–November 26 at 16:25. The repair work was completed and the compressor restarted.

N. Coal Feed Resumed–November 27 at 5:20.

O. Coal Feeder Transfer Problems–November 27 at 21:00. Problems with the coal feeder caused inconsistent feeds and temperature fluctuations in the PCD.

P. Coal Feeder Tripped–November 28/97 at 12:50.

Q. Increased Cycling of FD0520 to 5 minutes–November 28 at 18:40. Lower temperatures in the PCD cone signaled a possible accumulation of solids. This required that the spent fines transport system increase its throughput.

R. PLC Computer Accidentally Placed in Test Mode; Coal Feed (and all Clyde Systems) Stopped–December 02 at 9:20. While backing up the PLC computer, it was accidentally placed in test mode causing the coal feeder to stop.

S. Coal Feed Resumed–December 02 at 9:37.

T. Main Air Compressor Tripped; Coal Feed Stopped-December 05 at 5:03. A cooling water pump tripped for the air compressor. This stopped coal feed.

U. Main Air Compressor Back On-Line–December 05 at 5:38.

V. Coal Feed Resumed–December 05 at 5:41.

W. FD0520 Middle Spheri Valve Quick Dump Valve Failure (Repeatedly) – December 08 at 2:37. This began a series of problems with the FD0520 quick dump valve leaking nitrogen. Periodically, the problem was bad enough to stop all Clyde systems. This interrupted coal feed.

X. Coal Feeder Transfer Problems–December 08 at 16:10. Because of plugging in the exit line, the coal feeder caused stopped several times. This intermittent problem continued off and on for the next 3 hours.

Y. Coal Feed Stopped–December 09 at 6:20. The exit line plugged.

Z. Main Air Compressor Tripped–December 09 at 15:30. End of TC01I.

3.24.4 Run Outcome

The run was a successful one. No elements were broken from TC01H or TC01I, even with a few thermal events. There was some additional wear of the FD0502 shaft. The shaft had been reworked prior to TC01H and the wear had returned. Additional detail concerning the wear of the shaft can be found in the report on FD0502/FD0520 (section 3.30). This was the longest uninterrupted run for all of TC01.

3.25 TC01 ASH CHARACTERISTICS AND PCD PERFORMANCE

In situ particulate sampling runs were performed during TC01 on a regular basis at the PCD inlet and PCD outlet. These sampling runs were primarily to monitor changes in solids carryover from the transport reactor system and to detect any particle penetration that might be associated with the failure of one or more filter elements. The in situ particulate samples included 17 samples of the particulate mass entering the PCD and 18 samples of the particulate mass exiting the PCD. All of the samples collected at the PCD inlet and 16 of the 18 samples collected at the PCD outlet were total particulate mass samples collected on a single filter (mass samples). Two of the samples collected at the PCD outlet were size-segregated samples collected in a cascade impactor.

Throughout TC01, SRI sampling personnel coordinated with SCS operations personnel to ensure that the tranport reactor system was operating under steady-state conditions during each sampling run. The intent of the TC01 test program was to evaluate the long-term performance of the PCD over a 1,000-hr exposure to flue gas at a nominal gas temperature of 1,400°F (760°C) and a nominal gas pressure of 200 psig (13.8 bar). During the particulate sampling runs the average recorded temperature was 1,411 ± 8°F (766 ± 4°C) and the average recorded pressure was 195 ± 8 psig (13.4 bar ± 0.5 bar). The average gas velocities measured at the sampling nozzle varied from 23.1 to 29.1 ft/sec (7.0 to 8.9 m/sec) and were within ± 5 percent of the average process gas velocity for all sampling runs.

This report summarizes the particulate mass loadings determined from the TC01 sampling runs and PCD collection efficiencies calculated from the inlet and outlet loadings. Particle-size distributions determined by cascade impactor and particle-size analysis in the laboratory are discussed and compared to particle-size measurements from previous test series. Significant physical and chemical characteristics of the in situ samples are presented and compared to the characteristics of ash samples taken from the PCD hopper and dustcake samples taken from the filter elements during the PCD inspections in November and January. The various types of samples are compared in terms of their chemical composition, permeability, particle-size distribution, and other relevant properties.

3.25.1 Measurements of Particulate Mass Loadings

Inlet Measurements. Table 3.25.1-1 gives a summary of the results of all PCD inlet particle mass concentration measurements performed during all segments of TC01. As indicated in the table, the measured inlet loading varied from 6,100 to 15,600 ppmw with a mean value of 11,400 ppmw ± 2,300 ppmw (20 percent relative standard deviation, rsd). This is much improved from previous test programs where much higher mass loadings and much greater variations were seen. Improved operation of the transport reactor is credited with the increased consistency and reduced loadings.

Previous data indicated that the cleaning back-pulse from the PCD could cause increased mass loading because of reentrainment from the cyclone dipleg. Therefore, the TC01 tests were timed to unambiguously collect data either with or without a back-pulse occurring. For the five

inlet runs that were performed during a PCD back-pulse the mean loading was 11,100 ppmw ± 2,700 ppmw (24 percent rsd). For the 12 runs that did not include a PCD back-pulse the mean loading was 11,500 ppmw ± 2,300 ppmw (20 percent rsd). Although a catastrophic loss of the dipleg seal did not occur during any of the pulse tests a lower loading during pulsing is not the result that was expected.

Careful review of the operational data using the process information system (PI) indicated that four of the "no-pulse" tests were started less than 5 minutes after a severe upset of the dipleg seal. Although the dipleg ΔP data indicated that the seal had been reestablished before the test started all of those tests (TC01IMT-4, 12, 13, and 17) showed much higher mass concentrations than did the tests that had stable operating conditions in the 5 minutes prior to the test. It appears that the effects of upsetting the cyclone dipleg last longer than had been expected. Future testing will take this into account.

Another masking effect that limited the ability to resolve the effects of pulsing on PCD inlet particle loading is varying circulation rates in the transport reactor. For constant cyclone collection efficiency and constant particle-size distribution increasing the mass entering the cyclone will increase the mass entering the PCD. If the PCD inlet particle loadings are plotted against the cyclone feed solids rate calculated for each test the relationship in figure 3.25.1-1 is obtained. The dashed line on the figure is a linear regression compared with the data collected both with a pulse and when a pulse caused a loss of the dipleg seal within 5 minutes of the start of a test. The one data point at 8,200 ppmw was excluded from the linear regression because it was obtained during a period of unstable operation (personal communication from P. Smith, January 8, 1998). The solid line is a regression to the data collected without pulsing and with no seal losses. Although the accuracy or appropriateness of the regression lines is debatable they are useful to guide the eye. It appears that we can now observe an increase in mass exiting the transport reactor because of the PCD pulse upsetting the cyclone dipleg. However, the degree of increase is fairly minor and it is not perceived as problematic in analysis and evaluation of PCD operation.

Outlet Measurements. The outlet particulate measurements made during TC01 are summarized in table 3.25.1-2. No result is reported for run TC01OMT-11 because a leak in the sampling system tubing was detected after that run. Although the system passed a leak test immediately prior to the run the measurement had to be considered invalid, as the leak probably developed during the run. Since the leak occurred upstream of the flow measurement orifice (where the tubing is at high pressure) the total volume of flue gas that passed through the particulate sampler was actually much larger than that indicated by the flow orifice. This resulted in the collection of an inordinately large amount of particulate mass in the sampler, producing an artificially high loading (35 ppmw). Since this result is significantly higher than all other outlet loadings measured during TC01 there is a strong indication that the leak was substantial. Therefore, the result of TC01OMT-11 has been omitted from the table.

The blank values given in the last column of table 3.25.1-2 are the apparent particulate loadings collected on a secondary filter in series with the primary particulate-collection filter. The first four runs did not include the secondary filters so no blank values were determined for those runs. The blank values represent the net effect of several phenomena including: 1) adsorption

of flue gas species on the filter material; 2) filter weight changes associated with handling; and 3) penetration of trace amounts of particulate through the primary filter. The relative contribution of each mechanism is unknown and the blank value appears to vary in a manner that is not related to the actual particulate loading. The mean blank value during TC01 was 0.09 ppmw ± 0.04 ppmw (40 percent rsd). It is probably not appropriate to adjust the mass loading of each test by the blank value associated with that individual run based on this experience only. Instead, the blank values should be used as an indication of the typical noise level in the measurement. For all of the runs performed after September 19 the blank values amount to less than 4 percent of the measured outlet loading. For the runs prior to September 19 the blank values are a significant fraction of the measured loading. This result suggests that the effect of the blank needs to be carefully considered when dealing with very low outlet particulate loadings (<1 ppmw).

Prior to the first outlet sampling run on September 9 it had already been determined that one filter element was broken. This determination was made based on ceramic fragments that were collected in the ash discharge system on September 7. Although one element was broken at the outset the initial measurements performed during the period of September 9 to September 19 showed that the outlet loading was quite low (0.10 to 0.53 ppmw). This result suggests that the fail-safe device on the broken element prevented high levels of particle penetration during this initial time period. On September 19 additional ceramic fragments were removed from the ash discharge system and it was determined that one or two additional elements had broken. Measurements made between September 19 and October 31 showed that the outlet loading had increased significantly with the measured values ranging from 3.8 to about 13 ppmw. This result suggested that the fail-safe devices on one or both of the broken elements did not plug completely or that some other leak had developed that was allowing ash particles to penetrate from the dirty side to the clean side of the PCD.

On November 2 a rapid rise and fall in PCD temperatures occurred when problems were encountered with the coal feed to the transport reactor system. While operations personnel were trying to reestablish stable coal feed the ash discharge system became plugged with a large number of ceramic fragments, forcing a shutdown of the transport reactor system. Subsequent inspection of the PCD revealed that all 12 of the Coors P100A elements and 1 of the 3M type 203 element had been broken. The broken candles were replaced and the system was restarted on November 19 although stable operation on coal was not achieved for several days. The outlet particulate measurements made between December 1 and 8 indicated that the outlet loading was still in the range of 3.9 to 5.3 ppmw. This result suggested that there was still some sort of leak from the dirty side to the clean side of the PCD even after the PCD was recandled. Subsequent inspection of the PCD revealed that all of the candles appeared to be intact. The PCD was carefully inspected in January and a leak test was performed. The results of the leak test suggested that the particle penetration was probably occurring through leaking gaskets between the filter elements and the tubesheet.

Although the outlet loadings measured after September 19 were higher than expected it is important to note that the outlet loading never exceeded 13 ppmw, which is well within the New Source Performance Standards (≅ 30 ppmw). However, because of the potential effect on turbine blade erosion the concentration of large (>5- to 10-μm) particles may be a more

significant consideration than is the total mass emissions. The outlet particle-size measurements made during TC01 (after September 19) indicated that the mass median diameter (mmd) of the dust penetrating the PCD was about 2.5 μm. About 20 percent of the particulate mass was contained in particles larger than 5 μm and about 5 percent of the particulate mass was contained in particles larger than 10 μm. These percentages correspond to mass concentrations for particles larger than 5 μm of 0.76 to 2.5 ppmw and for particles larger than 10 μm of 0.19 to 0.64 ppmw.

Collection Efficiency. The particle collection performance of the PCD was calculated from the inlet and outlet mass concentrations; the results are shown in table 3.25.1-3. The table contains both values of PCD collection efficiency (the percentage of particle mass collected) and the particle penetration of the PCD (percentage of particle mass that escapes collection). Because of the great difference in mass concentration at the inlet and outlet the outlet sampling runs were much longer in duration than the inlet runs (typically 6 hours versus 30 minutes). Since the inlet and outlet samples were not simultaneous and because of considerable variability in the inlet concentration the PCD performance values were calculated based on the average inlet loading for all of TC01 (11,400 ppmw or 13,700 mg/scm). Prior to September 19 the collection efficiency exceeded 99.99 percent. Efficiency values ranged from 99.89 to 99.97 percent after that date. Thus, even the lowest collection efficiency recorded during TC01 was still quite good compared with the performance of most particulate control systems that are currently operating on coal-fired power plants.

Table 3.25.1-1

PCD Inlet Particulate Mass Loading Data for Test Program TC01

SRI Run No	Date Sampled	Run Time[1]		Particle Loading			PCD Pulse[2]
		Start	End	ppmw	gr/acf	mg/scm	
TC01IMT-1	9/10/97	8:20	8:50	6,100	12.6	7,400	No
TC01IMT-2	9/11/97	9:20	9:50	10,500	20.7	12,700	Yes
TC01IMT-3	9/12/97	8:05	8:35	15,200	30.3	18,500	Yes
TC01IMT-4	9/16/97	8:30	9:00	15,600	32.1	19,000	No
TC01IMT-5	9/19/97	12:40	13:10	9,600	20.0	11,600	Yes
TC01IMT-6	9/25/97	11:50	12:20	12,300	26.9	15,000	No
TC01IMT-7	10/3/97	7:50	8:15	11,200	24.3	13,500	No
TC01IMT-8	10/15/97	8:58	9:28	10,500	23.5	12,700	No
TC01IMT-9	10/21/97	8:45	9:15	10,400	21.7	12,700	No
TC01IMT-10	10/23/97	9:15	9:45	10,900	23.7	13,200	No
TC01IMT-11	10/28/97	9:38	10:03	10,800	23.2	13,100	No
TC01IMT-12	10/29/97	10:15	10:45	13,500	29.5	16,400	No
TC01IMT-13	10/30/97	10:13	10:43	12,700	28.3	15,400	No
TC01IMT-14	10/31/97	12:12	12:42	11,100	25.0	13,500	No
TC01IMT-15	12/3/97	9:55	10:25	12,200	26.6	14,900	Yes
TC01IMT-16	12/5/97	9:50	10:35	8,200	17.9	10,000	Yes
TC01IMT-17	12/8/97	10:55	11:25	12,400	27.0	15,200	No

1. All times are central standard time.
2. Indicates whether a back-pulse occurred during the run.

Table 3.25.1-2

PCD Outlet Particulate Mass Loading Data for Test Program TC01

SRI Run No	Date Sampled	Run Time[1]		Particle Loading			Blank ppmw[2]
		Start	End	ppmw	gr/acf	mg/scm	
TC01OMT-1	9/9/97	7:43	10:03	0.100	0.0002	0.119	NA
TC01OMT-2	9/10/97	7:46	13:46	0.114	0.0002	0.137	NA
TC01OMT-3	9/12/97	7:45	13:30	0.127	0.0003	0.155	NA
TC01OMT-4	9/16/97	7:30	13:30	0.530	0.0011	0.645	NA
TC01OMT-5	9/19/97	8:30	13:15	0.230	0.0005	0.279	0.05
TC01OMT-6	9/25/97	7:45	13:16	3.79	0.0086	4.61	0.11
TC01OMT-7	10/3/97	7:25	13:35	11.11	0.0249	13.5	0.05
TC01OMT-8	10/13/97	7:45	12:50	5.13	0.0124	6.22	0.11
TC01OMT-9	10/15/97	8:15	12:30	5.87	0.0136	7.13	0.08
TC01OMT-10	10/21/97	7:55	13:30	12.74	0.0280	15.5	0.05
TC01OMT-11	10/28/97	8.58	13:58	NA[3]	NA	NA	NA
TC01OMT-12	10/30/97	9:35	14:05	4.84	0.0112	5.92	0.17
TC01OMT-13	12/1/97	9:25	12:48	3.92	0.0089	4.75	0.07
TC01OMT-14	12/3/97	9:30	14:00	4.02	0.0091	4.91	0.09
TC01OMT-15	12/5/97	9:40	14:10	4.17	0.0094	5.08	0.14
TC01OMT-16	12/8/97	10:20	14:40	5.28	0.0119	6.44	0.10

1. All times are central standard time.
2. Equivalent particulate loading calculated from mass change of blank filter.
3. Run was not valid because of leak in sample line.

Table 3.25.1-3

PCD Particulate Collection Efficiencies for Test Program TC01

SRI Run No	Date Sampled	Run Time[1] Start	Run Time[1] End	Loading, mg/scm Inlet[2]	Loading, mg/scm Outlet	Efficiency (%)	Penetration (%)
TC01OMT-1	9/9/97	7:43	10:03	13,700	0.119	99.999	0.001
TC01OMT-2	9/10/97	7:46	13:46	13,700	0.137	99.999	0.001
TC01OMT-3	9/12/97	7:45	13:30	13,700	0.155	99.999	0.001
TC01OMT-4	9/16/97	7:30	13:30	13,700	0.645	99.995	0.005
TC01OMT-5	9/19/97	8:30	13:15	13,700	0.279	99.998	0.002
TC01OMT-6	9/25/97	7:45	13:16	13,700	4.61	99.966	0.034
TC01OMT-7	10/3/97	7:25	13:35	13,700	13.5	99.902	0.098
TC01OMT-8	10/13/97	7:45	12:50	13,700	6.22	99.955	0.045
TC01OMT-9	10/15/97	8:15	12:30	13,700	7.13	99.948	0.052
TC01OMT-10	10/21/97	7:55	13:30	13,700	15.5	99.887	0.113
TC01OMT-11	10/28/97	8.58	13:58	13,700	NA[3]	NA	NA
TC01OMT-12	10/30/97	9:35	14:05	13,700	5.92	99.957	0.043
TC01OMT-13	12/1/97	9:25	12:48	13,700	4.75	99.965	0.035
TC01OMT-14	12/3/97	9:30	14:00	13,700	4.91	99.964	0.036
TC01OMT-15	12/5/97	9:40	14:10	13,700	5.08	99.963	0.037
TC01OMT-16	12/8/97	10:20	14:40	13,700	6.44	99.953	0.047

1. All times are central standard time.
2. Inlet loading used for calculating efficiencies is average of all TC01 inlet runs.
3. Run was not valid because of leak in sample line.

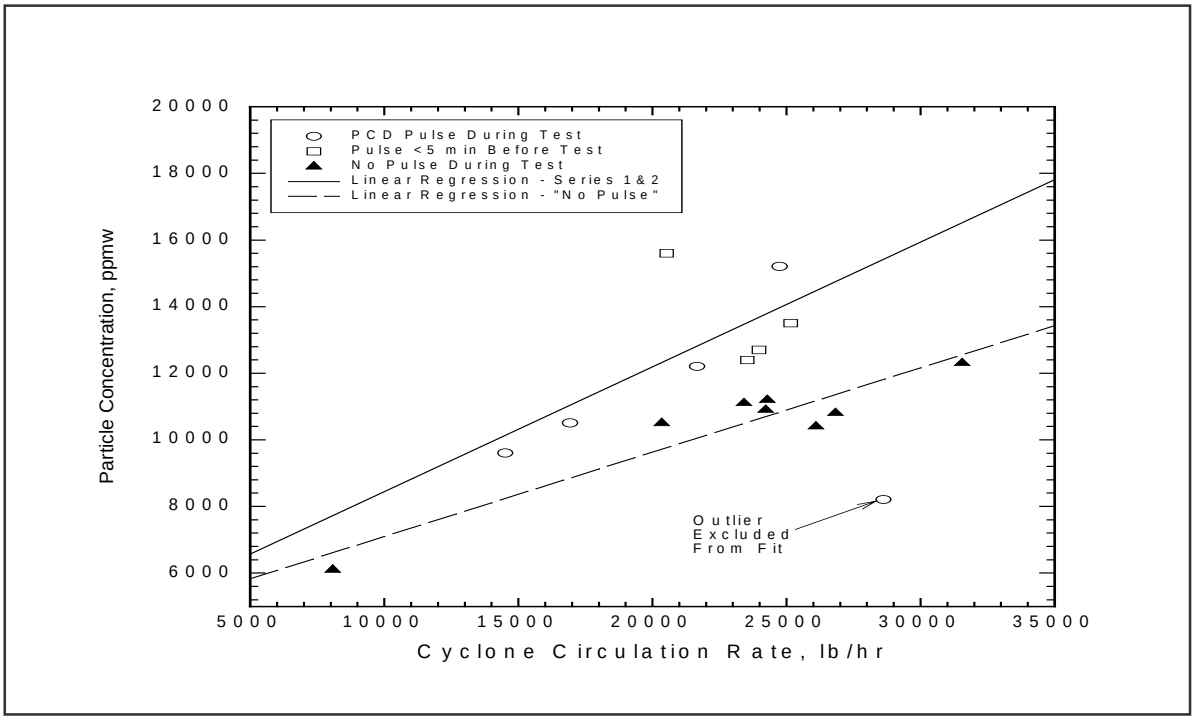


Figure 3.25.1-1 PCD Inlet Mass Concentration as a Function of Cyclone Solids Rate With and Without the Effect of PCD Pulsing

3.25.2 Measurements of Particle-Size Distributions

Figure 3.25.2-1 shows particle-size distributions measured on various inlet particulate samples on the basis of cumulative percentage of the mass contained in particles smaller than a given size. Figure 3.25.2-2 shows the same particle-size data presented as a differential mass distribution (i.e., the particulate mass contained in a given particle-size increment). For the samples collected during CCT4 and CCT5, these data were obtained by analysis of the inlet mass train samples using a combination of sieves and a Leeds & Northrup Microtrac X-100 particle-size analyzer. The data on CCT6 and TC01 samples were obtained using the Microtrac analyzer alone without sieving. Sieving was not necessary or even possible for the CCT6 and TC01 samples because the relatively low concentration of large particles did not present a problem for the Microtrac analyzer, and the higher concentration of small particles tended to blind the finest sieve. As evident from figures 3.25.2 -1 and -2, size-distribution measurements made during a given test series showed reasonably good consistency. One possible exception is the two measurements made during CCT5, which suggest significant differences in the size distributions at particle sizes below about 3 μm.

As shown in figures 3.25.2-1 and -2, the inlet size distributions for CCT4, CCT5, and CCT6 show a progression toward finer particle sizes as operations personnel achieved better control of particulate carryover from the transport reactor. The size distributions obtained during TC01 actually show a slight reversal of this trend although the TC01 size distributions are still significantly finer than those for CCT4 and CCT5. Comparison of the differential mass distributions (figure 3.25.2-2) shows that the distinct large-particle mode that was evident in the CCT4 data was eliminated in the subsequent tests. Again, the elimination of this large-particle mode is a result of the improved control of particulate carryover from the transport reactor.

Figures 3.25.2-3 and -4 show the outlet particle-size distributions obtained from the two cascade impactor runs performed during TC01. These measurements confirm that the ash penetrating through the PCD is quite fine (mmd ≅ 2 μm). The cumulative percentage distribution is nearly linear when plotted in log-probability space (figure 3.25.2-3), indicating that the outlet size distribution is almost perfectly lognormal and unimodal. A unimodal lognormal size distribution usually indicates that the particles have been generated by a single mechanism or that one or more size modes have been eliminated by some sort of size classifying mechanism. In this particular case it is possible that a large-particle mode could have been eliminated or minimized by preferential entrapment of the larger particles in the fail-safe devices. Nevertheless, some of the particles that are penetrating through the PCD are apparently large enough to be of concern from the standpoint of turbine blade erosion (particles larger than 5 μm account for approximately 20 percent of the total particulate mass, or about 1.3 ppmw). Of course, it is possible that most or even all of this particle penetration could be eliminated by seal welding the flange joints on the fail-safe devices.

Figure 3.25.2-5 shows a direct comparison of the inlet and outlet size distributions discussed above. It is important when comparing these distributions to note that the inlet size distributions were determined by Microtrac analysis of the inlet samples while the outlet size distributions were determined directly by in situ sampling with cascade impactors. Because of the difficulty in redispersing submicron particles the inlet data may not be reliable on very small

particle sizes (< 1 μm). Despite this limitation it is clear that the outlet size distribution is shifted toward finer particles in comparison to the inlet size distributions. Particles larger than about 30 μm have been almost completely eliminated, while the removal of the finest particles (< 1 μm) is obviously much less efficient. The effect on collection efficiency is illustrated dramatically in figure 3.25.2-6. Below 1 μm, the collection efficiency curve is shown as an extrapolation because of the uncertainty in the Microtrac data on these fine particles. Over the range of particle sizes that can be resolved penetration varies by three orders of magnitude (from 99.999 percent collection efficiency at 25 μm down to 99.5 percent collection efficiency at 0.8 μm). The total collection efficiency for all particle sizes is 99.96 percent.

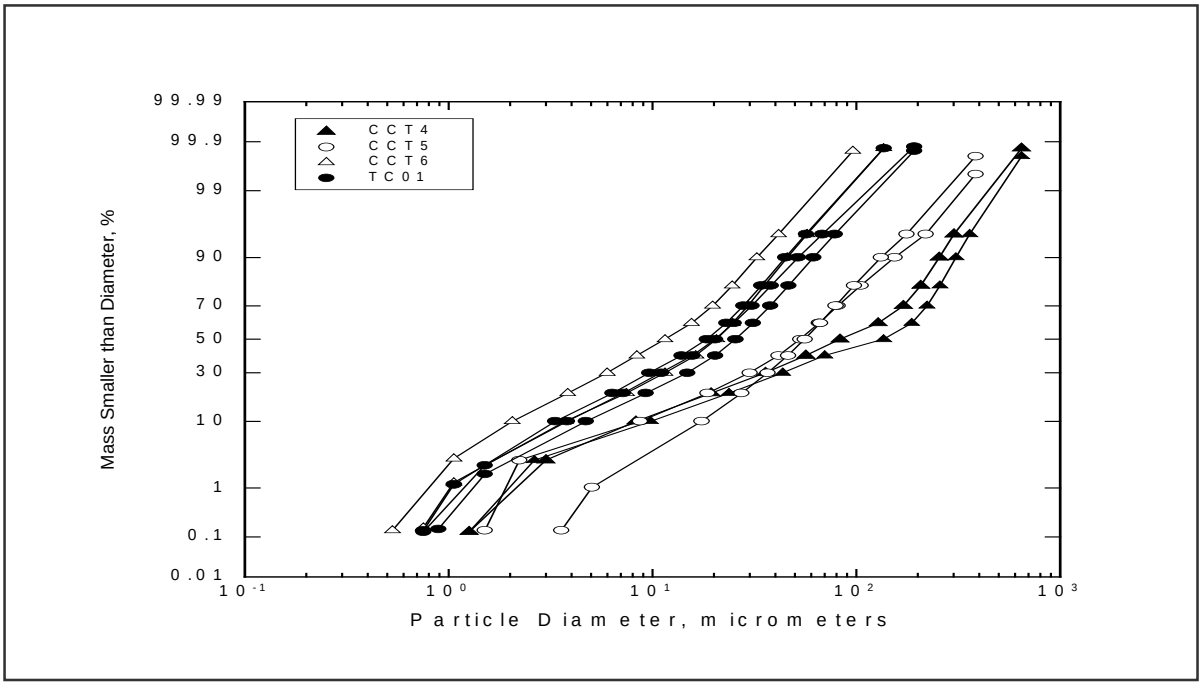


Figure 3.25.2-1 Cumulative Percentage Mass Distributions Measured at PCD Inlet

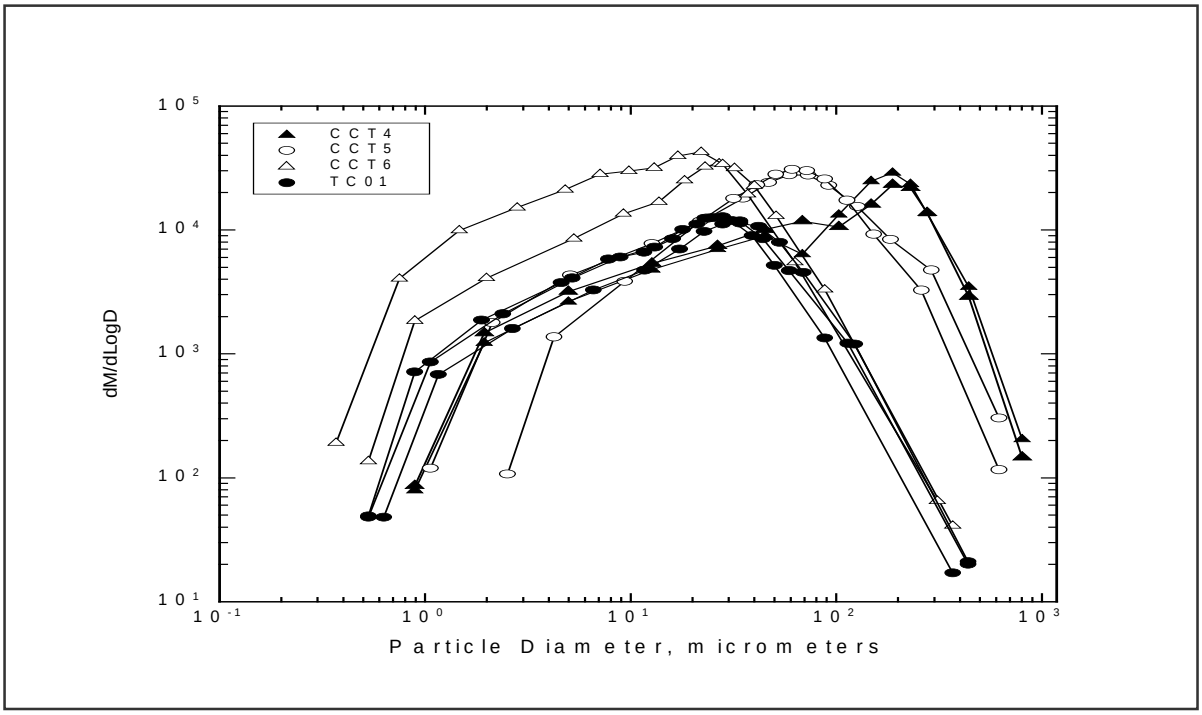


Figure 3.25.2-2 Differential Mass Distributions Measured at PCD Inlet

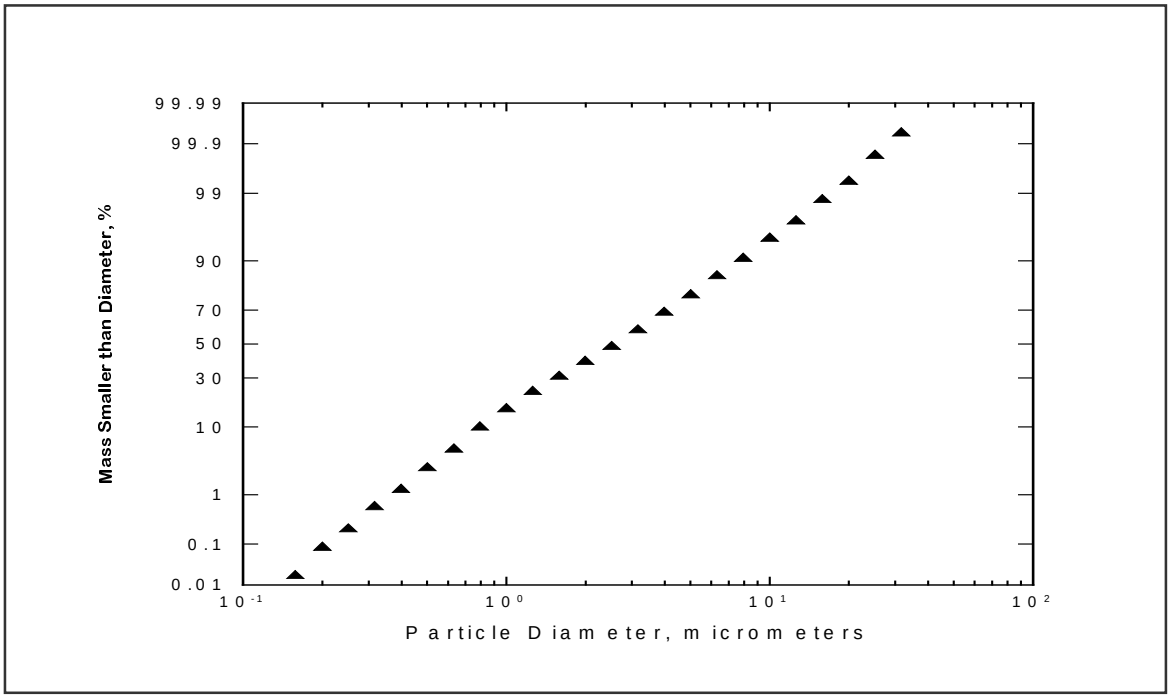


Figure 3.25.2-3 Cumulative Percentage Mass Distribution Measured at PCD Outlet

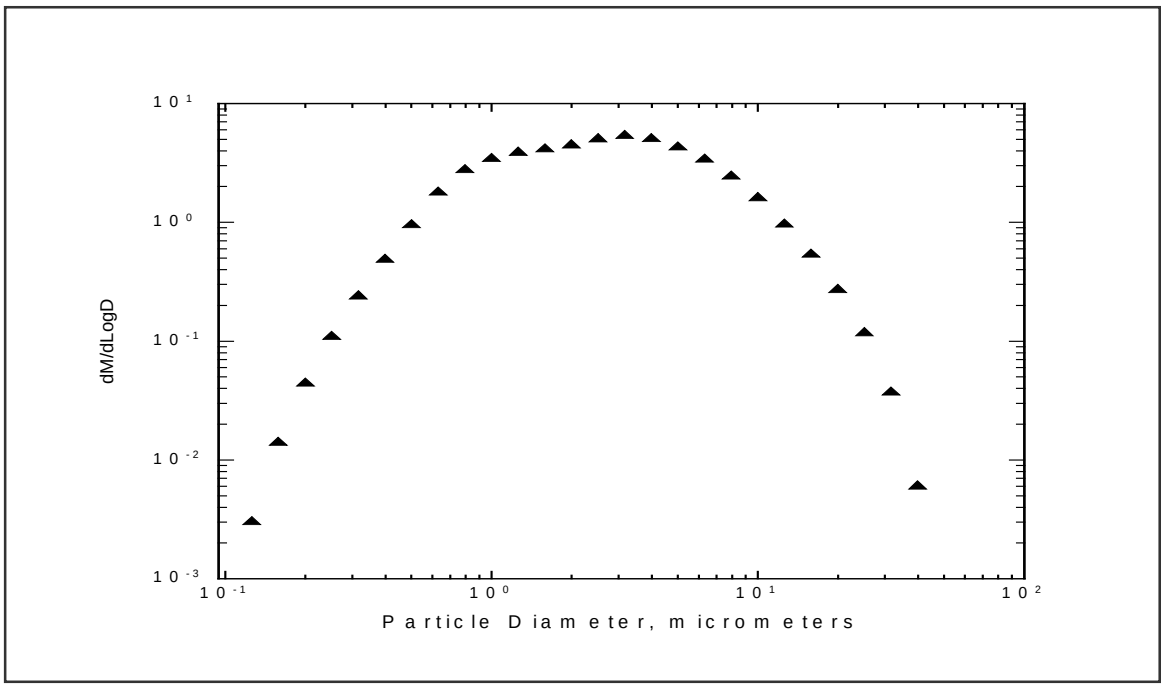


Figure 3.25.2-4 Differential Mass Distributions Measured at PCD Outlet

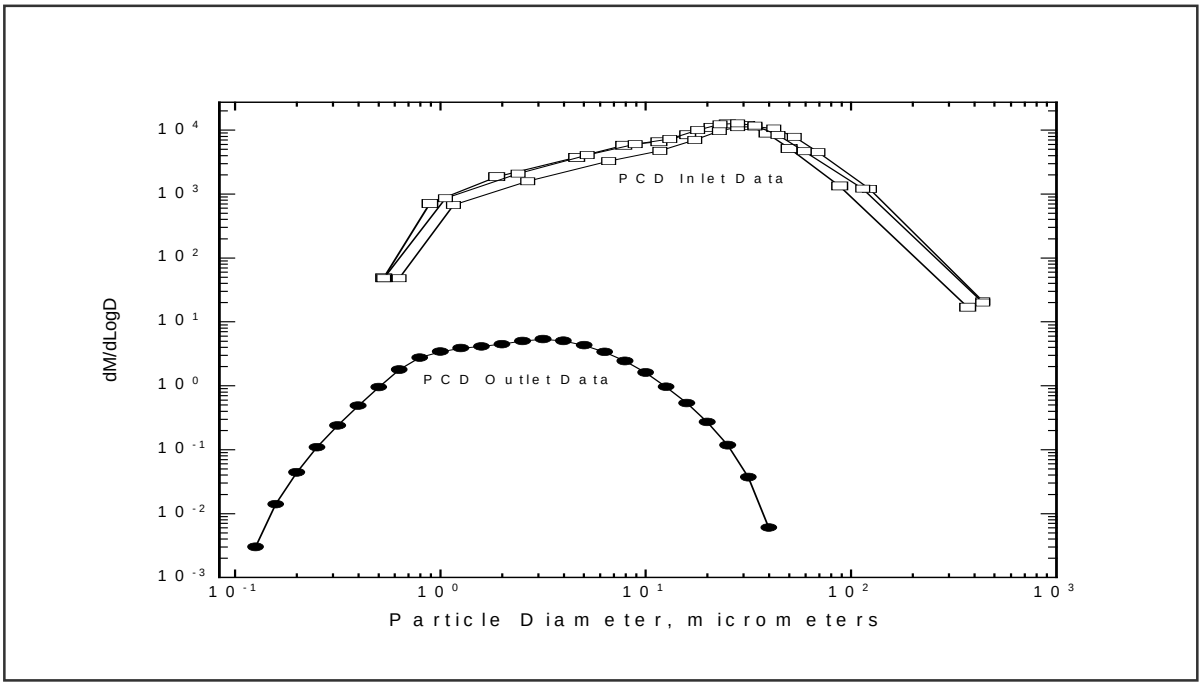


Figure 3.25.2-5 Comparison of Inlet and Outlet Differential Mass Distributions

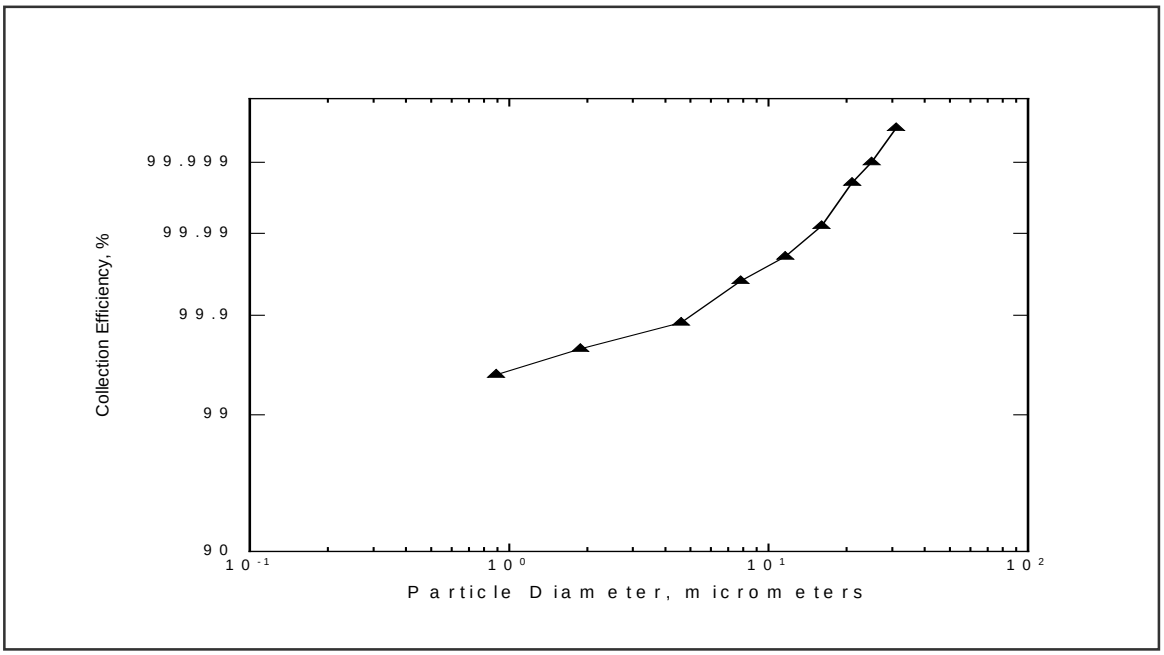


Figure 3.25.2-6 Calculated PCD Collection Efficiency as a Function of Particle Size

3.25.3 Chemical Analyses

The results of TC01 ash mineral analyses are summarized in tables 3.25.3-1a, -1b, -1c, -2, and -3. Tables 3.25.3-1a, -1b, and -1c summarize the chemical composition of selected hopper (FD0520) samples collected during TC01. Table 3.25.3-2 gives the same information for the isokinetically-collected ash samples, while table 3.25.3-3 contains the data for the dustcake samples taken from the PCD candles during the November and January PCD inspections. All of the analytical results are reported as the element on an ignited basis. The elemental concentrations are not reported in their oxide forms since calcium is predominantly present in the form of sulfate and carbonate. Other ash constituents are also present as sulfates and carbonates as well as other forms such as silicates, aluminosilicates, halides, and sulfides.

Based on the hopper ash analyses shown in table 3.25.3-1, the average calcium utilization (i.e., the percentage of the calcium that is converted to calcium sulfate on a molar basis) was 44.6 percent ± 8.9 percent. Given the large standard deviation this value of utilization is indistinguishable from the 50 percent utilization that would be expected based on the observed SO_2 removal (essentially 100 percent) and the targeted injection rate of dolomite (2-to-1 calcium-to-sulfur ratio, nominally). Since the sorbent is dolomite and the inherent calcium in the coal is quite low (typically <1 percent of the coal ash) the calcium-to-magnesium molar ratio in the ash would be expected to be close to 1-to-1. The average value calculated from the hopper ash analysis is 0.98-to-1.

The hopper ash analyses were used to calculate the average chemical composition of the solids collected in the PCD assuming that all of the sulfur was present as $CaSO_4$ and all of the carbon was present as $CaCO_3$. Any remaining calcium that was not accounted for as $CaSO_4$ or $CaCO_3$ was assumed to be present as CaO●MgO. Any remaining magnesium that was not accounted for as CaO●MgO was assumed to be present as MgO. The balance of each sample was assumed to be ash and sand (bed material). The choice of these particular calcium and magnesium compounds was based on free-energy minimization calculations performed by Dr. L. Shadle at DOE/FETC and reported by P. Smith (personal communication, March 6, 1998). The average chemical composition calculated in this manner is summarized below.

- 11.33 percent ± 2.04 percent $CaSO_4$.
- 9.06 percent ± 2.48 percent CaO●MgO.
- 1.19 percent ± 0.45 percent $CaCO_3$.
- 3.94 percent ± 0.84 percent MgO.
- 74.48 percent ± 3.01 percent ash/sand.

Three of the in situ samples from TC01 were subjected to chemical analysis (see table 3.25.3-2). Calcium utilization could not be determined for these samples because they were not analyzed for sulfur. Despite large variations in the calcium content (5.6 to 15.2 percent) and in the magnesium content (2.4 to 9.4 percent), the calcium-to-magnesium molar ratios on the three in situ samples

were reasonably consistent and reasonably close to 1-to-1 (0.96-to-1, 0.92-to-1, and 0.92-to-1). Nine additional samples have been submitted for analysis because of the large variations in these samples.

Chemical analyses were done on two dustcake samples from the November and January inspections. These samples were scraped off the filter element surface at the locations noted in table 3.25.3-3. In comparing dustcake samples collected in November and January, the November samples contain about 30 to 50 percent more calcium and about 70 to 230 percent more sulfur than the dustcake samples collected in January. Listed below are the calculated chemical compositions of the dustcake samples and compares them to the average chemical composition of the hopper samples.

	Dustcake 11/5/97	Dustcake 1/21/98	Hopper Ash Average
$CaCO_3$, Wt%	0.61 – 0.95	1.13 – 1.21	1.19 ± 0.45
$CaSO_4$, Wt%	10.29 – 11.77	3.61 – 5.99	11.33 ± 2.04
CaO●MgO, Wt%	2.41 – 3.04	3.10 – 3.90	9.06 ± 2.48
MgO, Wt%	5.70 – 6.11	2.83 – 3.73	3.94 ± 0.84
Ash/Sand (diff), Wt%	79.10 – 80.02	85.97 – 88.54	74.48 ± 3.01

As shown above, the November dustcake samples contain more $CaSO_4$ and MgO and less $CaCO_3$ and CaO●MgO than do the January dustcake samples. This suggests that more of the CaO●MgO has been converted to $CaSO_4$ and MgO in the November dustcake samples. Although the concentration of $CaSO_4$ in the November dustcake samples is similar to that found in the hopper samples the concentration of CaO●MgO is significantly lower in both sets of dustcake samples than it is in the hopper samples (3.11 ± 0.61 percent versus 9.06 ± 2.48 percent). The relatively low levels of CaO●MgO in the November dustcake samples coupled with $CaSO_4$ levels that are comparable to those of the hopper samples result in a significantly higher calcium utilization in the November dustcake samples (65 to 73 percent versus 34 to 53 percent for the hopper samples and the January dustcake samples).

In attempting to understand these compositional differences between the dustcake samples and the other types of samples, it is important to note that the dustcake samples represent residual solids that are left on the candles after numerous process transients including several system startups, shutdowns, disruptions in coal and sorbent feed, and numerous back-pulses after shutdown. Also, it is possible that the larger particles in the inlet gas stream are not collected on the filter elements in representative numbers. Therefore, it is not surprising that the chemical composition of the ash samples taken from the filter elements after shutdown bears little resemblance to that of the ash samples taken from the PCD hopper during testing. Additional work will be required to develop a better understanding of the factors that determine the ultimate chemical composition of the residual dustcake.

Table 3.25.3-1A

Elemental Analysis of Selected TC01 Hopper Samples[1]

I. D. No. (ABO-)	1688	1729	1759	1770	1771	1773	1806	1803	1834
Date Collected	9/11/97	9/16/97	9/17/97	9/17/97	9/18/97	9/18/97	9/19/97	9/22/97	9/25/97
Measured Composition									
Silicon (%)	22.18	21.13	20.94	21.65	19.55	21.45	20.62	21.32	22.85
Aluminum (%)	11.96	11.32	10.74	11.41	10.55	11.25	10.68	11.68	10.70
Titanium (%)	0.64	0.56	0.57	0.62	0.61	0.63	0.60	0.62	0.59
Iron (%)	3.33	3.00	2.99	3.06	3.22	3.16	3.17	3.21	3.40
Calcium (%)	8.31	8.72	8.87	8.39	8.00	8.86	8.05	8.06	6.09
Magnesium (%)	4.81	4.98	5.11	5.28	5.22	5.22	4.80	5.26	4.00
Potassium (%)	1.38	1.31	1.36	1.28	1.22	1.67	1.61	1.57	1.26
Sodium (%)	1.50	1.37	1.25	1.39	1.35	1.29	1.29	1.32	1.11
Phosphorous (%)	0.25	0.22	0.27	0.25	0.25	0.23	0.28	0.29	0.30
Sulfur (%)	2.51	1.74	2.39	2.88	3.03	3.05	3.04	3.59	3.35
Carbon (%)	0.18	0.02	0.14	0.20	0.15	0.18	0.16	0.05	0.14
Oxygen (%) (diff)	42.95	45.63	45.37	43.59	46.85	43.01	45.70	43.03	46.21
Calculated Parameters									
Utilization (%)[2]	37.8	24.9	33.7	42.9	47.3	43.0	47.2	55.7	68.8
Ca/S Molar Ratio	2.65	4.01	2.97	2.33	2.11	2.32	2.12	1.80	1.45
Ca/Mg Molar Ratio	1.04	1.05	1.04	0.95	0.92	1.02	1.01	0.92	0.91
$CaCO_3$ (%)	1.56	0.17	1.21	1.73	1.30	1.56	1.39	0.43	1.21
$CaSO_4$ (%)	10.67	7.40	10.16	12.24	12.88	12.96	12.92	15.26	14.24
CaO•MgO (%)	10.97	15.55	13.00	9.90	8.91	10.67	8.92	8.17	3.45
MgO (%)	3.44	1.82	3.10	4.68	4.99	4.25	4.28	5.36	5.23
Ash/Sand (%) (diff)	73.35	75.06	72.53	71.45	71.93	70.55	72.49	70.77	75.87

Notes: (1) Wt% ignited basis expressed as element (not oxide); excludes samples for which the sum of the oxides is less than 90 percent.
(2) Calcium utilization (i.e., % of Ca converted to $CaSO_4$ assuming all sulfur is present as $CaSO_4$).

Table 3.25.3-1B

Elemental Analysis of Selected TC01 Hopper Samples[1]

I. D. No. (ABO-)	2032	1888	2191	2327	2362	2363	2364	2365
Date Collected	10/3/97	10/5/97	11/1/97	11/21/97	11/29/97	11/30/97	11/30/97	11/30/97
Measured Composition								
Silicon (%)	21.12	22.94	21.45	20.74	22.47	21.02	21.58	20.88
Aluminum (%)	10.31	11.70	11.23	11.74	12.00	11.09	11.19	10.88
Titanium (%)	0.58	0.68	0.63	0.60	0.64	0.60	0.61	0.59
Iron (%)	3.31	3.64	3.69	3.45	3.57	3.35	3.35	3.27
Calcium (%)	6.88	5.92	8.65	8.71	6.16	5.76	7.69	6.99
Magnesium (%)	4.10	3.75	5.30	5.41	3.94	3.73	4.81	4.55
Potassium (%)	1.70	0.82	1.87	0.09	1.00	1.35	0.87	0.52
Sodium (%)	1.21	1.35	0.71	1.08	1.04	1.32	1.09	1.16
Phosphorous (%)	0.34	0.00	0.16	1.77	0.26	0.26	0.25	0.24
Sulfur (%)	1.67	1.85	3.09	3.06	2.64	2.51	2.60	2.39
Carbon (%)	0.14	0.12	0.09	0.19	0.14	0.09	0.20	0.15
Oxygen (%) (diff)	48.64	47.23	43.13	43.16	46.14	48.92	45.76	48.38
Calculated Parameters								
Utilization (%)[2]	30.3	39.1	44.7	43.9	53.6	54.5	42.3	42.7
Ca/S Molar Ratio	3.30	2.56	2.24	2.28	1.87	1.84	2.37	2.34
Ca/Mg Molar Ratio	1.01	0.95	0.98	0.97	0.94	0.93	0.96	0.92
$CaCO_3$ (%)	1.21	1.04	0.78	1.65	1.21	0.78	1.73	1.30
$CaSO_4$ (%)	7.10	7.86	13.13	13.01	11.22	10.67	11.05	10.16
CaO•MgO (%)	10.38	7.70	10.77	10.20	5.74	5.57	9.06	8.41
MgO (%)	2.51	3.04	4.35	4.77	4.17	3.89	4.24	4.08
Ash/Sand (%) (diff)	78.80	80.36	70.97	70.38	77.65	79.08	73.92	76.06

Notes: (1) Wt% ignited basis expressed as element (not oxide); excludes samples for which the sum of the oxides is less than 90 percent.
(2) Calcium utilization (i.e., % of Ca converted to $CaSO_4$ assuming all sulfur is present as $CaSO_4$).

Table 3.25.3-1C

Elemental Analysis of Selected TC01 Hopper Samples[1]

I. D. No. (ABO-)	2367	2392	2462	2464	2465	2476	Tables 1a, 1b, 1c.		
Date Collected	12/1/97	12/2/97	12/6/97	12/7/97	12/7/97	12/8/97	Avg	S.D.	RSD, %
Measured Composition									
Silicon (%)	21.04	21.55	21.47	21.06	23.01	21.10	21.44	0.81	3.79
Aluminum (%)	12.35	12.86	13.19	12.94	12.25	10.86	11.52	0.80	6.95
Titanium (%)	0.66	0.69	0.69	0.68	0.63	0.55	0.62	0.04	6.47
Iron (%)	3.56	3.68	3.41	3.38	3.15	3.05	3.32	0.21	6.35
Calcium (%)	8.17	7.29	6.04	7.28	7.39	7.71	7.56	1.02	13.50
Magnesium (%)	4.74	4.30	3.72	4.36	4.42	4.66	4.63	0.56	12.04
Potassium (%)	0.88	0.72	0.63	0.72	0.45	0.72	1.09	0.46	42.54
Sodium (%)	0.48	0.54	0.83	1.08	0.11	0.27	1.05	0.38	36.27
Phosphorous (%)	0.22	0.21	0.17	0.20	0.20	0.16	0.29	0.33	111.39
Sulfur (%)	2.57	2.77	2.29	2.74	2.71	2.86	2.67	0.48	17.97
Carbon (%)	0.23	0.17	0.07	0.09	0.09	0.16	0.14	0.05	38.29
Oxygen (%) (diff)	45.10	45.22	47.49	45.47	45.59	47.90	45.67	1.89	4.14
Calculated Parameters									
Utilization (%)[2]	39.3	47.5	47.4	47.0	45.8	46.4	44.6	8.9	20.0
Ca/S Molar Ratio	2.54	2.11	2.11	2.13	2.18	2.16	2.34	0.53	22.6
Ca/Mg Molar Ratio	1.03	1.02	0.97	1.00	1.00	0.99	0.98	0.04	4.5
$CaCO_3$ (%)	1.99	1.47	0.61	0.78	0.78	1.39	1.19	0.45	38.3
$CaSO_4$ (%)	10.92	11.77	9.73	11.65	11.52	12.16	11.33	2.04	18.0
CaO•MgO (%)	10.06	7.83	7.07	8.53	8.89	8.64	9.06	2.48	27.4
MgO (%)	3.71	3.91	3.26	3.71	3.66	4.17	3.94	0.84	21.3
Ash/Sand (%) (diff)	73.32	75.02	79.34	75.33	75.15	73.65	74.48	3.01	4.0

Notes: (1) Wt% ignited basis expressed as element (not oxide); excludes samples for which the sum of the oxides is less than 90 percent.
(2) Calcium utilization (i.e., % of Ca converted to $CaSO_4$ assuming all sulfur is present as $CaSO_4$).

Table 3.25.3-2

Elemental Analysis of Selected TC01 In Situ Samples[1]

I. D. No. (ABO-)	2512	2513	2514			
Date Collected	9/12/97	9/25/97	12/5/97	AVG	S. D.	RSD (%)
Measured Composition						
Silicon (%)	15.34	22.07	23.17	20.19	4.24	20.99
Aluminum (%)	7.73	11.29	12.02	10.35	2.30	22.18
Titanium (%)	0.44	0.66	0.66	0.59	0.13	21.65
Iron (%)	2.41	3.43	3.42	3.09	0.59	18.99
Calcium (%)	15.18	3.74	5.59	8.17	6.14	75.16
Magnesium (%)	9.45	2.43	3.63	5.17	3.75	72.63
Potassium (%)	0.65	0.72	1.22	0.86	0.31	36.01
Sodium (%)	1.91	1.14	1.83	1.63	0.42	26.03
Phosphorous (%)	0.22	0.30	0.26	0.26	0.04	15.38
Sulfur (%)	N. M.[2]	N. M.	N. M.			
Carbon (%)	N. M.	N. M.	N. M.			
Oxygen (%) (diff)	46.67	54.22	48.20	49.70	3.99	8.03
Calculated Parameters						
Ca/Mg Molar Ratio	0.96	0.92	0.92	0.94	0.02	2.47

Notes: (1) Wt% ignited basis expressed as element (not oxide).
(2) N.M. = Not measured.

Table 3.25.3-3

Elemental Analysis of Selected TC01 Candle Samples[1]

I. D. No. (ABO-)	2216	2219	2579	2580			
Sample Location	Top[2]	Bottom[3]	Top[2]	Bottom[3]			
Date Collected	11/5/97	11/5/97	1/21/98	1/21/98	AVG	S. D.	RSD (%)
Measured Composition							
Silicon (%)	25.23	24.56	23.60	22.76	24.04	1.08	4.51
Aluminum (%)	12.69	13.56	12.68	11.76	12.67	0.74	5.80
Titanium (%)	0.69	0.63	0.70	0.72	0.69	0.04	5.65
Iron (%)	3.75	3.48	4.17	4.36	3.94	0.40	10.12
Calcium (%)	4.66	4.70	3.12	3.52	4.00	0.80	20.05
Magnesium (%)	4.18	4.27	2.67	3.01	3.53	0.81	23.00
Potassium (%)	1.38	1.70	1.96	1.99	1.76	0.28	16.12
Sodium (%)	0.19	0.13	0.10	0.17	0.15	0.04	27.33
Phosphorous (%)	0.25	0.24	0.21	0.21	0.23	0.02	9.06
Sulfur (%)	2.42	2.77	0.85	1.41	1.86	0.89	47.66
Carbon (%)	0.11	0.07	0.13	0.14	0.11	0.03	27.52
Oxygen (%) (diff)	44.45	43.89	49.81	49.95	47.03	3.31	7.03
Calculated Parameters							
Utilization (%)[4]	64.9	73.7	34.1	50.1	55.68	17.40	31.25
Ca/S Molar Ratio	1.54	1.36	2.94	2.00	1.96	0.71	36.04
Ca/Mg Molar Ratio	0.67	0.66	0.70	0.70	0.68	0.02	3.15
$CaCO_3$ (%)	0.95	0.61	1.13	1.21	0.98	0.27	27.52
$CaSO_4$ (%)	10.29	11.77	3.61	5.99	7.92	3.77	47.66
CaO•MgO (%)	3.04	2.41	3.90	3.10	3.11	0.61	19.59
MgO (%)	5.70	6.11	2.83	3.73	4.59	1.57	34.23
Ash/Sand (%) (diff)	80.02	79.10	88.54	85.97	83.41	4.58	5.49

Notes: (1) Wt% ignited basis expressed as element (not oxide).
(2) Sample taken from top of candle in top tier of candles.
(3) Sample taken from bottom of candle in bottom tier of candles.
(4) Calcium utilization (i.e., % of Ca converted to $CaSO_4$ on a molar basis).

3.25.4 Measurements of Permeability and Related Properties

Permeability tests have been performed on selected in situ samples, dustcake samples, and hopper samples. Tables 3.25.4-1 and -2 give a summary of the permeability test results which are expressed in terms of drag-equivalent diameter (DED) along with the results of other significant physical measurements including: true (skeletal particle) density, bulk density, uncompacted bulk porosity (UBP), surface area, and mass median diameter (MMD). The DED is not a physical size, but rather a fitted parameter that can be used to rank the characteristic gas flow resistance of ashes at equal porosities. Measurements of physical size generally correlate with DED but the DED best expresses the fineness of an ash as it relates to its effect on gas flow resistance (drag). Increasing values of DED indicate lower resistance to gas flow (less drag) at a given porosity. Using the DED as an indicator of flow resistance eliminates much of the ambiguity associated with drag measurements, which are a strong function of porosity.

True density measurements were made by helium pycnometry using a Quantachrome Model 1000 Ultrapycnometer. Bulk density was determined by measuring the volume of a known weight of ash and uncompacted bulk porosity was calculated from the true density and bulk density. Specific surface area was determined by the BET method using a Micromeritics FloSorb-II analyzer, and the MMD was based on particle-size analysis on a Leeds & Northrup Microtrac X-100 analyzer.

Table 3.25.4-1 contains the physical properties measured for in situ samples collected during CCT4, CCT5, CCT6, and TC01. Only a few samples were analyzed from the earlier test programs because unstable operation of the transport reactor makes those samples of questionable value. Comparison of the averages for the test programs shows that improved reactor operation with increased operating time has reduced median particle size, increased surface area, and increased dustcake flow resistance.

The physical properties of dust samples removed from the filter elements during TC01 are shown in table 3.25.4-2. Two sets of dustcake samples are included (November 5, 1997, and January 21, 1998) with four samples representing different vertical elevations in the PCD in each set. No consistent variation in any of the properties can be correlated to elevation. On January 21, 1998, a fifth sample was taken from the innermost candle of the bottom tier to determine if the area away from the cyclonic flow contained fewer large particles. The particle size distribution of this sample was not significantly different from the other samples collected at the perimeter of the candle bundle.

Also shown in table 3.25.4-2 are properties of selected PCD hopper samples. Listed below are results obtained on the three basic types of samples examined during TC01: in situ, dustcake, and hopper.

	In Situ	Dustcake	Hopper
True Density, g/cc	2.71 ± 0.13	2.80 ± 0.31	2.67 ± 0.04
Bulk Density, g/cc	0.54 ± 0.05	0.50 ± 0.02	0.59 ± 0.05
UBP, %	79.8 ± 2.3	82.0 ± 2.0	77.1 ± 1.5
Surface Area, m^2/g	2.96 ± 0.38	4.27 ± 0.63	N. D.
MMD, μm	22.0 ± 3.7	8.7 ± 0.7	28.8 ± 9.7
DED, μm	2.47 ± 0.62	1.68 ± 0.52	2.32 ± 0.57
Calcium, Wt %	8.17 ± 6.14	4.00 ± 0.80	8.05

In terms of the physical properties listed above, the in situ samples appear to be fairly similar to the hopper samples but there appear to be some significant differences between these types of samples and the dustcake samples. The true densities, bulk densities, and uncompacted bulk porosities of the candle samples are similar to the values measured for the other samples. However, the candle samples exhibit somewhat higher surface areas along with lower MMDs, DEDs, and calcium content. The mathematical models currently being used to correlate drag data predict that a smaller MMD or a higher surface area would tend to produce a smaller DED (i.e., more drag).

Work has just begun to develop a better understanding of how flow resistance, or DED, varies with various parameters. Several preliminary correlations are shown in figures 3.25.4-1, -2, and -3. The effect of calcium content on the DED is illustrated in figure 3.25.4-1. This graph is based on only three data points because most of the chemical analyses of the in situ samples have not yet been completed. (Analyses were not complete when this report was drafted and results will be reported in the future.) Although the data are limited it is reasonable to expect this type of relationship between calcium content and DED since similar relationships have been documented in previous studies of fabric filter performance (Bush, Snyder, and Chang, "Determination of Baghouse Performance from Coal and Ash Properties: Part II," *J. Air Pollut Control Assoc*, 39 (3), pp. 361-372).

Figures 3.25.4-2 and -3 illustrate the effect of specific surface area on DED based on an analysis of dustcake samples alone and on an analysis of all samples (16 in situ samples, eight dustcake samples, and one hopper sample). (Simultaneous measurements of specific surface area and DED are currently available on only one hopper sample because the permeability studies that have been done to date have focused mainly on in situ samples and dustcake samples.) Both graphs show the expected trend toward lower DEDs (more flow resistance) as specific surface area increases. The increasing surface area is partly a consequence of decreasing particle size, and similar trends can be obtained by plotting DED versus MMD. It is interesting to note that the November dustcake samples have significantly higher surface areas than the January samples (4.83 ± 0.22 m^2/g versus 3.72 ± 0.20 m^2/g) and somewhat lower MMDs (8.3 ± 0.5 μm versus 9.1 ± 0.7 μm). The ratio of the average surface areas is about 1.3-to-1, while the ratio of the

squares of the average MMDs is about 1.2-to-1. Thus, most but not all of the difference in surface areas can be explained by the difference in median particle size.

The analysis of the TC01 particulate data (permeability, physical properties, and chemistry) is currently ongoing. In the months ahead additional analytical data will be received and additional permeability tests will be performed. As this new information becomes available the tables and graphs presented here will be updated accordingly. More meaningful correlations of the data will also be developed with the objective of refining our understanding of PCD performance. Ultimately, our goal is to reach the point where changes in PCD performance can be diagnosed and even predicted from the results of these types of laboratory tests.

Table 3.25.4-1

Physical Properties of In Situ Samples

Run Number	Date Sampled	Lab ID No.	True Density (g/cc)	Bulk Density (g/cc)	UBP[1] (%)	Surface Area (m^2/g)	MMD[2] (μm)	DED[3] (μm)
Test Program CCT4								
CCT4IMT-7	5/1/97	AB01289	2.54	1.01	60.2	0.94	83.1	9.28
CCT4IMT-8	5/2/97	AB01290	2.53	1.09	56.9	0.48	135.5	13.36
Average for CCT4			2.54	1.05	58.58	0.71	109.3	11.32
Test Program CCT5								
CCT5IMT-4	5/16/97	AB01294	2.85	0.92	67.7	1.26	53.0	7.02
CCT5IMT-5	5/16/97	AB01295	2.74	0.86	68.6	1.31	55.8	7.74
Average for CCT5			2.80	0.89	68.17	1.29	54.4	7.38
Test Program CCT6								
CCT6IMT-1	6/24/97	AB01410	2.94	0.75	74.5	2.23	20.6	4.56
CCT6IMT-2	6/24/97	AB01411	3.12	0.74	76.3	2.56	11.5	2.65
Average for CCT6			3.03	0.75	75.39	2.40	16.1	3.60
Test Program TC01								
TC01IMT-2	9/11/97	AB01931	2.71	0.55	79.7	2.65	18.5	2.71
TC01IMT-3	9/12/97	AB02512	2.73	0.53	80.6	2.64	17.1	3.11
TC01IMT-4	9/16/97	AB02575	2.62	0.73	72.1	1.87	30.5	4.26
TC01IMT-5	9/19/97	AB01932	2.67	0.51	80.9	2.98	25.5	2.61
TC01IMT-6	9/25/97	AB02513	2.51	0.52	79.3	2.96	27.5	2.41
TC01IMT-7	10/3/97	AB01933	2.58	0.52	79.8	3.25	21.3	2.38
TC01IMT-8	10/5/97	AB02209	2.77	0.52	81.2	2.82	17.6	1.77
TC01IMT-9	10/21/97	AB02210	2.69	0.53	80.3	3.09	20.1	2.19
TC01IMT-10	10/23/97	AB02211	2.89	0.53	81.7	2.98	20.5	1.98
TC01IMT-11	10/28/97	AB02212	2.85	0.50	82.5	3.17	20.2	1.84
TC01IMT-12	10/29/97	AB02213	3.00	0.56	81.3	3.22	20.6	1.86
TC01IMT-13	10/30/97	AB02214	2.75	0.55	80.0	3.08	22.5	2.16
TC01IMT-14	10/31/97	AB02215	2.77	0.53	80.9	3.28	21.0	2.04
TC01IMT-15	12/3/97	AB02576	2.58	0.54	79.1	2.76	19.1	2.90
TC01IMT-16	12/5/97	AB02514	2.57	0.53	79.4	3.58	24.8	2.49
TC01IMT-17	12/8/97	AB02577	2.60	0.56	78.5	3.05	25.0	2.80
Average For TC01			2.71	0.54	79.83	2.96	22.0	2.47
Standard Deviation			0.13	0.05	2.30	0.38	3.73	0.63

Notes: (1) Uncompacted Bulk Porosity.
(2) Mass Median Diameter.
(3) Drag Equivalent Diameter.

Table 3.25.4-2

Physical Properties of TC01 Candle and Hopper Samples

Sample Description	Lab ID No.	True Density (g/cc)	Bulk Density (g/cc)	UBP[1] (%)	Surface Area (m^2/g)	MMD[2] (μm)	DED[3] (μm)
Candle Samples From 11/5/97							
Top Tier, Top Half	AB02216	2.92	0.51	82.5	4.59	8.6	1.32
Top Tier, Bottom Half	AB02217	2.81	0.47	83.3	4.71	8.8	1.39
Bottom Tier, Top Half	AB02218	3.39	0.52	84.7	5.00	7.8	0.89
Bottom Tier, Bottom Half	AB02219	3.05	0.49	83.9	5.03	8.0	1.26
Average of 11/5/97 Samples		3.04	0.50	83.60	4.83	8.30	1.21
Standard Deviation		0.25	0.02	0.91	0.22	0.51	0.22
Candle Samples From 1/21/98							
Top Tier, Top Half	AB02579	2.56	0.49	80.9	3.88	8.4	2.14
Top Tier, Bottom Half	AB02578	2.52	0.47	81.3	3.88	9.5	2.15
Bottom Tier, Top Half	AB02581	2.57	0.50	80.5	3.46	8.6	2.04
Bottom Tier, Bottom Half	AB02580	2.54	0.54	78.7	3.64	9.8	2.24
Bottom Tier, Center Candle	AB02618					8.4	
Average of 1/21/97 Samples		2.55	0.50	80.37	3.72	8.94	2.14
Standard Deviation		0.02	0.03	1.14	0.20	0.66	0.08
TC01 Hopper Samples							
FD0520, 9/19/97	AB01806	2.62	0.59	77.5		25.7	2.89
FS0520, 10/23/97	AB02064	2.69	0.58	78.4		23.5	2.31
FD0520, 10/31/97	AB02163		0.54			22.7	1.76
FD0520, 12/5/97	AB02461	2.69	0.66	75.5		43.2	
Average of Hopper Samples		2.67	0.59	77.13		28.78	2.32
Standard Deviation		0.04	0.05	1.52		9.70	0.57

Notes: (1) Uncompacted Bulk Porosity.
(2) Mass Median Diameter.
(3) Drag Equivalent Diameter.

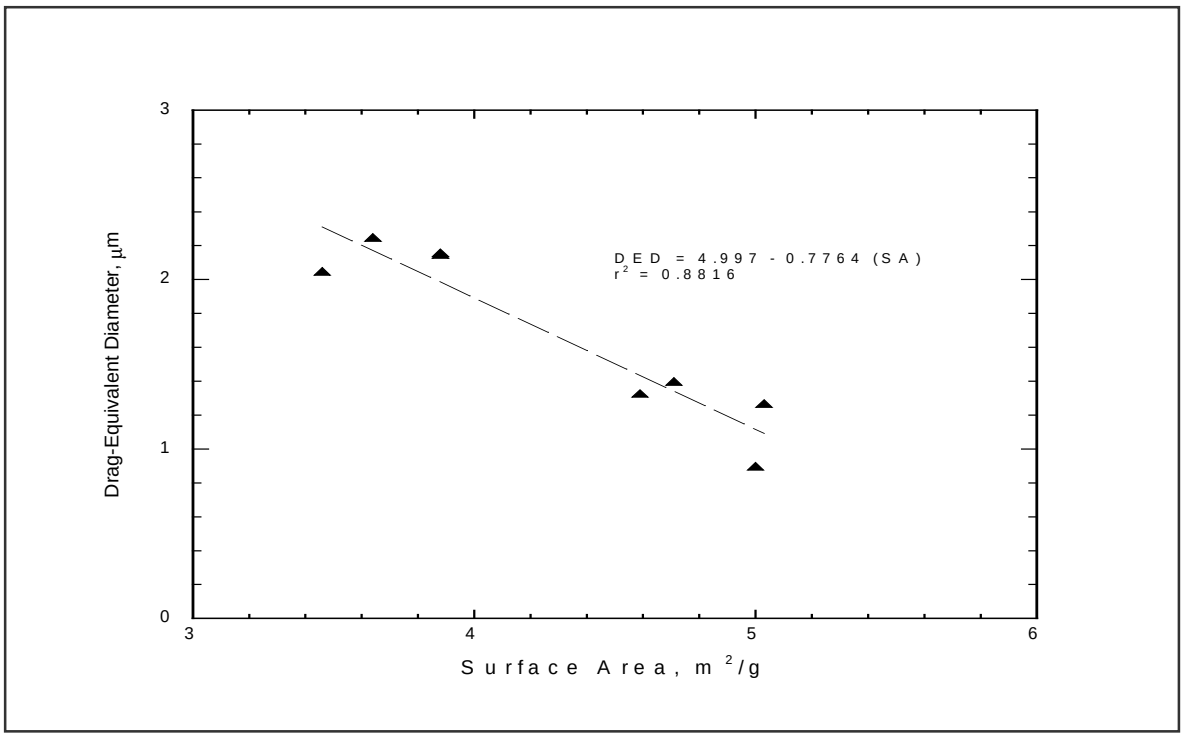


Figure 3.25.4-1 Drag-Equivalent Diameter Versus Calcium Content of In Situ Samples

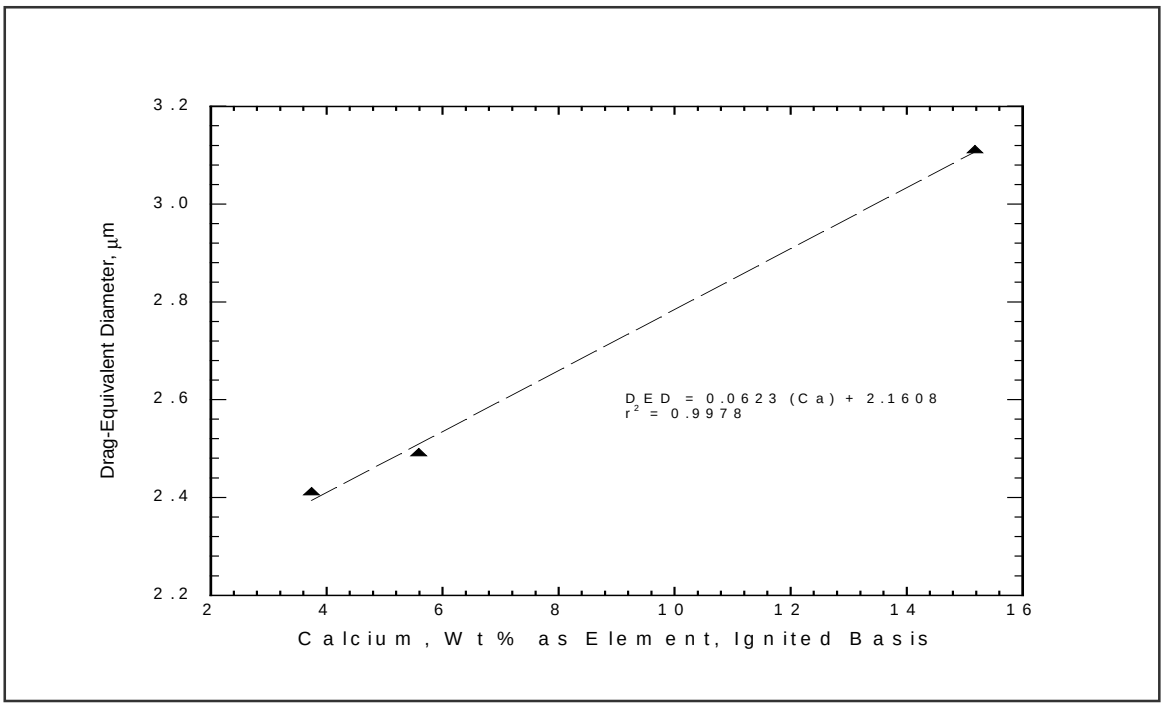


Figure 3.25.4-2 Drag-Equivalent Diameter Versus Surface Area of Dustcake Samples

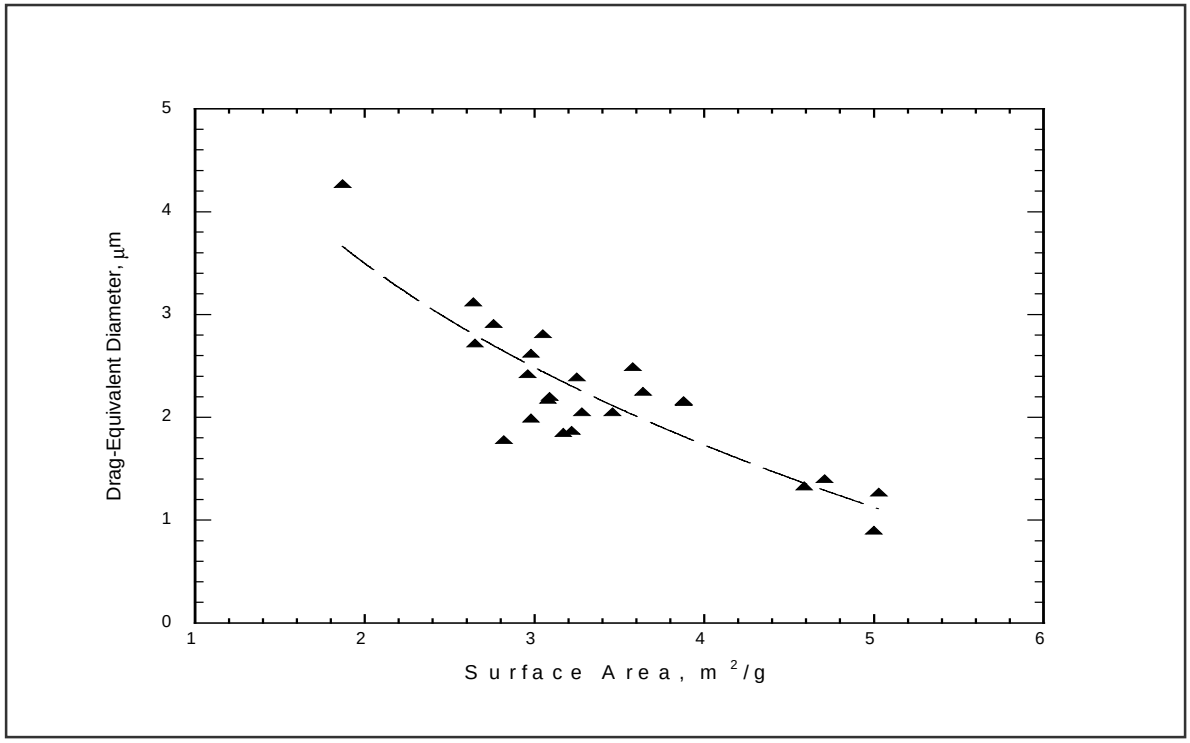


Figure 3.25.4-3 Drag-Equivalent Diameter Versus Surface Area for All Samples

3.26 INSPECTION REPORT FOR TC01I

3.26.1 Run Summary

TC01I was the last TC01 run that ended on December 9, 1997. During TC01I there was no evidence of filter element damage and the PCD performed well even though there was a large amount of solids carryover to the PCD on December 26, 1997. The spent fines transport system (FD0520), however, experienced a number of problems such as malfunction of the contact switch, spheri valve seal failure, wrong indication of the level probe, plugging on the vent line, drop pipe, discharge line, etc.

After the TC01I, part of the spent fines transport system (FD0520) was evaluated, redesigned, and implemented to improve the reliability, operability, and maintainability. (Please refer to section 3.30, FD0502/FD0520, for detailed information about the inspection and modifications.)

For the PCD FL0301, the plenums were pulled out and placed in the maintenance bay area on January 19, 1998. The filter elements were removed from the plenums on January 27 and 28, 1998. The purpose of this removal was to inspect and conduct quality control (QC) on the filter elements after the 1,000-hour test run (TC01) and determine the source of the 4- to 5-ppm outlet loading. A total of 89 elements (36 on top and 53 on bottom plenum), and one blank and one sample post, were carefully removed from the plenums and were visually examined on-site. Fail-safes and gaskets were also examined. This report presents the inspection results for the removal.

3.26.2 Filter Elements

To reference the locations of the filter elements on the plenums, the layout (no. 6) and a location map are shown in figures 3.26.2-1 and -2, respectively. The labeled numbers are also for other components in the same filter element holders. Those elements numbered with a preceding letter T were on the top plenum and those with letter B were on the bottom plenum.

All filter elements were successfully removed without breakage. Only one filter element (T9) had a cracking sound (like cracking china) when it was pulled out from the holder. The cracking sound was from the top part of the filter element. However, no visible crack was found.

The ashcake on the outside of the filter elements was fairly uniform. The 3M filter elements had relatively thicker ashcake than others did. The morphological structure of the ashcake looked quite different from those in the previous runs. The surface of the ashcake was rough and lumpy. The roughness on 3M filter elements was even more significant.

Slight tip-shaped ash build-up had been observed on the bottom filter elements located at outer edge of the plenum. The tip line faced against the flow and deviated from the axial line as it extended downward.

An ash layer was found on the inside surface of many filters. The ash layer was thicker at the flange part and gradually faded a few inches into the filter element. The ash layer had a very smooth surface and looked like dried slurry. Loose ash accumulation was also observed in the filter elements, as it was in the previous inspection (November 1997). The qualitative mass of ash layer in the filter is shown in figure 3.26.2-3.

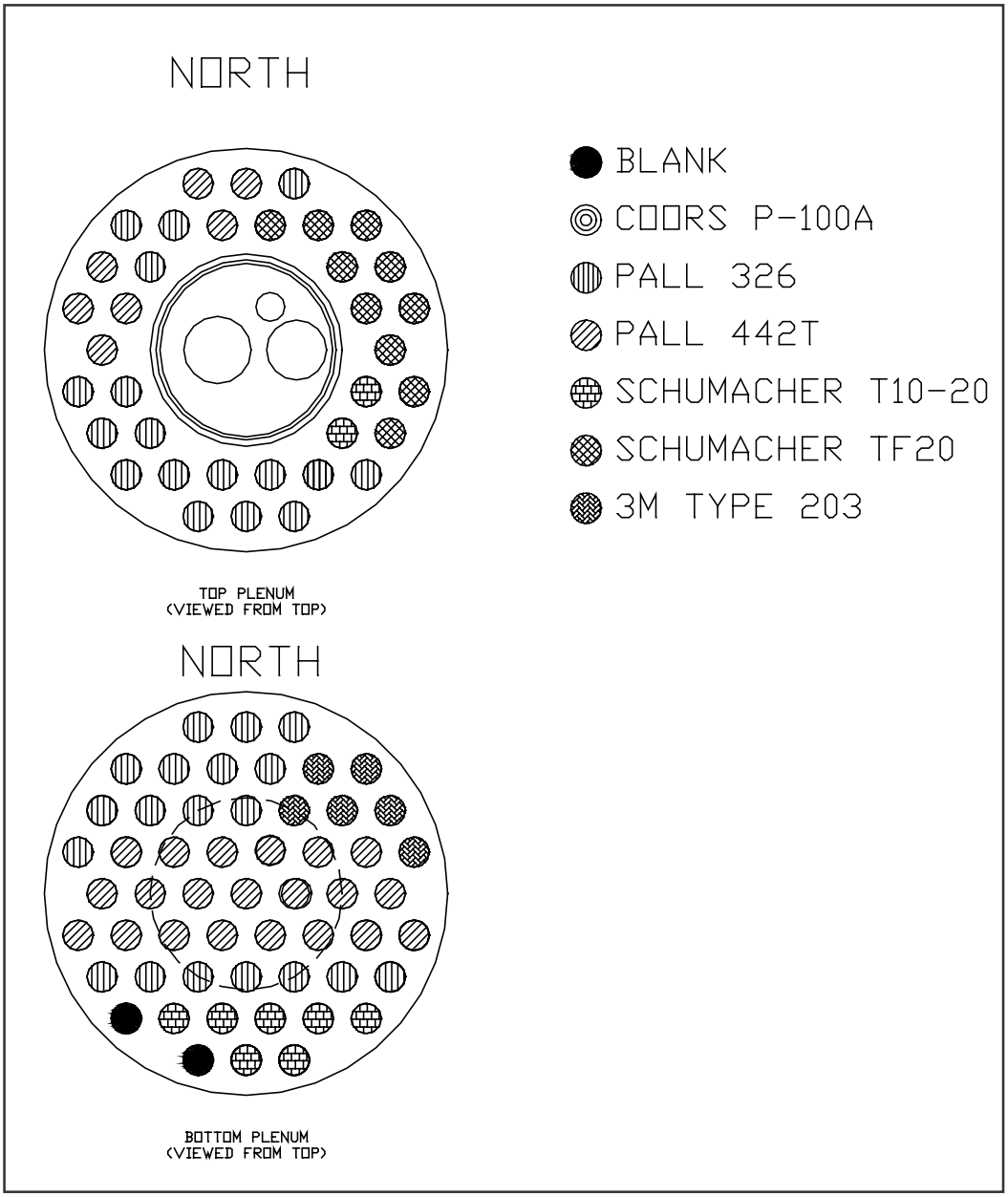


Figure 3.26.2-1 Filter Element Layout for TC01I (Layout No. 6)

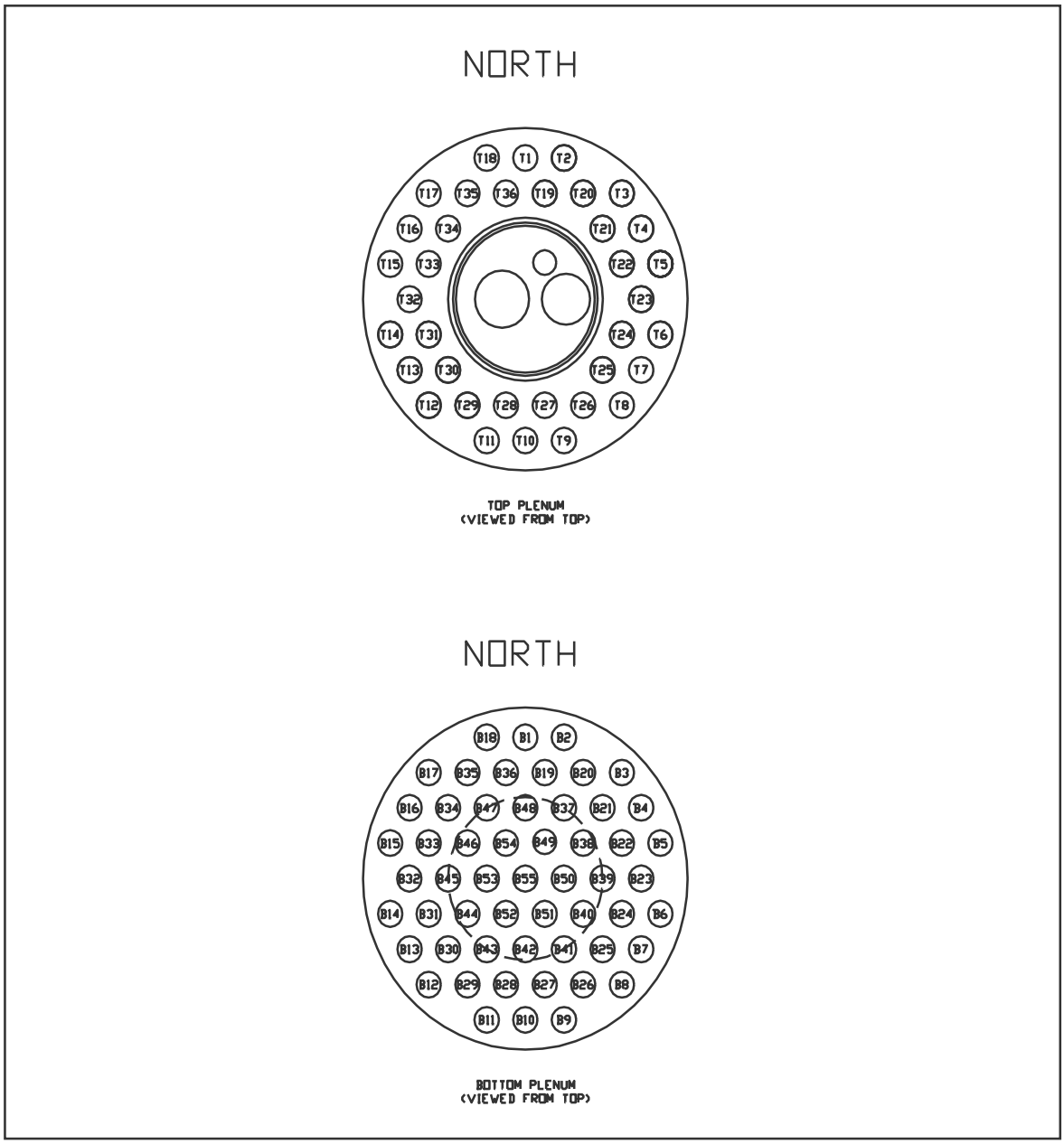


Figure 3.26.2-2 Filter Element Locations

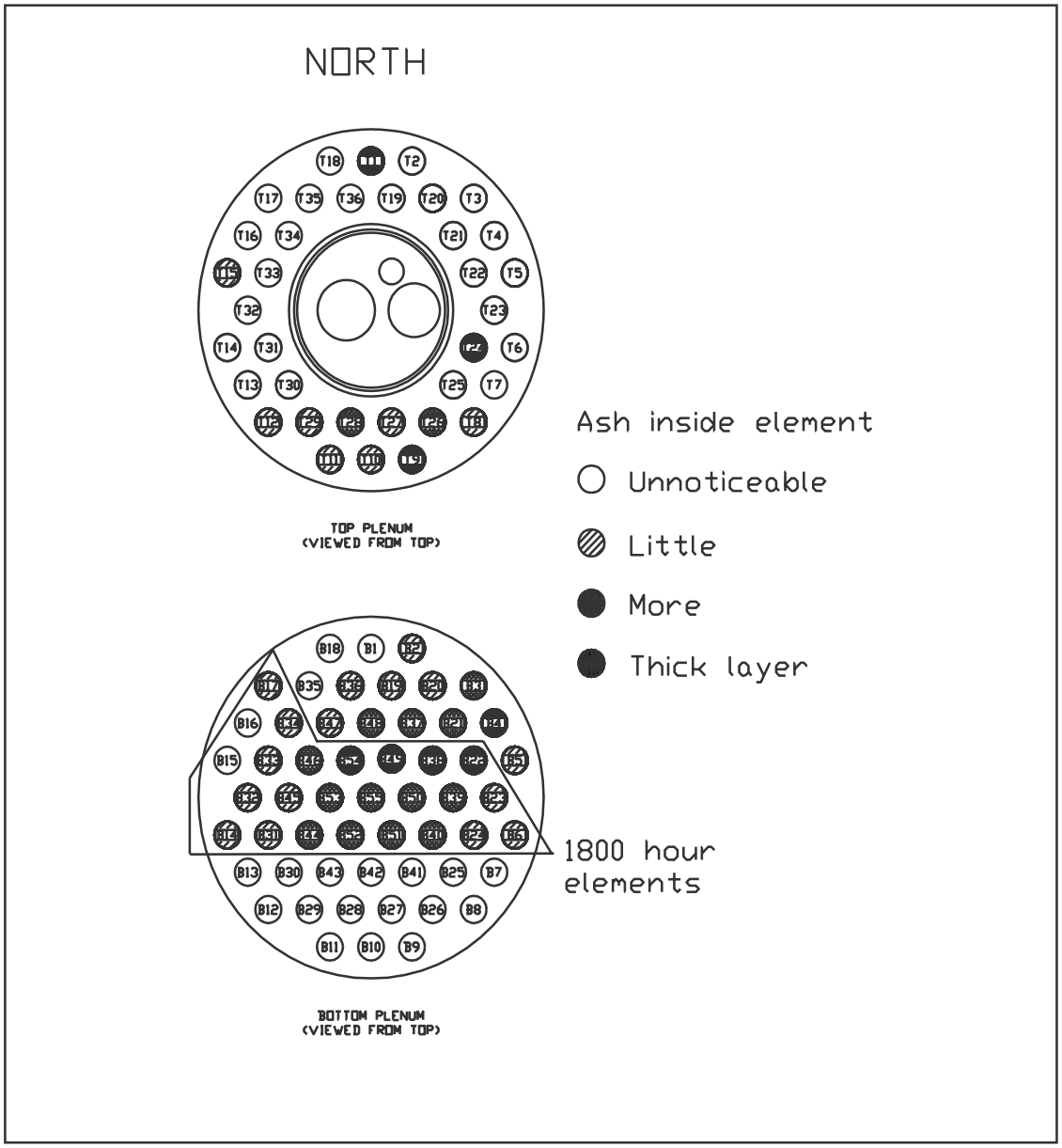


Figure 3.26.2-3 Ash Inside the Filter Elements

3.26.3 Fail-Safes

Most fail-safes could be easily removed from the filter element holders. About 10 fail-safes needed extra external forces such as using screwdrivers. B47 was stuck tightly and had to be removed with much more force and effort.

A large number of fiberfrax wraps were damaged or twisted leaving part of the side surface of the fail-safe uncovered. Only about 10 to 15 percent of the wraps were intact on the fail-safes that came out of the holders loosely.

The fiberfrax rings had a problem similar to the wraps. Only a few fail-safes had complete rings on them when they were removed from the holders. Other rings were more or less damaged (the rings could also be damaged during the removal). Since this ring is supposed to be a seal between the outside of the fail-safe and the holder, the damage during the installation or operation could result in leakage if the upstream seal failed or was damaged. This was evident as different amounts of ash accumulation were observed on the outside surface of the fail-safes and on the holder walls.

Gas leakage through the small holes at the tack-weld points between the fail-safe body and top cap and between the fail-safe body and lower flange was observed. For example, on the T22 fail-safe, the ash accumulation on the outside surface was blown to a conical-shape trail by the gas from the filter element.

On the inlet of many fail-safes ash was built-up near the center of the screen. As more ash was built-up the area was spread to the outer edge. The structure of the ash build-up looked similar to that found inside the filter elements (i.e., smooth, dry-slurry like). The build-up had a sharp tip facing the filter element indicating that the ash was from the filter element (this does not necessarily mean that the ash was originally from the filter element). Figure 3.26.3-1 shows the qualitative ash build-up on the inlet screens.

Only a few fail-safes showed ash build-up on the outlet screens and the build-up was much lighter than that on the inlet screens. Also, the ash build-up was scattered near the edge of the screen. The build-up was flat and the color was slightly different from that on the inlet screens. Figure 3.26.3-2 shows the qualitative ash build-up on the outlet screens.

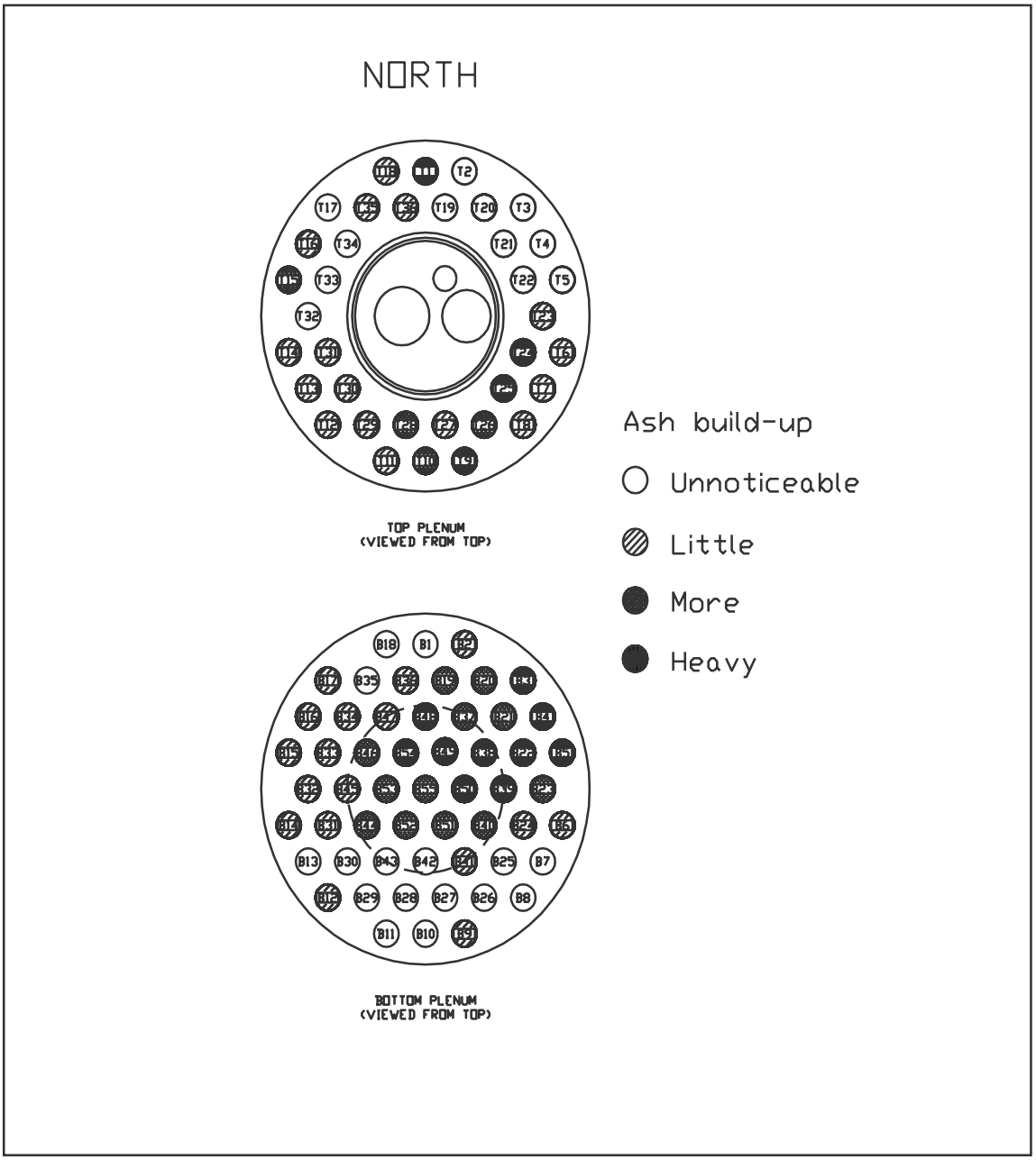


Figure 3.26.3-1 Ash on Inlet Screen of the Fail-Safes

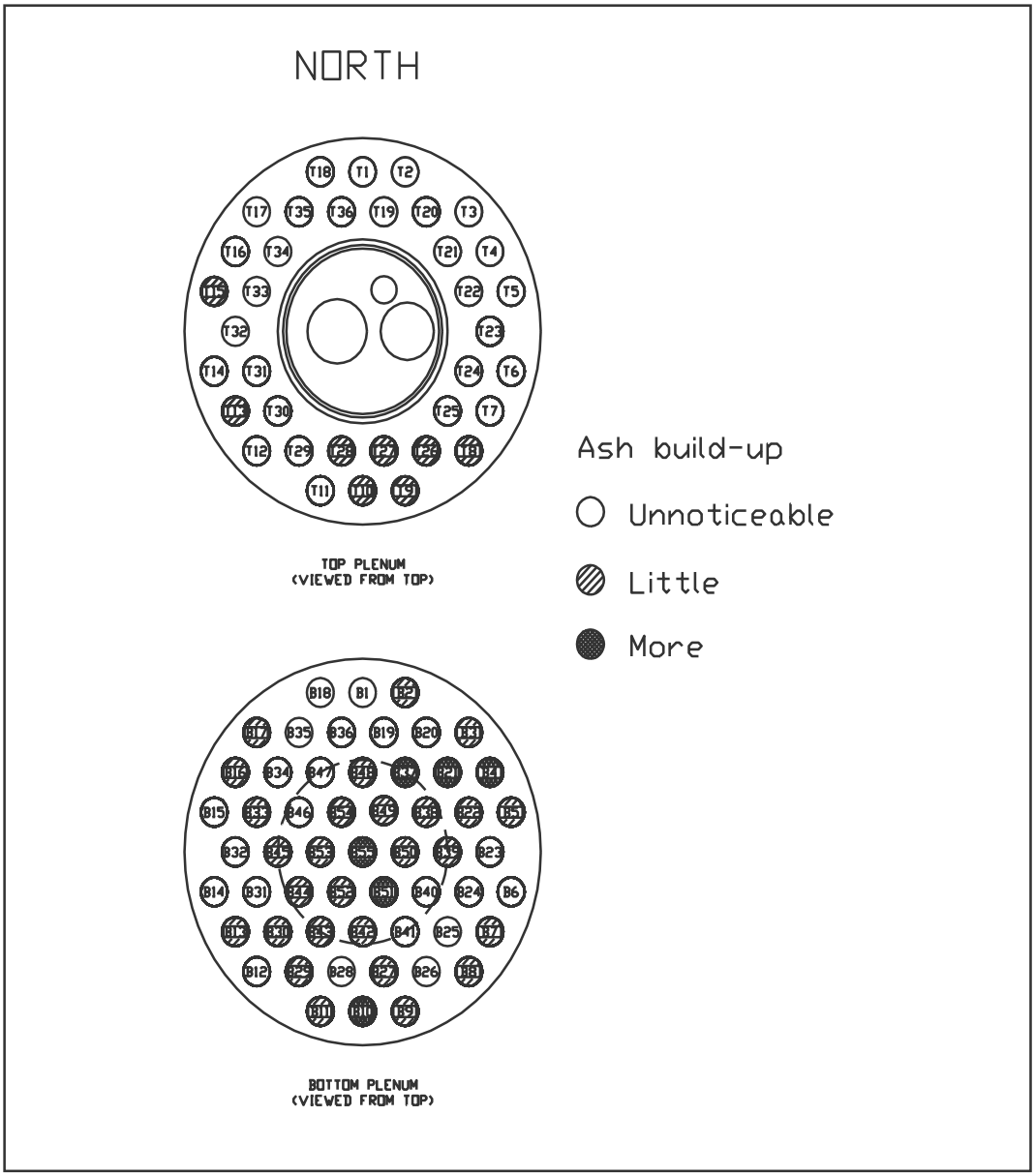


Figure 3.26.3-2 Ash on Outlet Screen of the Fail-Safes

3.26.4 Gaskets

In general, most of the top "doughnut" gaskets were clean on both sides. However, ash was found on the top doughnut gaskets of T9, T13, and B40 showing possible ash penetration. Both T9 and B40 had significant amount of ash inside the filter elements.

Several top doughnut gaskets had eccentric indents caused by the edges of the fail-safes. In this case the filter element flange might not be seated properly on the fail-safe. This might have caused uneven sealing force on the gasket. However, no noticeable ash had been examined on these gaskets.

On the outer edges of many top doughnut gaskets there was distinct ash accumulation. This indicated that the ash could reach the outside of this point.

No severe ash build-up had been found on the surfaces of the "sock" and bottom doughnut gaskets. It was hard to tell the ash penetration directly from the ash build-up on these surfaces. However, the ash accumulation on the holder at this point clearly indicated that the ash did pass through the contacting surface between the holder and the sock and lower doughnut gaskets. This implied that the seal (if this contacting surface was a seal) could be improved.

Practically, the sock and bottom doughnut gaskets serve as part of the sealing chain in addition to their other roles. They are compressed by the filter nut to fill the space between the filter element flange, holder, and fail-safe. If this seal is not tight, the ash from the dirty side can get into the filter element and fail-safe if the sealing at the top doughnut gasket also fails; or the ash can pass through the gap between the fail-safe and the holder if the fiberfrax ring is damaged. In either way, the leakage can result in larger particulate loading on the clean side, or ash can be accumulated inside the filter element (this may not be the only ash source).

3.26.5 Filter Element Holders

Ash accumulation was found on holder walls in different locations. On the B4 holder a heavy ash layer covered all the holder walls. Ash was also found on the holder walls of B3, B5, B9, B10, B11, B17, B26, and B29. The ash on the walls near the fail-safe and filter element flange was different from the ash on the clean-side walls. The structure of the ash layer near the fail-safe looked much the same as the ash cake on the outside of the filter element. However, the ash on the clean-side walls was similar to that inside the filter elements and on the screens of the fail-safes.

3.26.6 Miscellaneous

Colorful material layers were found on the dirty side of metal surfaces such as plenums, holders, filter nuts, bolts, and nuts. The first layer was yellowish and the second was green. Normal ash layer covered these colorful layers. However, these colorful layers were not found on the clean-side parts.

Visual examination through the plenum pipes showed no visible ash accumulation on the viewed parts of the plenums. Boroscope examination was also conducted for the indirectly viewed portions of the plenums. There were scattered ash lumps and other materials, but no dense ash accumulation.

A thick layer of rough and lumpy ash covered the shroud and the wall of the vessel liner.

3.26.7 Comments

Regarding the ash accumulation inside the filter elements, there are three possible causes:

1. Ash penetration through the filtration surface (fine particles through unusually large pores or channeled structure).

2. Ash entrainment by the back-pulse gas.

3. Ash leakage through seals and filter element cracks.

It is difficult to accurately trace the ash sources since the plenums are connected to each other and any ash accumulation in one location may affect other locations.

It is difficult to quantitatively correlate the ash accumulation on the holders to the performance of the filter elements, fail-safes, and gaskets installed last time. Ash accumulation may have occurred during the previous runs before the recandling (layout no. 6). Filter element breakage could also have affected the ash accumulation. On the other hand, the ash amount inside the filter elements is a function of the exposure time of the filter elements. Some filter elements have been on the plenums for about 1,800 hours. Caution should be taken in comparing the presented data, as they lack a common basis.

The current sealing system for the filter element fitting needs improvement. There are multiple ash paths between the dirty and clean sides. Major sealing points should be enhanced.

3.27 PULSE VALVE TESTS AND OPERATIONS

3.27.1 Run Summary

Parametric tests have been conducted for a Müller SVS-F80 Coax valve used in the filter element cleaning process for the Westinghouse particulate control device (PCD) FL0301. The purpose of this testing was to acquire detailed information about the opening behavior in order to better operate the back-pulse valve and control the cleaning process. The valve was tested at back-pulse pressures ranging from 200 to 900 psig, for different electrical pulse durations (0.3, 0.6, 0.9, and 1.2 seconds), and pilot pressures (100, 120, and 140 psig). The results showed that the mass discharge per pulse did not always increase with the differential pressure across the valve. The maximum values of the mass discharge per pulse and corresponding differential pressure varied with the operating parameters (i.e., electrical pulse duration and pilot pressure). The characteristic times (i.e., the times describing the valve movement) for the valve opening were also affected by these operating parameters.

3.27.2 Test Objectives

Back-pulse tests were conducted on the Müller SVS-F80 coax back-pulse valve SV3112B. The objectives of this testing were to investigate the opening behavior of the valve in various operating conditions and to characterize the operating parameters.

3.27.3 Introduction

Back-pulse valves are major components in the back-pulse skid for cleaning of filter elements in a PCD. When the valve is actuated to open the back-pulse gas flows through the valve in a relatively short period of time. During the back-pulse a sharp increase of reverse differential pressure and a certain amount of mass flowing through the filtration surface is achieved to remove ashcake on the filter elements. Therefore, the opening behavior of the valve is critical to the cleaning process.

To obtain best cleaning results a variety of operating conditions for the valves may be needed; for example, different back-pulse pressures, open times, and pilot pressures. From previous operations it was found that the valves were not open (or not fully open) in some situations. This definitely affects the mass discharge through the valves and, therefore, narrows the operating range of the back-pulse valves. This testing was motivated by the need that more complete and detailed information about the performance of the valves should be obtained in order to better control the cleaning process. The results of the testing would be useful in understanding and operating the valves.

3.27.4 Test Procedure

Figure 3.27.4-1 shows the back-pulse system. Back-pulse media (N_2) was pressurized and then stored in the accumulator tank (FL0301-DR02). The pilot pressure was introduced from the purge tank and adjusted to the specified value by a regulator. A 1,000-ml reservoir was used upstream of the pilot valve to minimize the effect of pressure decay during the back-pulse. When the back-pulse valve (SV3112B) was initiated to open the pilot valve was opened first and the pilot pressure actuated the back-pulse valve to open. The back-pulse media was then released to the PCD through the back-pulse valve. The data of electrical signals for the pilot valve and limit switch signals for the back-pulse valve were collected by a fast data acquisition device (WinDaq/200, DATAQ Instruments). All other operating information was recorded by the plant information (PI) system.

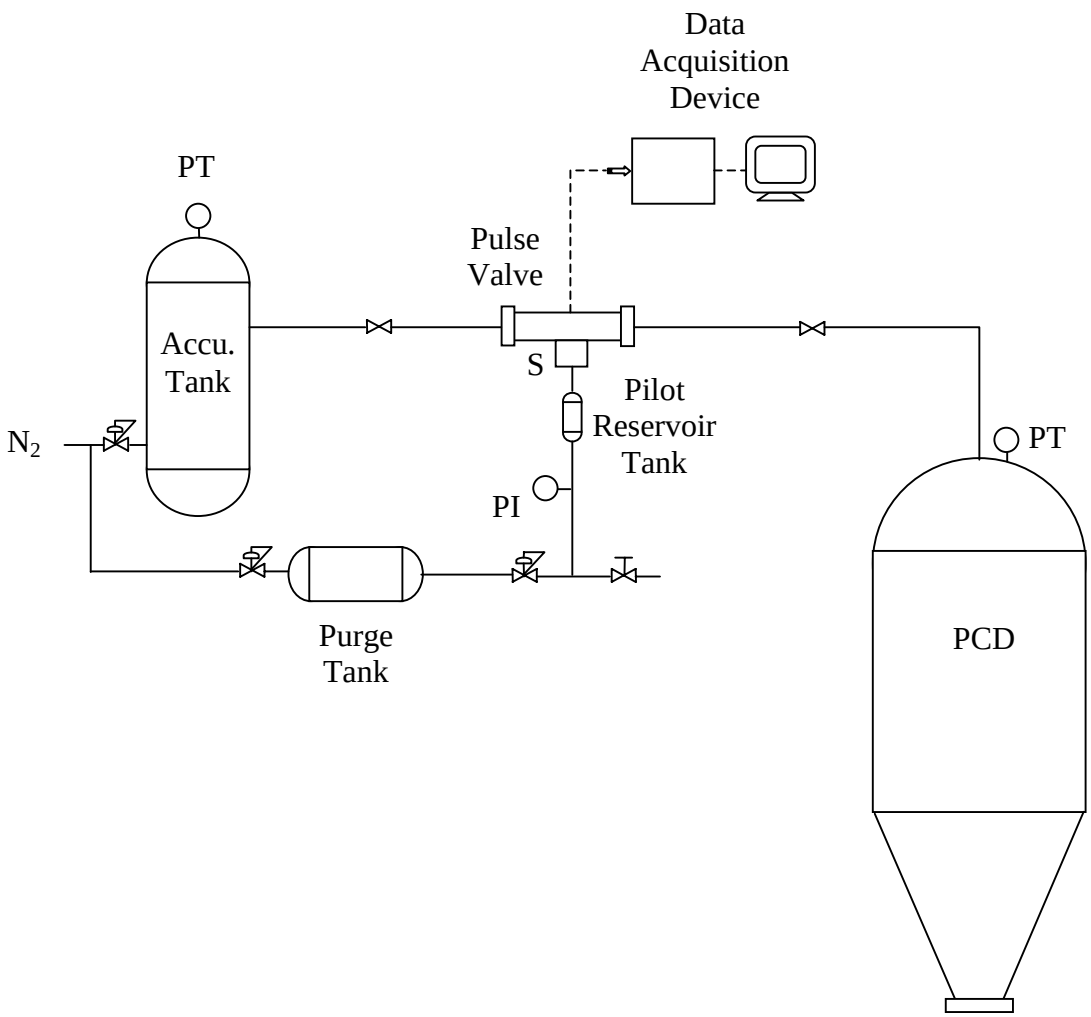
The three operating parameters of electrical pulse duration (t), pilot pressure (P_{pilot}), and back-pulse pressure (P_{pulse}) were varied in the given ranges. The PCD pressure (P_{pcd}) during the tests varied from about 100 to 200 psig. The tests were grouped into 12 runs by the combinations of t and P_{pilot} as listed in table 3.27.4-1.

Manual or automatic pulses were performed in each run, over a range of P_{pulse} with a 50-psig increment between data points. Actual back-pulse pressures might be slightly different from the set values and could be obtained from the PI system.

Table 3.27.4-1

Test Arrangements

Run	Date	T (sec)	P_{pilot} (psig)	P_{pulse} (psig, setting)
1	9/24/97-9/25/97	0.3	100	350-800
2	9/30/97	1.2	100	200-850
3	9/30/97	1.2	120	200-850
4	9/30/97	1.2	140	200-850
5	10/1/97	0.3	120	350-850
6	10/1/97	0.3	140	350-850
7	10/1/97	0.6	100	350-900
8	10/1/97	0.6	120	350-900
9	10/1/97	0.6	140	250-850
10	10/9/97	0.9	100	250-900
11	10/9/97	0.9	120	250-900
12	10/9/97	0.9	140	250-900



S – Pilot valve (Solenoid type)
PT – Pressure transmitter
PI – Pressure indicator

Figure 3.27.4-1 Schematic Presentation of the Back-Pulse System

3.27.5 Test Results and Data Analysis

Test data were categorized in two sets: mass discharge and characteristic times.

3.27.5.1 Mass Discharge

The mass discharge in one pulse (M/P) was calculated by the mass change in the accumulator tank before and after the back-pulse. The mass in the accumulator tank is determined by the ideal gas law:

$$Mass = V * \frac{(P + 14.7) * 28}{10.73 * (T + 460)} \quad (1)$$

Where:

V = Tank volume (16 ft^3)
P = Accumulator tank pressure, psig
T = Accumulator tank temperature, °F

The pressure and temperature data were retrieved from the PI system. The compressibility factor for nitrogen in the testing conditions is very close to 1.0 and was not considered in the calculations.

The force balance for the valve and previous testing data indicate that the mass discharge per pulse could be related to the pressure difference between the accumulator tank and PCD ($\Delta P = P_{pulse} - P_{pcd}$), rather than P_{pulse} or P_{pcd} itself (see section 3.27.6.1). Therefore, the mass discharge data were interpreted in terms of the pressure difference ΔP.

t = 0.3 seconds

Tables 3.27.5-1 through -3 show the raw data and calculated mass discharge for P_{pilot} = 100, 120, and 140 psig, respectively. The results are summarized in figure 3.27.5-1.

t = 0.6 seconds

Tables 3.27.5-4 through -6 show the raw data and calculated mass discharge for P_{pilot} = 100, 120, and 140 psig, respectively. The results are summarized in figure 3.27.5-2.

t = 0.9 seconds

Tables 3.27.5-7 through -9 show the raw data and calculated mass discharge for P_{pilot} = 100, 120, and 140 psig, respectively. The results are summarized in figure 3.27.5-3.

t = 1.2 seconds

Tables 3.27.5-10 through -12 show the raw data and calculated mass discharge for P_{pilot} = 100, 120, and 140 psig, respectively. The results are summarized in figure 3.27.5-4.

3.27.5.2 Characteristic Times

Figure 3.27.5-5 defines the terms that were used in the measurements. The characteristic times were measured by using the playback software for the data acquisition device.

t = 0.3 seconds

Tables 3.27.5-13 through -15 show the measured data for P_{pilot} = 100, 120, and 140 psig, respectively. The fully open times are summarized in figure 3.27.5-6. The response times are summarized in figure 3.27.5-7.

t = 0.6 seconds

Tables 3.27.5-16 through -18 show the measured data for P_{pilot} = 100, 120, and 140 psig, respectively. The fully open times are summarized in figure 3.27.5-8 and the response times are summarized in figure 3.27.5-9.

t = 0.9 seconds

Tables 3.27.5-19 through -21 show the measured data for P_{pilot} = 100, 120, and 140 psig, respectively. The fully open times are summarized in figure 3.27.5-10 and the response times are summarized in figure 3.27.5-11.

t = 1.2 seconds

Tables 3.27.5-22 through -24 show the measured data for P_{pilot} = 100, 120, and 140 psig, respectively. The fully open times are summarized in figure 3.27.5-12 and the response times are summarized in figure 3.27.5-13

Table 3.27.5-1

SV3112B Valve Test With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 100 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI3028 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
9/24/97 15:40	350	347	275	186	161	81.8	27.9	22.3	5.5	Fully Open
9/24/97 16:20	400	389	318	186	203	83.1	31.0	25.6	5.5	Fully Open
9/24/97 17:00	450	442	349	187	255	83.8	35.1	27.9	7.1	Fully Open
9/24/97 17:40	500	488	402	188	300	84.8	38.5	31.9	6.6	Fully Open
9/24/97 18:20	550	538	490	186	352	85.0	42.3	38.7	3.7	Not Open
9/25/97 13:26	500	492	419	195	297	75.1	39.5	33.8	5.7	Partly Open
9/25/97 14:06	550	542	497	195	347	76.2	43.3	39.8	3.5	Not Open
9/25/97 14:46	600	588	551	195	393	77.2	46.8	44.0	2.9	Not Open
9/25/97 15:26	650	641	594	195	446	78.2	50.9	47.2	3.6	Not Open
9/25/97 16:06	700	688	650	195	493	78.6	54.5	51.5	2.9	Not Open
9/25/97 16:46	750	739	698	194	545	79.4	58.3	55.2	3.2	Not Open
9/25/97 17:26	800	790	739	195	595	79.2	62.3	58.4	3.9	Not Open

Table 3.27.5-2

SV3112B Valve Test With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 120 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI3028 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
10/1/97 8:11		522	410	191	331	81.8	41.4	32.7	8.6	Fully Open
10/1/97 8:29		398	310	190	208	78.9	32.0	25.2	6.8	Fully Open
10/1/97 9:01	400	394	312	191	203	82.5	31.5	25.1	6.3	Fully Open
10/1/97 9:09	450	446	344	191	255	88.9	35.0	27.3	7.8	Fully Open
10/1/97 9:12	500	506	394	193	313	90.3	39.5	31.0	8.5	Fully Open
10/1/97 9:15	550	554	440	193	361	93.7	42.9	34.3	8.6	Fully Open
10/1/97 9:18	600	604	501	191	413	95.1	46.5	38.8	7.7	Fully Open
10/1/97 9:21	650	651	563	192	459	97.1	49.9	43.3	6.6	Fully Open
10/1/97 9:24	700	706	650	192	514	96.7	54.1	49.9	4.2	Partly Open
10/1/97 9:27	750	754	692	191	563	97.0	57.6	53.0	4.6	Not Open
10/1/97 9:29	800	803	746	192	611	97.3	61.3	57.0	4.3	Not Open
10/1/97 9:36	850	839	784	192	647	95.6	64.2	60.0	4.1	Not Open

Table 3.27.5-3

SV3112B Valve Test With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 140 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI3028 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
10/1/97 9:59	850	838	765	191	647	87.3	65.1	59.5	5.6	Not Open
10/1/97 10:01	800	804	732	192	612	86.8	62.5	57.0	5.5	Not Open
10/1/97 10:03	750	779	712	191	588	85.2	60.8	55.7	5.1	Not Open
10/1/97 10:06	750	751	692	192	559	83.3	58.8	54.3	4.5	Not Open
10/1/97 10:09	700	711	621	192	519	80.5	56.1	49.1	7.0	Partly Open
10/1/97 10:13	650	656	543	192	464	80.6	51.8	43.1	8.7	Fully Open
10/1/97 10:16	600	612	474	192	420	79.2	48.5	37.8	10.7	Fully Open
10/1/97 10:19	550	574	447	192	382	79.3	45.6	35.7	9.8	Fully Open
10/1/97 10:22	500	508	401	192	316	78.6	40.5	32.2	8.3	Fully Open
10/1/97 10:24	450	463	369	193	270	77.9	37.1	29.8	7.3	Fully Open
10/1/97 10:26	400	426	334	191	235	77.6	34.2	27.1	7.1	Fully Open
10/1/97 10:30	350	387	310	192	195	77.8	31.2	25.2	6.0	Fully Open
10/1/97 10:32	300	350	287	192	158	78.0	28.3	23.4	4.9	Fully Open

Table 3.27.5-4

SV3112B Valve Test With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 100 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI3028 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
10/1/97 11:31	350	352	237	192	160	82.3	28.2	19.4	8.9	Fully Open
10/1/97 11:34	400	403	259	193	210	89.2	31.8	20.8	10.9	Fully Open
10/1/97 11:39	450	448	285	192	256	97.7	34.6	22.4	12.2	Fully Open
10/1/97 11:44	500	498	334	193	305	99.4	38.3	26.0	12.2	Fully Open
10/1/97 11:51	550	543	380	192	351	99.6	41.6	29.4	12.2	Fully Open
10/1/97 11:53	600	604	451	192	412	97.7	46.3	34.9	11.5	Fully Open
10/1/97 11:56	650	655	547	191	464	101.9	49.8	41.7	8.0	Not Open
10/1/97 11:59	700	707	602	191	516	101.9	53.6	45.8	7.8	Not Open
10/1/97 12:02	750	757	655	191	566	101.9	57.3	49.8	7.6	Not Open
10/1/97 12:04	800	807	702	191	616	102.0	61.0	53.2	7.8	Not Open
10/1/97 12:07	850	857	739	191	666	102.0	64.8	56.0	8.8	Not Open
10/1/97 12:10	900	907	798	191	716	102.0	68.5	60.4	8.1	Not Open

Table 3.27.5-5

SV3112B Valve Test With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 120 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI3028 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
10/1/97 12:21	900	892	754	192	700	96.4	68.0	57.7	10.4	Not Open
10/1/97 12:23	850	856	735	192	664	92.6	65.8	56.6	9.1	Not Open
10/1/97 12:28	800	796	678	192	604	88.3	61.7	52.7	9.0	Not Open
10/1/97 12:30	750	751	638	192	559	86.4	58.5	49.9	8.6	Not Open
10/1/97 12:33	700	701	549	192	509	83.8	55.0	43.3	11.7	Fully Open
10/1/97 12:35	650	666	478	192	474	83.2	52.3	37.9	14.5	Fully Open
10/1/97 12:36	600	613	416	192	421	82.7	48.3	33.1	15.2	Fully Open
10/1/97 12:38	550	563	345	192	371	83.3	44.4	27.6	16.8	Fully Open
10/1/97 12:40	500	499	320	192	307	83.5	39.5	25.7	13.8	Fully Open
10/1/97 12:42	450	446	283	192	254	84.8	35.3	22.8	12.5	Fully Open
10/1/97 12:46	400	396	251	191	205	85.8	31.4	20.3	11.1	Fully Open
10/1/97 12:50	350	345	243	191	154	85.4	27.5	19.7	7.8	Fully Open

Table 3.27.5-6

SV3112B Valve Test With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 140 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI3028 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
10/1/97 15:42	250	256	166	99	157	88.4	20.6	13.8	6.9	Fully Open
10/1/97 15:50	300	297	175	99	198	96.4	23.4	14.2	9.2	Fully Open
10/1/97 15:54	350	350	219	99	251	102.2	27.1	17.4	9.7	Fully Open
10/1/97 15:58	400	403	249	99	304	104.3	30.9	19.5	11.4	Fully Open
10/1/97 16:04	450	448	280	99	349	105.3	34.2	21.8	12.4	Fully Open
10/1/97 16:09	500	501	292	99	402	106.5	38.0	22.6	15.4	Fully Open
10/1/97 16:13	550	551	332	99	452	107.1	41.6	25.5	16.1	Fully Open
10/1/97 16:18	600	601	396	98	503	107.2	45.3	30.2	15.1	Fully Open
10/1/97 16:24	650	648	425	98	550	106.2	48.9	32.4	16.4	Fully Open
10/1/97 16:28	700	707	509	98	609	104.9	53.3	38.7	14.6	Fully Open
10/1/97 16:32	750	751	609	98	653	106.4	56.4	46.0	10.5	Not Open
10/1/97 16:36	800	803	657	98	705	105.1	60.4	49.6	10.8	Not Open
10/1/97 16:39	850	860	727	98	762	104.9	64.6	54.8	9.8	Not Open

Table 3.27.5-7

SV3112B Valve Test With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 100 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI428 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
10/9/97 11:25	250	243	131	97	146	78.1	20.0	11.3	8.7	Fully Open
10/9/97 11:29	300	303	153	98	205	89.8	24.1	12.7	11.4	Fully Open
10/9/97 11:33	350	356	183	98	258	95.2	27.9	14.9	13.0	Fully Open
10/9/97 11:37	400	405	207	98	307	98.0	31.4	16.6	14.8	Fully Open
10/9/97 11:41	450	457	229	98	359	99.2	35.2	18.2	17.0	Fully Open
10/9/97 11:44	500	507	286	98	409	99.7	38.9	22.4	16.5	Fully Open
10/9/97 11:48	550	556	362	98	458	99.0	42.6	28.1	14.5	Fully Open
10/9/97 11:51	600	606	452	97	509	98.4	46.4	34.9	11.5	Not Open
10/9/97 11:54	650	655	512	98	557	97.4	50.2	39.5	10.7	Not Open
10/9/97 11:57	700	705	558	98	607	96.3	54.0	43.0	11.0	Not Open
10/9/97 12:00	750	756	591	98	658	95.9	57.9	45.5	12.4	Not Open
10/9/97 12:04	800	806	635	98	708	95.9	61.6	48.8	12.8	Not Open
10/9/97 12:06	850	855	693	98	757	96.0	65.3	53.1	12.2	Not Open
10/9/97 12:09	900	907	729	98	809	96.2	69.2	55.8	13.4	Not Open

Table 3.27.5-8

SV3112B Valve Test With Electrical Pulse Duration of 0.9 sec and Pilot Pressure of 120 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI428 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
10/9/97 12:20	900	892	702	97	795	91.0	68.7	54.3	14.4	Not Open
10/9/97 12:24	850	845	658	98	747	85.0	65.9	51.5	14.3	Not Open
10/9/97 12:26	800	802	621	98	704	83.0	62.8	48.9	13.9	Not Open
10/9/97 12:27	750	761	590	98	663	80.9	59.9	46.7	13.2	Not Open
10/9/97 12:29	700	718	541	97	621	79.9	56.7	43.0	13.7	Not Open
10/9/97 12:31	650	680	465	98	582	80.5	53.7	37.1	16.6	Fully Open
10/9/97 12:34	650	640	383	98	542	81.4	50.5	30.7	19.8	Fully Open
10/9/97 12:36	600	593	322	97	496	82.6	46.8	25.9	20.9	Fully Open
10/9/97 12:40	550	538	278	98	440	87.0	42.2	22.3	19.8	Fully Open
10/9/97 12:42	500	512	256	97	415	89.0	40.1	20.6	19.5	Fully Open
10/9/97 12:46	550	555	286	98	457	98.3	42.6	22.5	20.1	Fully Open
10/9/97 12:49	500	488	247	98	390	94.2	37.9	19.7	18.2	Fully Open
10/9/97 12:52	450	448	225	98	350	93.0	34.9	18.1	16.8	Fully Open
10/9/97 12:56	400	392	198	97	295	92.9	30.7	16.1	14.6	Fully Open
10/9/97 12:58	350	343	176	97	246	91.6	27.1	14.4	12.6	Fully Open
10/9/97 13:01	300	297	145	97	200	90.4	23.6	12.1	11.5	Fully Open
10/9/97 13:04	250	259	135	98	161	90.6	20.8	11.4	9.4	Fully Open

Table 3.27.5-9

SV3112B Valve Test With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 140 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI428 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
10/9/97 13:23	250	246	143	97	149	88.7	19.8	12.0	7.8	Fully Open
10/9/97 13:28	300	307	148	98	209	97.0	24.1	12.2	11.9	Fully Open
10/9/97 13:32	300	291	150	98	193	97.3	22.9	12.3	10.6	Fully Open
10/9/97 13:35	350	355	170	97	258	101.9	27.5	13.7	13.7	Fully Open
10/9/97 13:39	400	405	193	98	307	104.4	31.0	15.4	15.7	Fully Open
10/9/97 13:43	450	456	210	97	359	106.5	34.7	16.6	18.1	Fully Open
10/9/97 13:47	500	506	242	98	408	108.2	38.3	18.9	19.4	Fully Open
10/9/97 13:51	550	562	276	98	464	109.8	42.3	21.3	21.0	Fully Open
10/9/97 13:54	600	605	311	98	507	108.8	45.5	23.9	21.6	Fully Open
10/9/97 13:59	650	658	352	98	560	111.1	49.2	26.8	22.4	Fully Open
10/9/97 14:02	700	708	386	98	610	107.2	53.2	29.5	23.7	Fully Open
10/9/97 14:05	750	756	438	98	658	109.1	56.5	33.2	23.3	Fully Open
10/9/97 14:07	800	806	527	97	709	108.7	60.3	39.8	20.5	Fully Open
10/9/97 14:10	850	855	649	98	757	107.1	64.0	48.9	15.2	Not Open
10/9/97 14:12	900	905	683	98	807	107.5	67.7	51.3	16.3	Not Open

Table 3.27.5-10

SV3112B Valve Test With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 100 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI3028 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
9/30/97 12:46	200	201	102	98	103	85.9	16.5	8.9	7.6	Fully Open
9/30/97 12:52	250	249	119	98	151	91.2	20.0	10.1	9.8	Fully Open
9/30/97 12:55	300	299	133	98	201	98.1	23.5	11.0	12.4	Fully Open
9/30/97 12:58	350	351	155	98	253	102.8	27.1	12.6	14.5	Fully Open
9/30/97 13:01	400	401	157	98	303	105.2	30.7	12.7	18.0	Fully Open
9/30/97 13:05	450	452	200	98	354	107.2	34.4	15.8	18.5	Fully Open
9/30/97 13:08	500	501	240	98	403	107.5	37.9	18.7	19.2	Fully Open
9/30/97 13:11	550	551	308	98	453	107.0	41.7	23.8	17.9	Fully Open
9/30/97 13:13	600	603	363	97	506	105.3	45.6	27.9	17.7	Fully Open
9/30/97 13:15	650	654	447	97	557	103.7	49.5	34.2	15.3	Not Open
9/30/97 13:18	700	702	490	98	604	101.8	53.3	37.5	15.8	Not Open
9/30/97 13:20	750	754	558	98	656	101.4	57.2	42.6	14.6	Not Open
9/30/97 13:22	800	802	592	99	703	100.2	60.9	45.2	15.7	Not Open
9/30/97 13:24	850	854	628	98	756	100.1	64.8	47.9	16.8	Not Open

Table 3.27.5-11

SV3112B Valve Test With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 120 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI3028 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
9/30/97 13:29	850	850	605	98	752	98.0	64.7	46.4	18.3	Not Open
9/30/97 13:34	800	794	568	98	696	90.6	61.3	44.2	17.1	Not Open
9/30/97 13:37	750	747	469	98	649	86.3	58.2	37.0	21.2	Fully Open
9/30/97 13:42	700	693	375	98	595	88.4	53.9	29.7	24.2	Fully Open
9/30/97 13:44	650	646	299	98	548	88.9	50.3	23.9	26.4	Fully Open
9/30/97 13:47	600	594	270	98	496	92.2	46.0	21.5	24.5	Fully Open
9/30/97 13:51	550	550	248	97	453	97.2	42.3	19.7	22.6	Fully Open
9/30/97 13:54	500	501	212	98	403	98.0	38.6	17.0	21.6	Fully Open
9/30/97 13:57	450	452	194	98	354	97.8	34.9	15.6	19.3	Fully Open
9/30/97 13:59	400	399	172	98	301	97.3	31.0	14.0	17.0	Fully Open
9/30/97 14:02	350	351	149	98	253	97.3	27.4	12.3	15.1	Fully Open
9/30/97 14:06	300	309	125	98	211	97.7	24.2	10.5	13.8	Fully Open
9/30/97 14:09	250	256	112	97	159	97.3	20.3	9.5	10.8	Fully Open
9/30/97 14:12	200	208	104	97	111	94.6	16.8	8.9	7.8	Fully Open

Table 3.27.5-12

SV3112B Valve Test With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 140 psig

Date/Time	PI4663 Set Pres (psig)	PI3106 Initial Tank Pres (psig)	PI3106 Final Tank Pres (psig)	PI3028 PCD Pres (psig)	Pres Diff Between Tank and PCD (psig)	TI3196 Temp (F)	Initial Mass (lb)	Final Mass (lb)	Mass Discharge (lb)	Note
9/30/97 14:20	200	194	108	97	97	93.0	15.8	9.3	6.5	Fully Open
9/30/97 14:23	250	254	120	97	157	99.9	20.0	10.0	10.0	Fully Open
9/30/97 14:27	300	300	128	97	203	105.1	23.3	10.5	12.7	Fully Open
9/30/97 14:31	350	356	140	99	257	109.9	27.2	11.3	15.8	Fully Open
9/30/97 14:35	400	411	177	99	312	110.3	31.2	14.0	17.1	Fully Open
9/30/97 14:38	450	452	168	99	353	112.1	34.1	13.3	20.7	Fully Open
9/30/97 14:41	450	450	191	99	351	111.1	34.0	15.0	18.9	Fully Open
9/30/97 14:45	500	502	186	100	402	113.5	37.6	14.6	23.0	Fully Open
9/30/97 14:48	500	501	220	102	399	112.8	37.6	17.1	20.5	Fully Open
9/30/97 14:51	550	553	216	104	449	115.1	41.2	16.7	24.5	Fully Open

Table 3.27.5-13

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.3 sec and Pilot Pressure of 100 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
9/24/97	15:40	94	199	92	385	174	300	347	100	186	161
9/24/97	16:20	92	186	92	370	187	300	389	100	186	203
9/24/97	17:00	94	154	91	339	216	300	442	100	187	255
9/24/97	17:40	94	105	91	290	266	300	488	100	188	300
9/24/97	18:20		0		0		300	538	100	186	352
9/25/97	13:26		0		176		300	492	100	195	297
9/25/97	14:06		0		0		300	542	100	195	347
9/25/97	14:46		0		0		300	588	100	195	393
9/25/97	15:26		0		0		300	641	100	195	446
9/25/97	16:06		0		0		300	688	100	195	493
9/25/97	16:46		0		0		300	739	100	194	545
9/25/97	17:26		0		0		300	790	100	195	595

Table 3.27.5-14

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 120 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
10/1/97	8:11	100	157	95	352	216	300	522	120	191	331
10/1/97	8:29	96	200	94	390	174	300	398	120	190	208
10/1/97	9:01	97	195	93	385	171	300	394	120	191	203
10/1/97	9:09	95	198	93	386	178	300	446	120	191	255
10/1/97	9:12	98	187	92	377	186	300	506	120	193	313
10/1/97	9:15	99	165	94	358	206	300	554	120	193	361
10/1/97	9:18	98	132	93	323	235	300	604	120	191	413
10/1/97	9:21	98	46	92	236	329	300	651	120	192	459
10/1/97	9:24		0		95		300	706	120	192	514
10/1/97	9:27		0		0		300	754	120	191	563
10/1/97	9:29		0		0		300	803	120	192	611
10/1/97	9:36		0		0		300	839	120	192	647

Table 3.27.5-15

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.3 Sec and Pilot Pressure of 140 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
10/1/97	9:59		0		0		300	838	140	191	647
10/1/97	10:01		0		0		300	804	140	192	612
10/1/97	10:03		0		0		300	779	140	191	588
10/1/97	10:06		0		0		300	751	140	192	559
10/1/97	10:09		0		146		300	711	140	192	519
10/1/97	10:13	99	68	92	259	305	300	656	140	192	464
10/1/97	10:16	94	145	91	330	226	300	612	140	192	420
10/1/97	10:19	98	163	91	352	210	300	574	140	192	382
10/1/97	10:22	98	170	92	360	199	300	508	140	192	316
10/1/97	10:24	94	194	91	379	178	300	463	140	193	270
10/1/97	10:26	93	197	92	382	172	300	426	140	191	235
10/1/97	10:30	93	197	91	381	171	300	387	140	192	195
10/1/97	10:32	96	197	92	385	171	300	350	140	192	158

Table 3.27.5-16

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 100 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
10/1/97	11:31	93	496	90	679	178	600	352	100	192	160
10/1/97	11:34	90	486	90	666	184	600	403	100	193	210
10/1/97	11:39	91	462	90	643	213	600	448	100	192	256
10/1/97	11:44	91	384	90	565	290	600	498	100	193	305
10/1/97	11:51	93	251	90	434	422	600	543	100	192	351
10/1/97	11:53	93	18	90	201	656	600	604	100	192	412
10/1/97	11:56		0		0		600	655	100	191	464
10/1/97	11:59		0		0		600	707	100	191	516
10/1/97	12:02		0		0		600	757	100	191	566
10/1/97	12:04		0		0		600	807	100	191	616
10/1/97	12:07		0		0		600	857	100	191	666
10/1/97	12:10		0		0		600	907	100	191	716

Table 3.27.5-17

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 120 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
10/1/97	12:21		0		0		600	892	120	192	700
10/1/97	12:23		0		0		600	856	120	192	664
10/1/97	12:28		0		0		600	796	120	192	604
10/1/97	12:30		0		0		600	751	120	192	559
10/1/97	12:33	99	8	90	197	661	600	701	120	192	509
10/1/97	12:35	94	187	91	372	482	600	666	120	192	474
10/1/97	12:36	93	328	91	512	346	600	613	120	192	421
10/1/97	12:38	94	424	91	609	250	600	563	120	192	371
10/1/97	12:40	93	472	91	656	203	600	499	120	192	307
10/1/97	12:42	93	490	91	674	184	600	446	120	192	254
10/1/97	12:46	91	502	91	684	170	600	396	120	191	205
10/1/97	12:50	96	504	91	691	170	600	345	120	191	154

Table 3.27.5-18

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.6 Sec and Pilot Pressure of 140 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
10/1/97	15:42	94	509	91	694	165	600	256	140	99	157
10/1/97	15:50	91	506	91	688	165	600	297	140	99	198
10/1/97	15:54	91	499	90	680	174	600	350	140	99	251
10/1/97	15:58	96	482	90	668	190	600	403	140	99	304
10/1/97	16:04	98	472	90	660	202	600	448	140	99	349
10/1/97	16:09	93	456	90	639	216	600	501	140	99	402
10/1/97	16:13	93	389	90	572	282	600	551	140	99	452
10/1/97	16:18	96	325	90	511	347	600	601	140	98	503
10/1/97	16:24	94	224	90	408	445	600	648	140	98	550
10/1/97	16:28	96	69	90	255	602	600	707	140	98	609
10/1/97	16:32				0		600	751	140	98	653
10/1/97	16:36				0		600	803	140	98	705
10/1/97	16:39				0		600	860	140	98	762

Table 3.27.5-19

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 100 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
10/9/97	11:25	99	790	93	982	176	900	243	100	97	146
10/9/97	11:29	93	790	90	973	186	900	303	100	98	205
10/9/97	11:33	93	768	93	954	205	900	356	100	98	258
10/9/97	11:37	93	710	90	893	262	900	405	100	98	307
10/9/97	11:41	96	586	93	775	387	900	457	100	98	359
10/9/97	11:44	99	384	90	573	592	900	507	100	98	409
10/9/97	11:48	96	131	93	320	842	900	556	100	98	458
10/9/97	11:51		0		0		900	606	100	97	509
10/9/97	11:54		0		0		900	655	100	98	557
10/9/97	11:57		0		0		900	705	100	98	607
10/9/97	12:00		0		0		900	756	100	98	658
10/9/97	12:04		0		0		900	806	100	98	708
10/9/97	12;06		0		0		900	855	100	98	757
10/9/97	12:09		0		0		900	907	100	98	809

Table 3.27.5-20

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 120 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
10/9/97	12:20		0		0		900	892	120	97	795
10/9/97	12:24		0		0		900	845	120	98	747
10/9/97	12:26		0		0		900	802	120	98	704
10/9/97	12:27		0		0		900	761	120	98	663
10/9/97	12:29		0		0		900	718	120	97	621
10/9/97	12:31	102	35	90	227	941	900	680	120	98	582
10/9/97	12:34	99	298	93	490	669	900	640	120	98	542
10/9/97	12:36	99	493	90	682	483	900	593	120	97	496
10/9/97	12:40	102	614	93	809	358	900	538	120	98	440
10/9/97	12:42	99	659	93	851	310	900	512	120	97	415
10/9/97	12:46	99	586	90	775	387	900	555	120	98	457
10/9/97	12:49	99	685	93	877	285	900	488	120	98	390
10/9/97	12:52	96	758	90	944	214	900	448	120	98	350
10/9/97	12:56	99	774	90	963	202	900	392	120	97	295
10/9/97	12:58	93	797	93	983	176	900	343	120	97	246
10/9/97	13:01	93	803	90	986	173	900	297	120	97	200
10/9/97	13:04	96	803	90	989	170	900	259	120	98	161

Table 3.27.5-21

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 0.9 Sec and Pilot Pressure of 140 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
10/9/97	13:23	96	806	93	995	163	900	246	140	97	149
10/9/97	13:28	96	800	93	989	170	900	307	140	98	209
10/9/97	13:32	93	806	90	989	166	900	291	140	98	193
10/9/97	13:35	93	797	90	980	176	900	355	140	97	258
10/9/97	13:39	102	771	90	963	198	900	405	140	98	307
10/9/97	13:43	99	771	90	960	205	900	456	140	97	359
10/9/97	13:47	99	755	90	944	221	900	506	140	98	408
10/9/97	13:51	96	691	90	877	282	900	562	140	98	464
10/9/97	13:54	99	634	93	826	336	900	605	140	98	507
10/9/97	13:59	96	557	90	743	416	900	658	140	98	560
10/9/97	14:02	96	429	93	618	544	900	708	140	98	610
10/9/97	14:05	96	262	90	448	714	900	756	140	98	658
10/9/97	14:07	99	96	90	285	877	900	806	140	97	709
10/9/97	14:10		0		0		900	855	140	98	757
10/9/97	14:12		0		0		900	905	140	98	807

Table 3.27.5-22

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 100 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
9/30/97	12:46	96	1107	90	1293	170	1200	201	100	98	103
9/30/97	12:52	93	1104	90	1287	173	1200	249	100	98	151
9/30/97	12:55	90	1098	90	1278	179	1200	299	100	98	201
9/30/97	12:58	96	1062	90	1248	214	1200	351	100	98	253
9/30/97	13:01	96	986	90	1172	288	1200	401	100	98	303
9/30/97	13:05	96	838	93	1027	435	1200	452	100	98	354
9/30/97	13:08	96	614	93	803	659	1200	501	100	98	403
9/30/97	13:11	96	326	93	515	947	1200	551	100	98	453
9/30/97	13:13	96	42	93	231	1232	1200	603	100	97	506
9/30/97	13:15		0		0		1200	654	100	97	557
9/30/97	13:18		0		0		1200	702	100	98	604
9/30/97	13:20		0		0		1200	754	100	98	656
9/30/97	13:22		0		0		1200	802	100	99	703
9/30/97	13:24		0		0		1200	854	100	98	756

Table 3.27.5-23

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 120 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
9/30/97	13:29		0		0		1200	850	120	98	752
9/30/97	13:34		0		0		1200	794	120	98	696
9/30/97	13:37	99	45	93	237	1229	1200	747	120	98	649
9/30/97	13:42	102	342	90	534	934	1200	693	120	98	595
9/30/97	13:44	102	541	93	736	733	1200	646	120	98	548
9/30/97	13:47	102	736	90	928	541	1200	594	120	98	496
9/30/97	13:51	102	861	90	1053	416	1200	550	120	97	453
9/30/97	13:54	102	950	90	1142	323	1200	501	120	98	403
9/30/97	13:57	96	1034	90	1220	240	1200	452	120	98	354
9/30/97	13:59	96	1069	90	1255	208	1200	399	120	98	301
9/30/97	14:02	99	1075	93	1267	198	1200	351	120	98	253
9/30/97	14:06	93	1101	90	1284	176	1200	309	120	98	211
9/30/97	14:09	96	1104	93	1293	173	1200	256	120	97	159
9/30/97	14:12	96	1104	90	1290	170	1200	208	120	97	111

Table 3.27.5-24

Characteristic Times for Valve SV3112B With Electrical Pulse Duration of 1.2 Sec and Pilot Pressure of 140 psig

Date	Time	Time to Open (ms)	Fully Open Time (ms)	Time to Close (ms)	Duration of Close Limit Switch Signal (ms)	Response Time (ms)	Elect. Pulse Duration (ms)	Accu. Tank Pressure (psig)	Pilot Pressure (psig)	PCD Pressure Before Pulse (psig)	Pres Diff Between Tank and PCD (psig)
9/30/97	14:20	96	1107	93	1296	166	1200	194	140	97	97
9/30/97	14:23	96	1107	90	1293	170	1200	254	140	97	157
9/30/97	14:27	93	1104	90	1287	173	1200	300	140	97	203
9/30/97	14:31	93	1091	90	1274	179	1200	356	140	99	257
9/30/97	14:35	99	1075	93	1267	195	1200	411	140	99	312
9/30/97	14:38	99	1069	90	1258	208	1200	452	140	99	353
9/30/97	14:41	96	1072	93	1261	202	1200	450	140	99	351
9/30/97	14:45	96	1053	93	1242	221	1200	502	140	100	402
9/30/97	14:48	96	1046	90	1232	221	1200	501	140	102	399
9/30/97	14:51	99	992	93	1184	282	1200	553	140	104	449

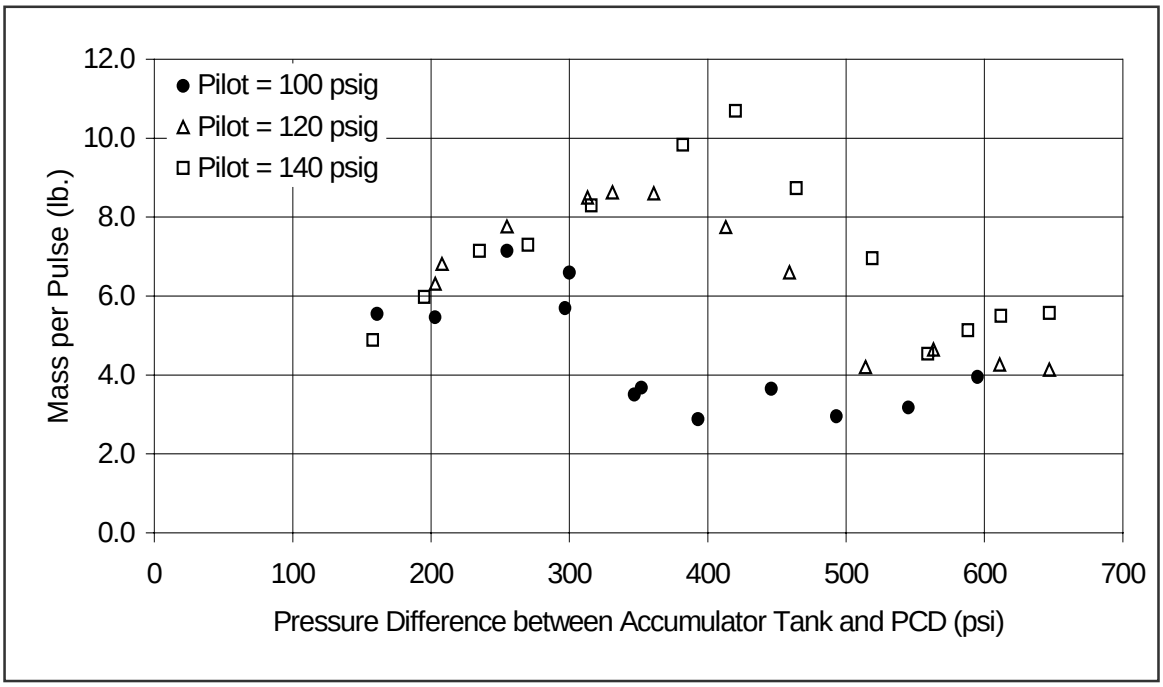


Figure 3.27.5-1 Mass Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.3 Seconds

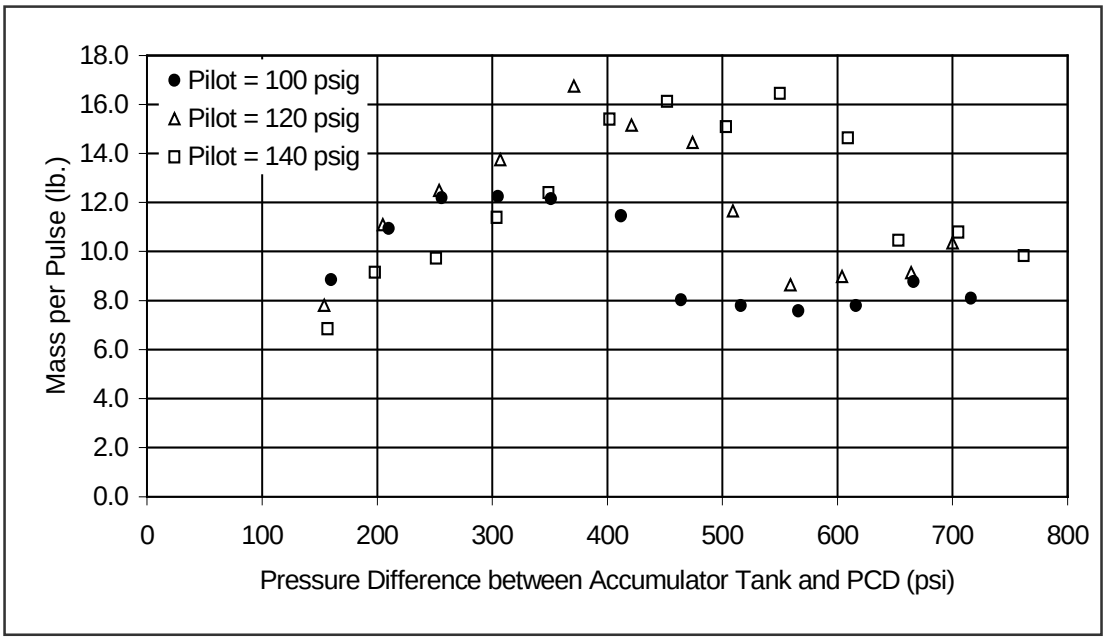


Figure 3.27.5-2 Mass Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.6 Seconds

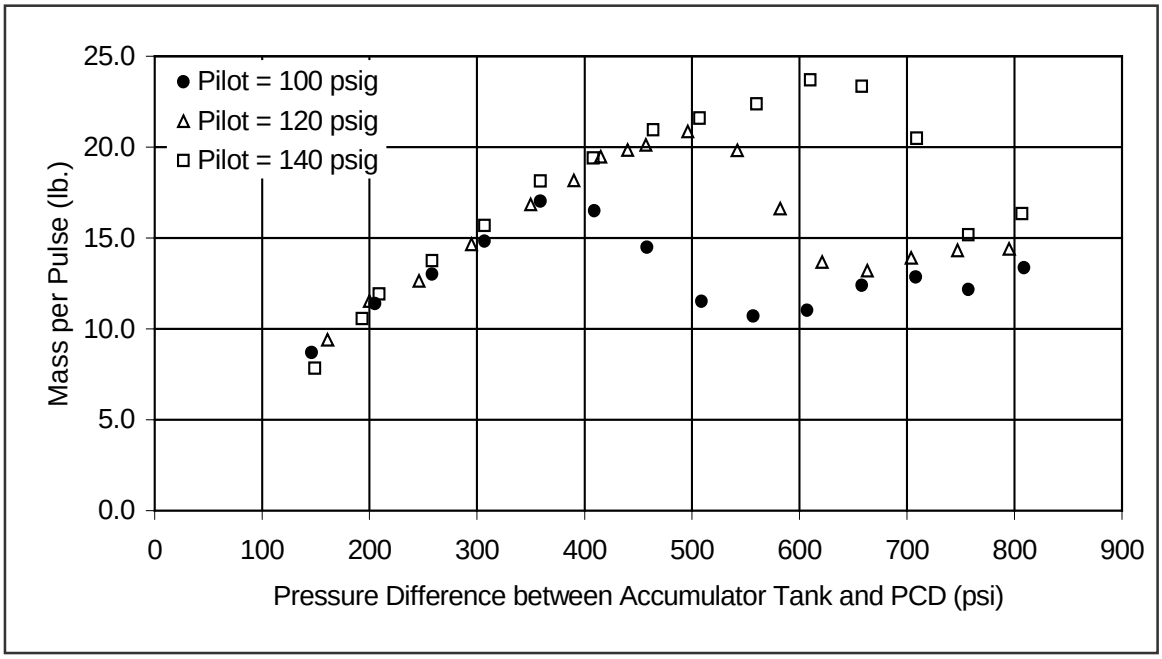


Figure 3.27.5-3 Mass Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.9 Seconds

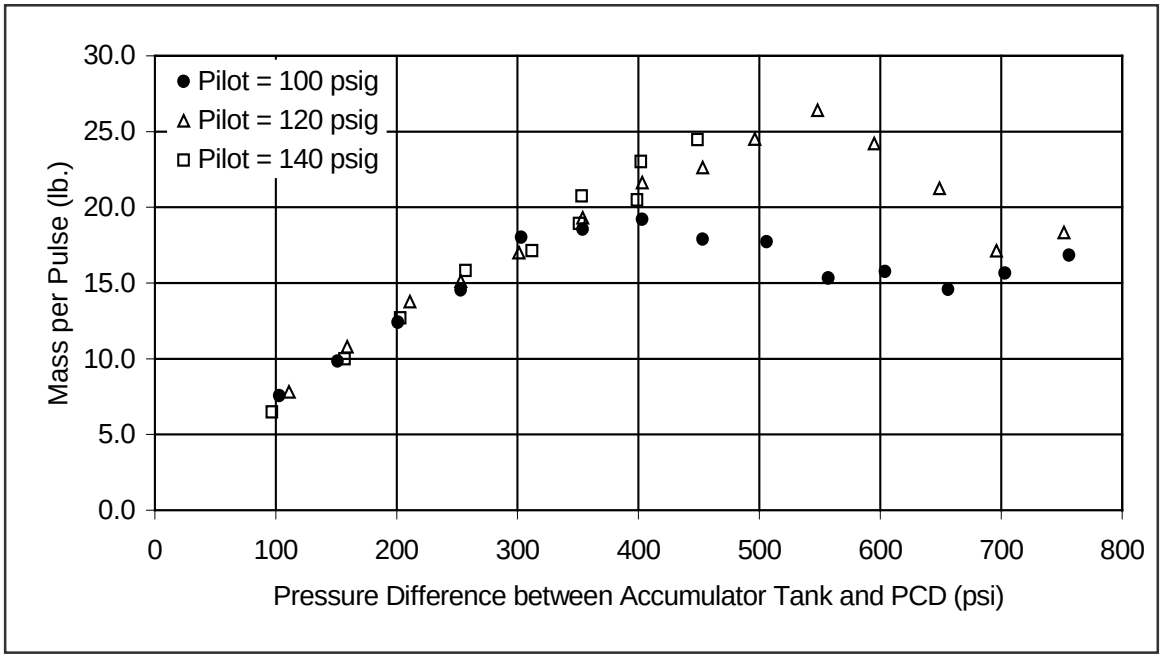
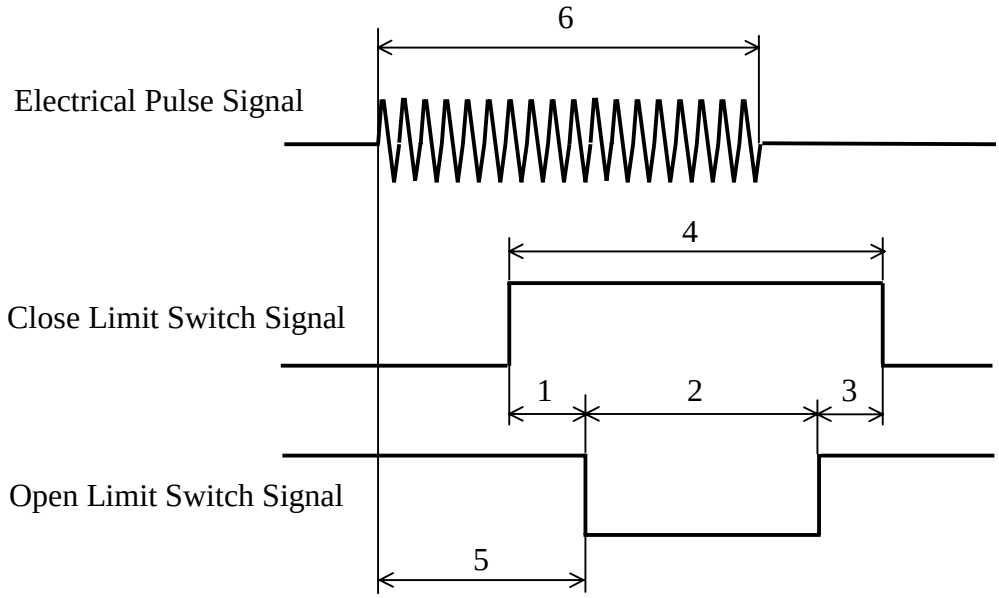


Figure 3.27.5-4 Mass Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 1.2 Seconds



1 – Time to Open
2 – Fully Open Time
3 – Time to Close
4 – Duration of Close Limit Switch Signal
5 – Response Time
6 – Electrical Pulse Duration to the Pilot Valve

Figure 3.27.5-5 Definition of Characteristic Times of Valve Movement

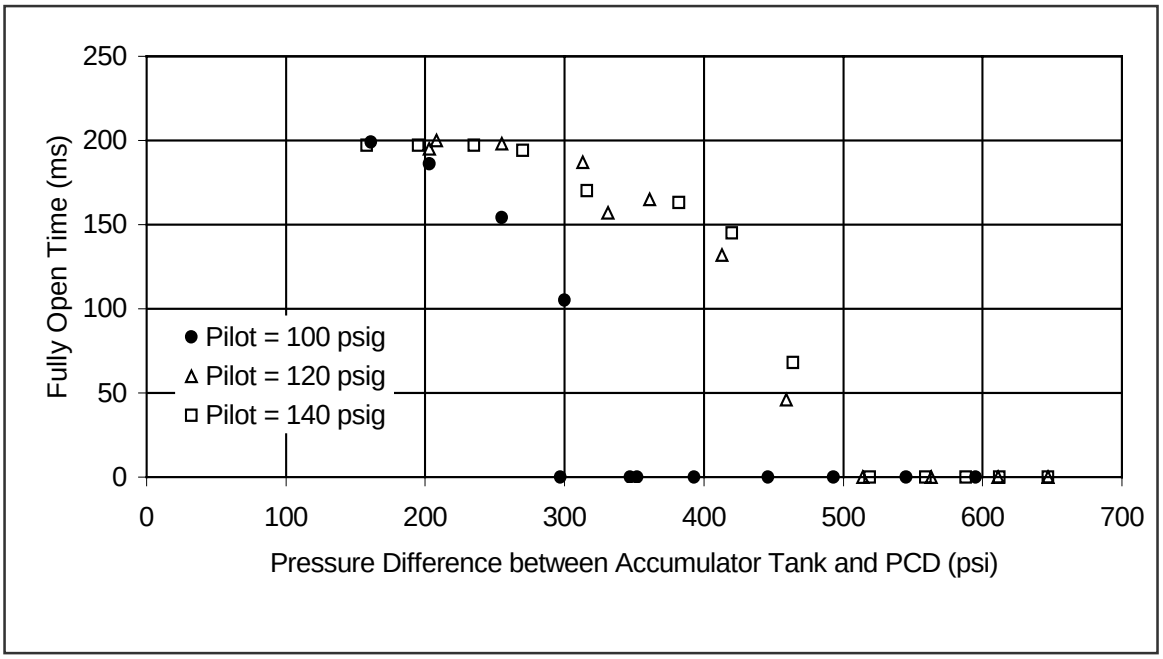


Figure 3.27.5-6 Fully Open Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.3 Seconds

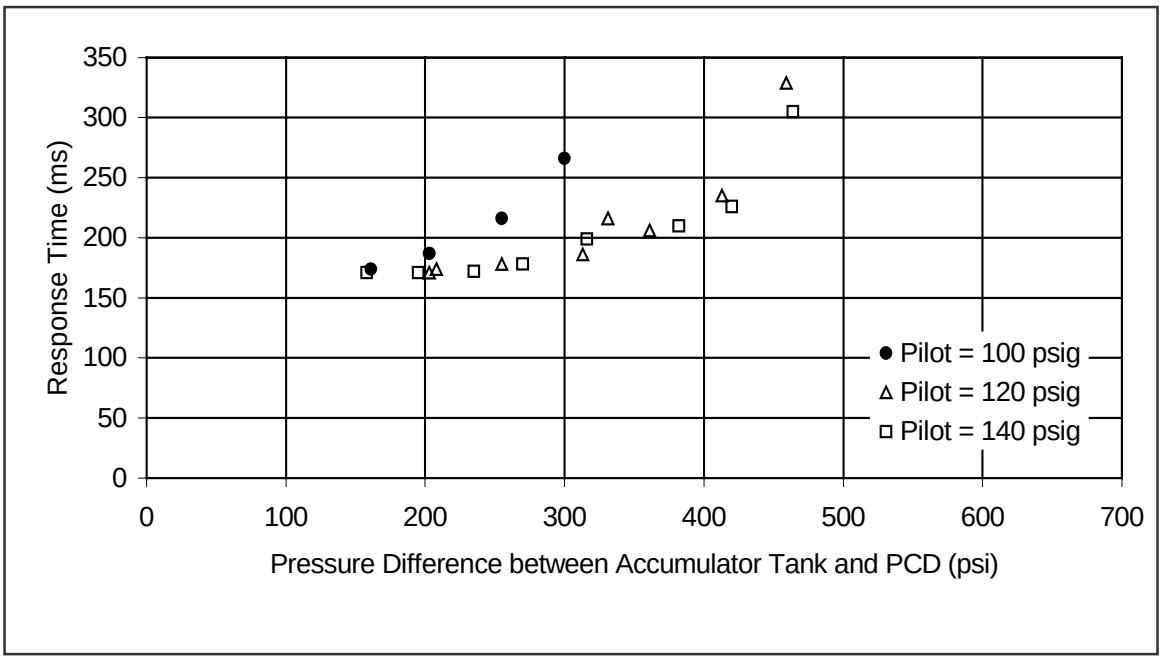


Figure 3.27.5-7 Response Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.3 Seconds

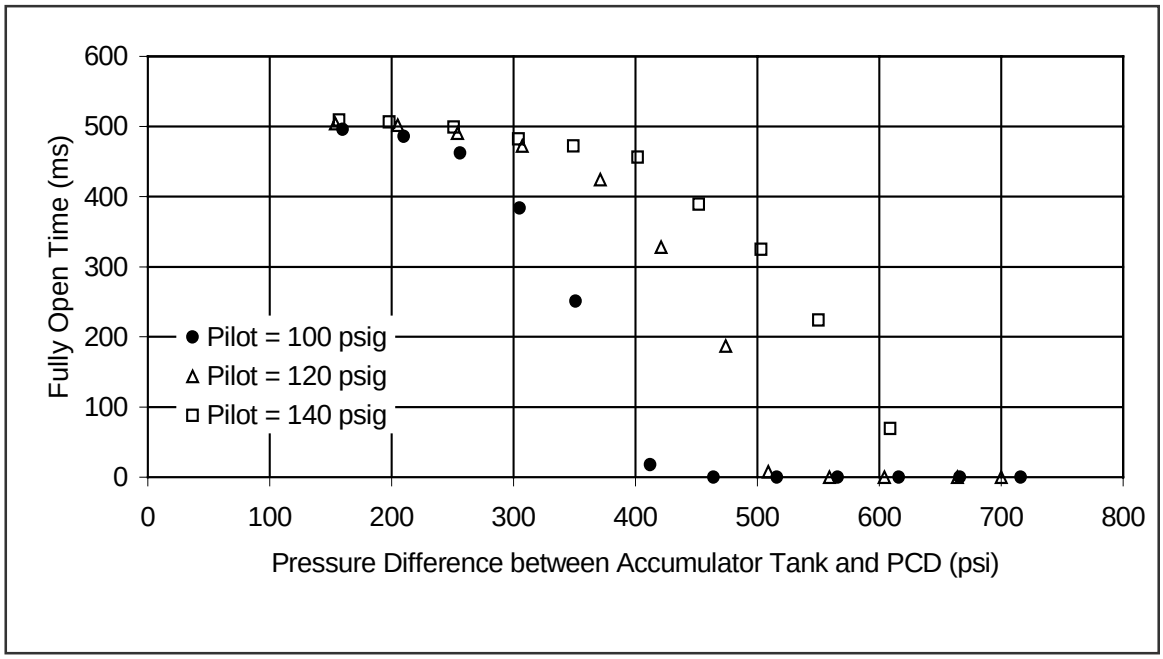


Figure 3.27.5-8 Fully Open Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.6 Seconds

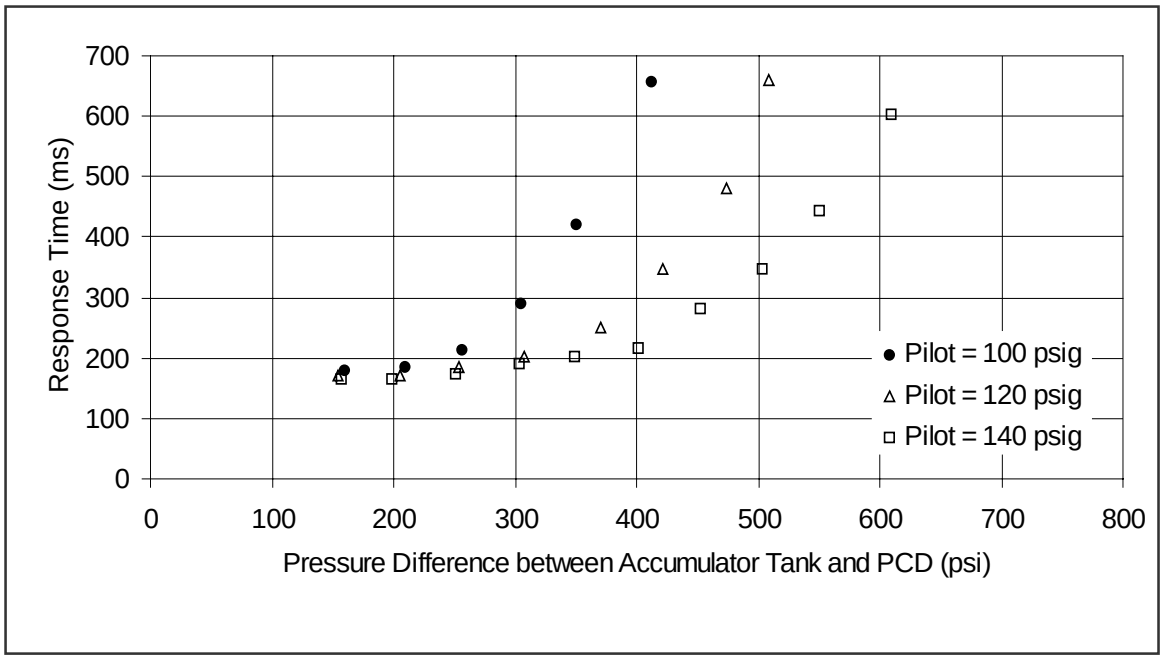


Figure 3.27.5-9 Response Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.6 Seconds

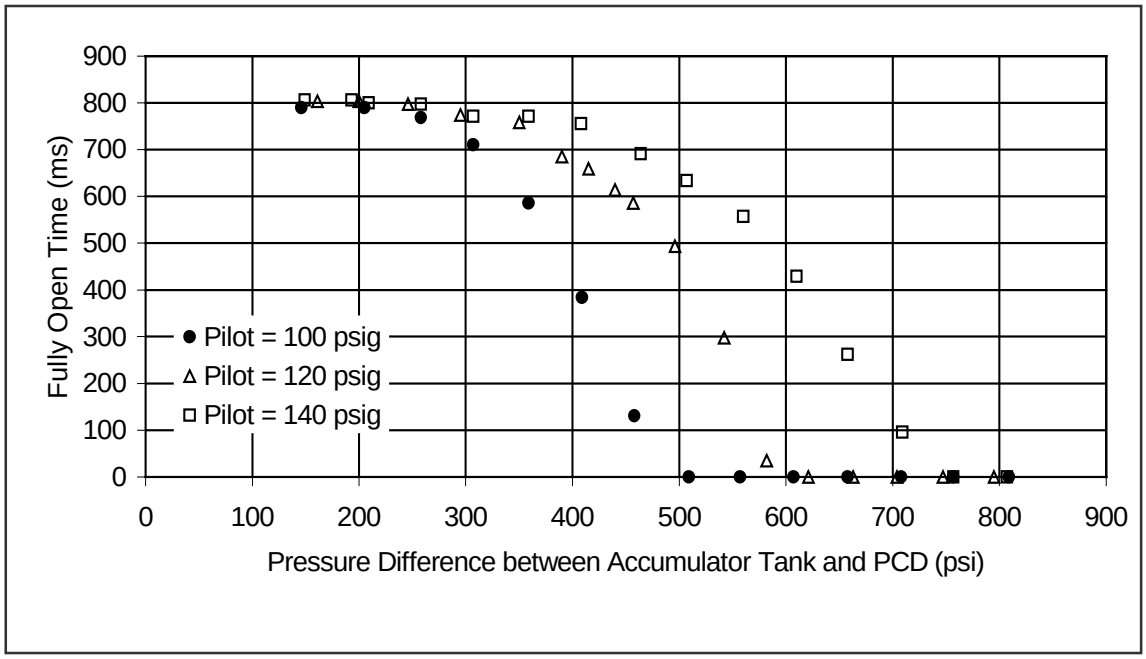


Figure 3.27.5-10 Fully Open Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.9 Seconds

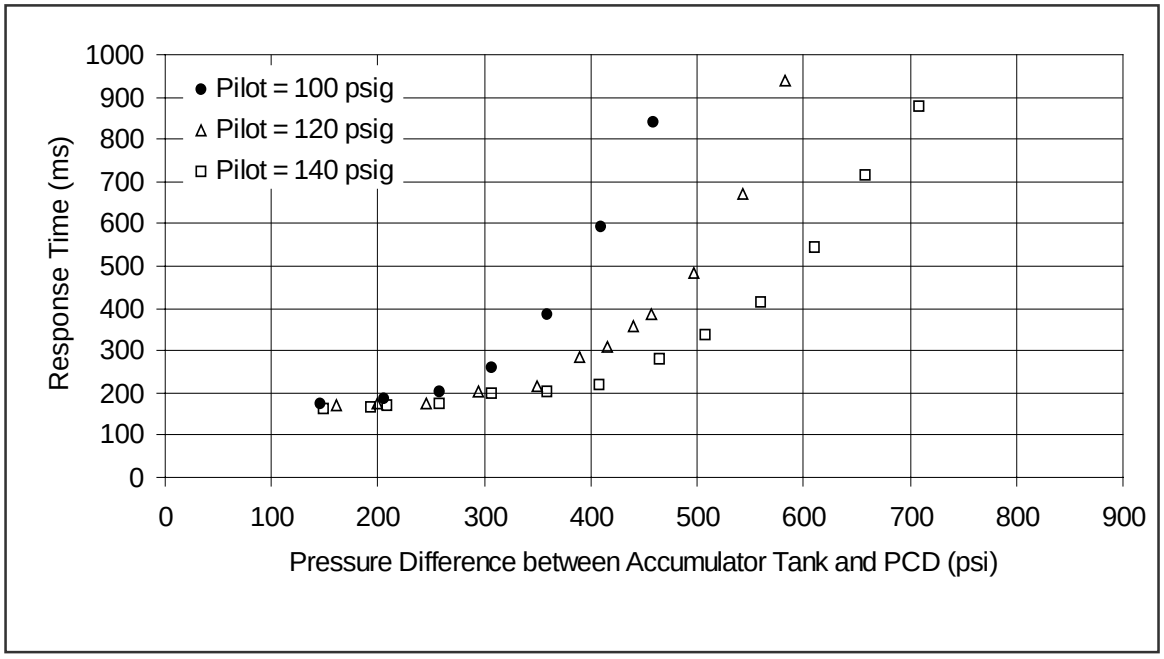


Figure 3.27.5-11 Response Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 0.9 Seconds

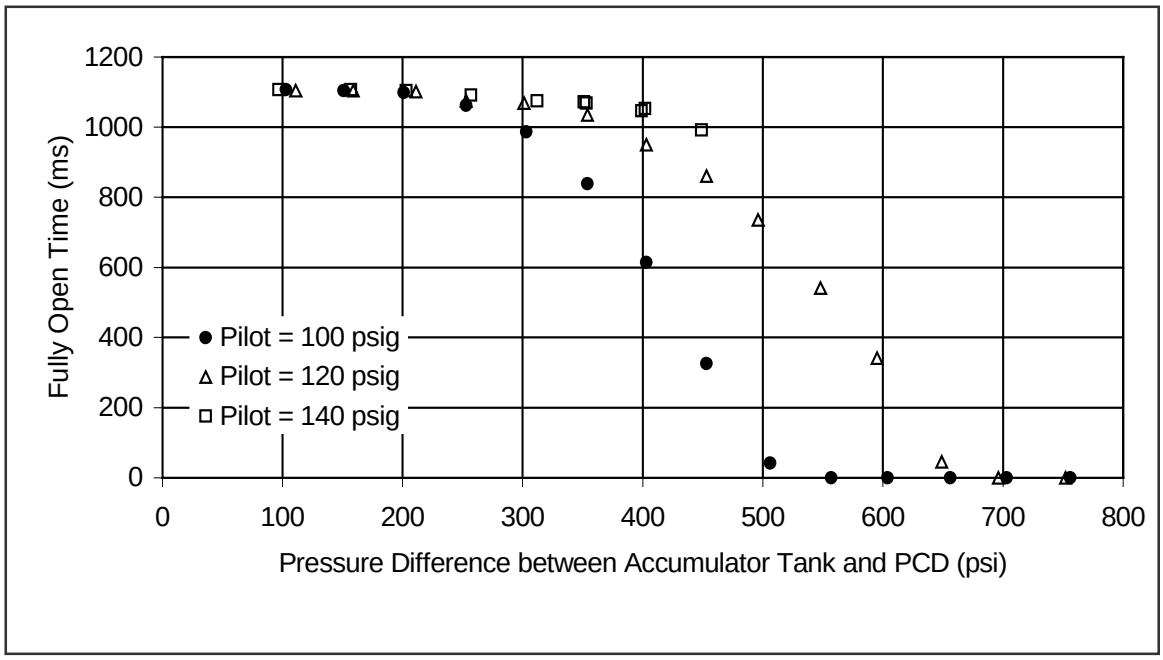


Figure 3.27.5-12 Fully Open Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 1.2 Seconds

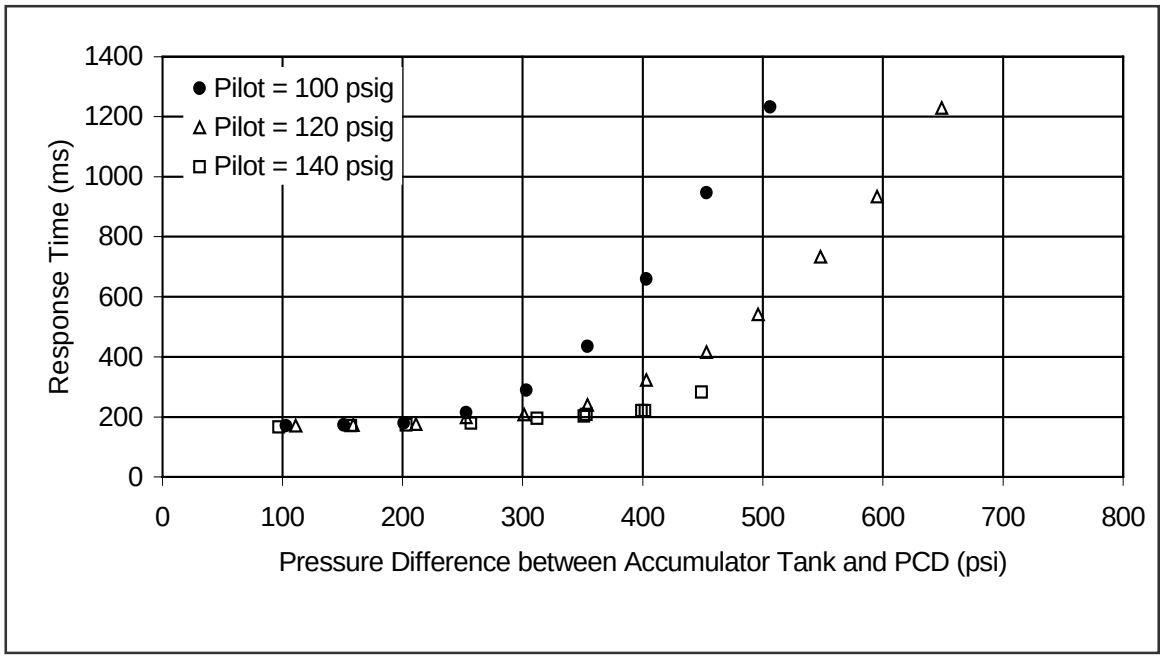


Figure 3.27.5-13 Response Time Vs Valve Differential Pressure for SV3112B With Electrical Pulse Duration of 1.2 Seconds

3.27.6 Observations and Conclusions

3.27.6.1 Force Balance for the Moving Part of the Coax Valve

The driving forces for valve VSV F80, and their effects, are analyzed in this section to facilitate presentation of the test results. A quasi-static force balance on the moving part is also conducted as the first approach to find controlling factors. Actually, the movement of the part is a dynamic procedure that needs more accurate data to calculate.

A sketch for the moving part of the valve is shown in figure 3.27.6-1. In general (without detailed information about the internal dimensions), forces during the opening are categorized as:

- In the direction to close:
  - (P_{in} A_1): acting on the inlet end of the cylinder.
  - F_s: spring force that is a function of δ and spring constant.
  - F_f: frictional force (static and dynamic) that is a function of sealing surface condition and compressive forces (from sealing elements and pressure).
  - F_d: drag force due to friction of fluid on the inner wall of the cylinder. It is a function of the surface condition of wall, flow regime, cylinder dimension, velocity, and fluid properties.

- In the direction to open:
  - (P_{pilot} A_3): acting on the piston.
  - (P_{out} A_2 $\sin\alpha$): acting on the outlet end of the cylinder.

- Force balance at a partly open position:

$$(P_{in}\ A_1) + F_s + F_f + F_d = (P_{pilot}\ A_3) + (P_{out}\ A_2 \sin\alpha) \qquad (2)$$

To Close To Open

Since (A_2 $\sin\alpha$) is close to A_1 and ($P_{in} - P_{out}$) is close to ΔP, the following expression may apply as an approximation:

$$\Delta P\ A_1 + F_s + F_f + F_d = (P_{pilot}\ A_3) \qquad (3)$$

In equation (3), ΔP and P_{pilot} are operating parameters. F_d is closely related to ΔP. All other factors can be (or almost) determined by the valve structure. Further consideration of the controlling factor electrical pulse duration shows that there are three operating parameters for the valve. The testing conditions were determined based on this analysis.

Equation (3) indicates that increasing (P_{pilot} A_3), which is referred to as actuation force, will enhance the opening procedure, while increasing ΔP will negate the actuation force. Since the valve movement is a dynamic process the forces are actually not balanced in a static position. The net force will provide acceleration in the open direction during the movement and will be balanced by the stop mechanism at the end of the movement. The electrical pulse duration does not appear explicitly in equation (3). However, it will affect the dynamic process in a number of ways, including the effect of the pressure decay in the actuation line as discussed in section 3.27.6.4.

It should be noted that this analysis was conducted without detailed profiles or dimensions of the internal structure of the valve, particularly the outlet end. Therefore, the analysis results are qualitative and should be used merely for understanding the controlling factors in the valve operation.

3.27.6.2 Mass Discharge

In all cases, the curves of mass per pulse (M/P) vs. pressure difference between accumulator tank and PCD (ΔP) exhibit the same trend. Figure 3.27.6-2 shows a typical curve consisting of three distinct regions (regions I, II, and III).

Generally, the peak and valley (points A and B in figure 3.27.6-3) migrate toward high ΔP and large M/P regions as the electrical pulse duration or pilot pressure increases. The maximum M/P and its corresponding ΔP are shown in table 3.27.6-1.

For the given electrical pulse duration, 20 percent increase in P_{pilot} resulted in a 21- to 38-percent increase in M/P and a 40-percent increase in P_{pilot} resulted in a 34- to 51-percent increase in M/P. In the corresponding situations ΔP increased by 22 to 42 percent and 65 to 80 percent, respectively.

The valve behavior in different regions will be described in detail as following.

<u>Region I</u>

The M/P increased in this region with ΔP, as shown in figures 3.27.5-1 and 3.27.6-1 through -4. The valve was fully open and the open time was almost independent of ΔP (see figures 3.27.5-6, -8, -10, and -12). Therefore, the mass discharge through the valve was controlled by the pressure difference across the valve.

The actuation force in this region associated with the pilot pressure dominates the valve opening. Since the actuation force was in excess, the fully open time was weakly related to the pilot pressure and so was the mass discharge (with an exception in the case of t = 0.6 sec and P_{pilot} = 140 psig). However, the mass discharge was considerably affected by the electrical pulse duration (t) because the open time was a strong function of t. Longer duration induced more mass discharge especially in the short duration region (i.e., from t = 0.3 to 0.6 seconds). The relationship of M/P vs. ΔP is shown in figure 3.27.6-3 for P_{pilot} =

100 psig. In the long duration region, the open time was so long that the pressure in the accumulator tank dropped significantly. Therefore, the nitrogen storage in the accumulator tank was not sufficient to provide the corresponding flow.

Region II

The valve was still fully open in the beginning but was not open near the end (point B in figure 3.27.6-2) of this region. The transition point from fully open to not open varied depending on the testing conditions. At t = 0.3 seconds the valve has been observed to be partly open near the end of region II for three pilot pressures. In those situations the moving cylinder left the close limit switch but did not contact the open limit switch.

The M/P in region II was controlled by the fully open time, which declined with ΔP in all cases. Therefore, the mass discharge decreased in this region. Force balance indicates that the ΔP produced a closing force in addition to the spring force. When ΔP increased to such an extent that the actuation force was no longer dominant the net force for the opening was decreasing with increasing ΔP. This resulted in reduced fully open time. The point (point A in figure 3.27.6-2) where the actuation force lost the domination separates regions I and II. Another factor worsening the opening is the drag force that is a strong function of ΔP. Accurate analysis and calculation for these forces depend on detailed internal dimensions that are not available at this time. Further efforts are needed if quantitative analysis is desired.

Region III

As ΔP further increased the valve was no longer open but the mass discharge exhibited a slight increase in region III.

The explanation for the mass discharge without valve opened is that the driving force for opening was not large enough to overcome the forces in the closing direction, and therefore, the moving cylinder never left the close position. However, the valve lost the sealing and was actually leaking or "bleeding" through a small gap between the outlet end of the moving cylinder and seat when the valve was actuated to open. The gap was not large enough to cause the close limit switch to lose contact but was sufficient to allow a certain amount of mass to go through.

The reason for the increase in mass discharge is unclear with no detailed information. The speculation is that the flow in this region might be in "choke" condition, that is, the velocity did not change with increasing ΔP. When ΔP increased, however, the density of the incoming pulse gas increased accordingly. Therefore, mass discharge increased, assuming the gap did not change. The data of mass change in this region roughly match the calculations of density change with pressure. In reality, the gap size might also have changed and affected the mass discharge by altering the choke flow condition. Larger mass discharge in the case of higher pilot pressure (so the larger gap size) may support this analysis. Apparently the overall trend of the mass discharge in this region was influenced by the pressure difference across the valve.

3.27.6.3 Characteristic Times

The movement of the cylinder is a dynamic procedure that is controlled by driving forces and resistance. The dynamic procedure is characterized by the fully open time, response time, time to open, and time to close.

Fully Open Time

In general, the fully open time could be affected by the electrical pulse duration (t) and pilot pressure (P_{pilot}) (see figures 3.27.5-6, -6, -10, and -12). The curves for the relationship between the fully open time and ΔP exhibit three regions corresponding to those in M/P vs. ΔP curves. In Region I, the fully open time was almost constant and independent of the pilot pressure. The value was about 100 ms less than the electrical pulse duration in all cases. In Region II the fully open time gradually decreased to zero and was a function of both electrical pulse duration and pilot pressure. The shorter the electrical pulse duration or the lower the pilot pressure the shorter the fully open time. The effect of the electrical pulse duration on the fully open time is shown in figure 3.27.6-4 for P_{pilot} = 100 psig. The fully open time was always zero in Region III.

Response Time

The response time is a representative quantity of the dynamic response of the moving part to the driving forces. The longer response time indicates that the valve is more reluctant to open. Since the response time was measured from the beginning of the electrical pulse signal to the beginning of the open limit switch signal, the data only show up in the region where the valve is fully open (see figures 3.27.5-7, -9, -11, and -13). These show that the response time was about 170 ms in the lower ΔP region in all cases. As ΔP increased, the response time diverged and was affected by the pilot pressure. High pilot pressure produced short response time. This is expected since the net force for opening increased with the pilot pressure, and therefore, the valve was easier to open. On the other hand, the response time was almost independent of the electrical pulse duration for a given pilot pressure. Figures 3.27.6-5 through -7 show the relationship of the response time vs. ΔP for P_{pilot} = 100, 120, and 140 psig, respectively.

Time to Open and Time to Close

These two characteristic times reflect the mechanical response of the moving part controlled by the spring rather than the interaction with the fluid flow (ΔP). Therefore, the time to open and time to close were fairly constant in all cases. The time to open was 90 to 102 ms and the time to close was 90 to 95 ms. These data imply that the moving part traveled at the same speed no matter how the operating conditions changed.

3.27.6.4 Actuation System

During the back-pulses there were notable decreases in the pilot pressure observed. This is because the flow rate needed to retain the actuation pressure was much higher than that provided by the pressure regulator used to control the actuation pressure upstream of the pilot reservoir tank. When the pilot valve was open and actuation gas flowed into the cavity in the valve for opening the sudden change in volume induced a pressure drop in the actuation line. This pressure drop definitely affected the opening procedure. For example, the long response time at high ΔP may be partially due to this pressure drop.

The pressure drop occurred not only in the opening procedure but also in the closing procedure. At longer electrical pulse duration (e.g., t = 0.9 and 1.2 sec) the pilot pressure dropped twice within one back-pulse, which corresponded to the opening and closing, respectively. At shorter electrical pulse duration the two drops were so close that no apparent separation has been observed.

Table 3.27.6-1

Maximum Mass Per Pulse and Its Corresponding ΔP (Point A in Figure 3.27.6-2)

Pilot Pressure (psig)	Electrical Pulse Duration (sec)			
	0.3	0.6	0.9	1.2
	(M/P)/ΔP (lb for M/P and psig for ΔP)			
100	7.1/255	12.2/305	17.0/359	19.2/403
120	8.6/361	16.8/371	20.9/496	26.4/548
140	10.7/420	16.4/550	23.7/610	24.5/449*

*Not at peak due to the incomplete run.

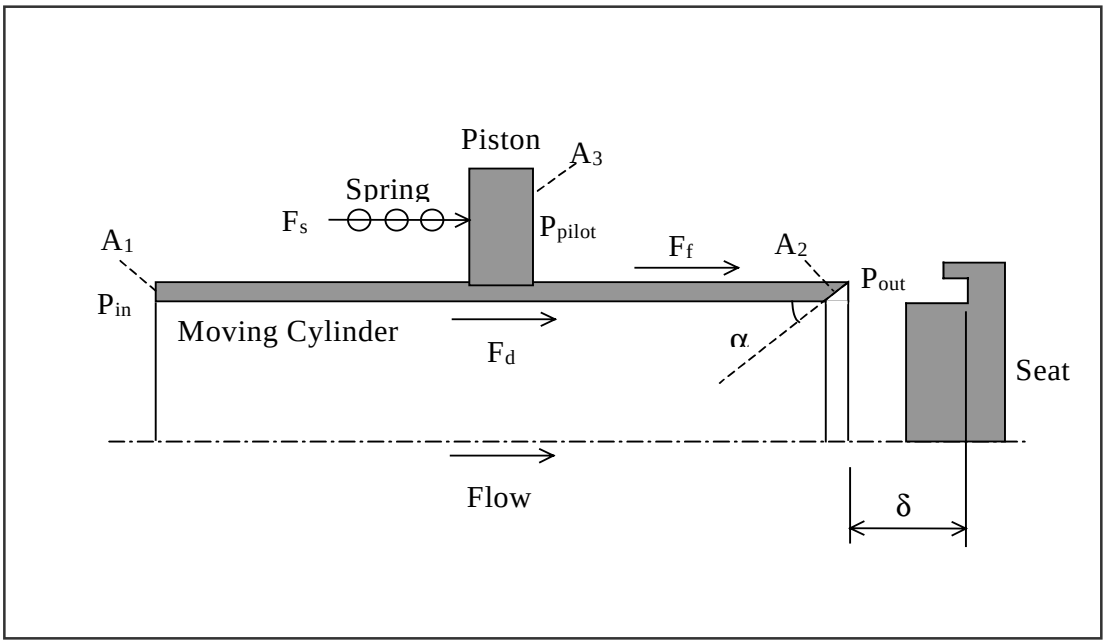


Figure 3.27.6-1 Forces at a Partly Open Position

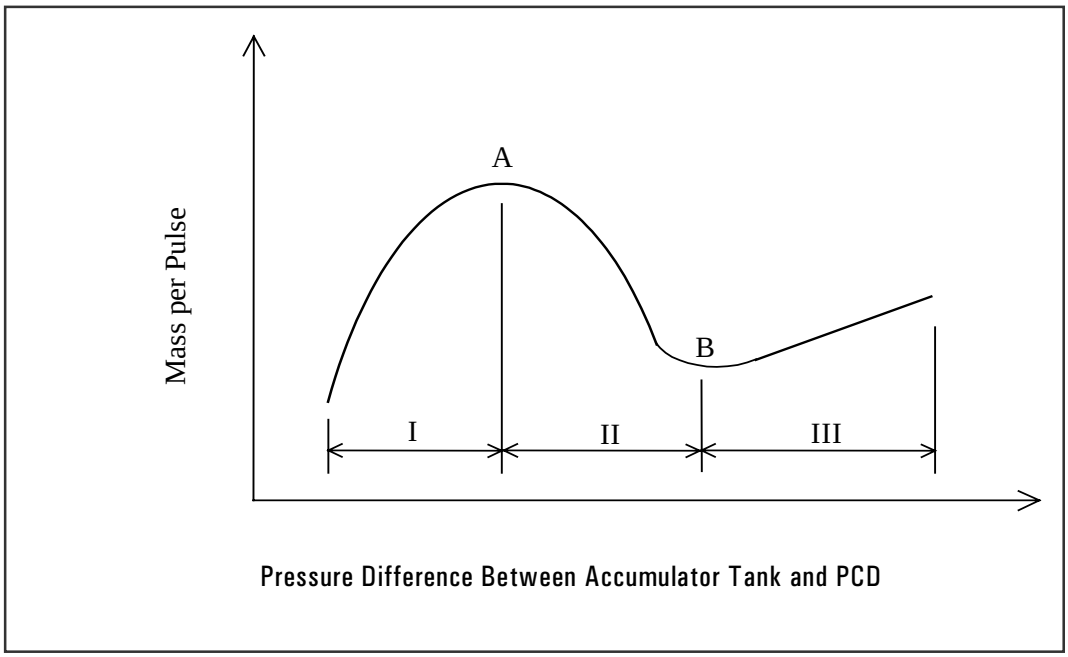


Figure 3.27.6-2 Representation of the Curve for M/P Vs Valve Differential Pressure

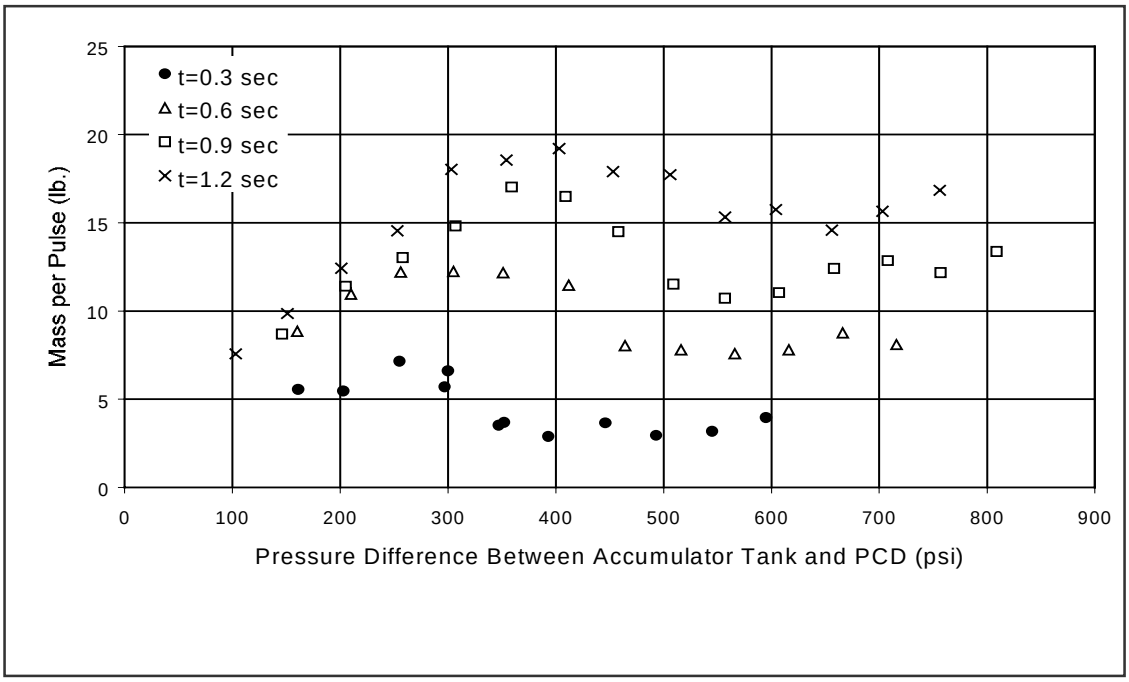


Figure 3.27.6-3 Mass Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 100 psig

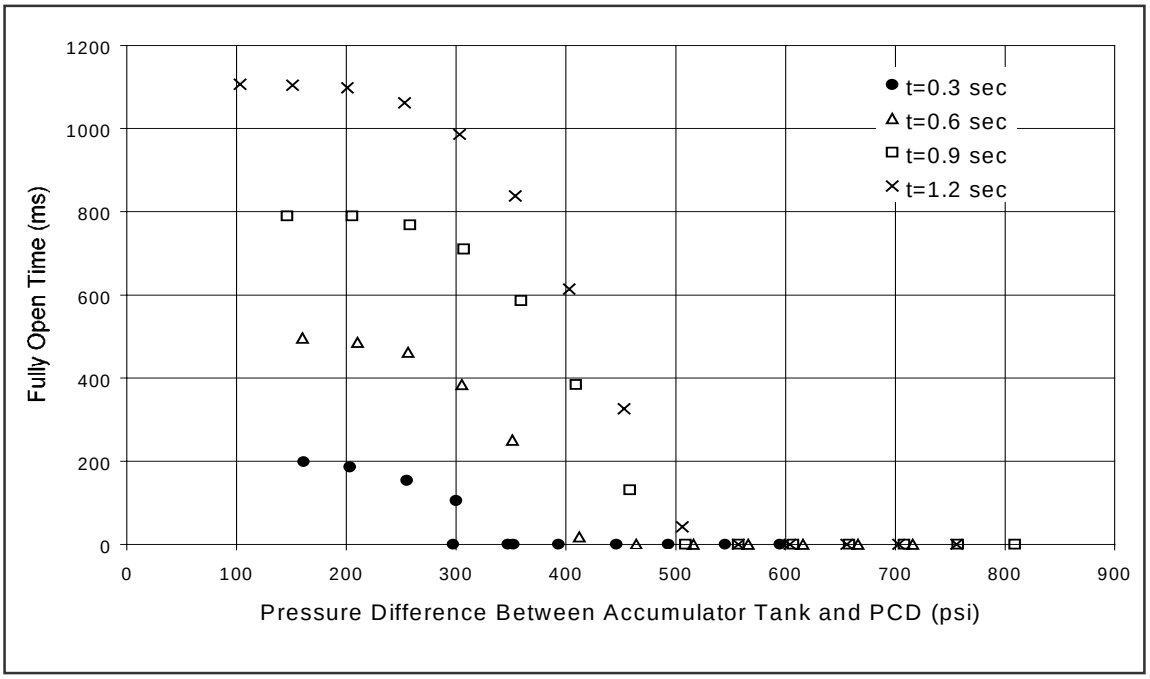


Figure 3.27.6-4 Fully Open Time Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 100 psig

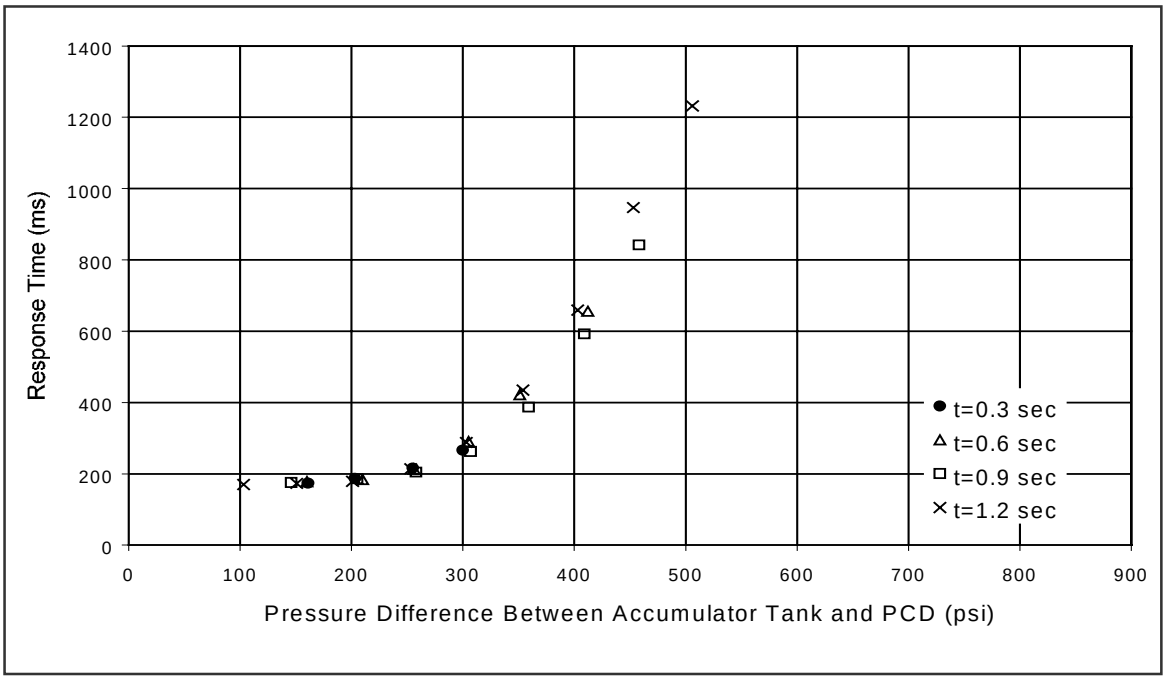


Figure 3.27.6-5 Response Time Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 100 psig

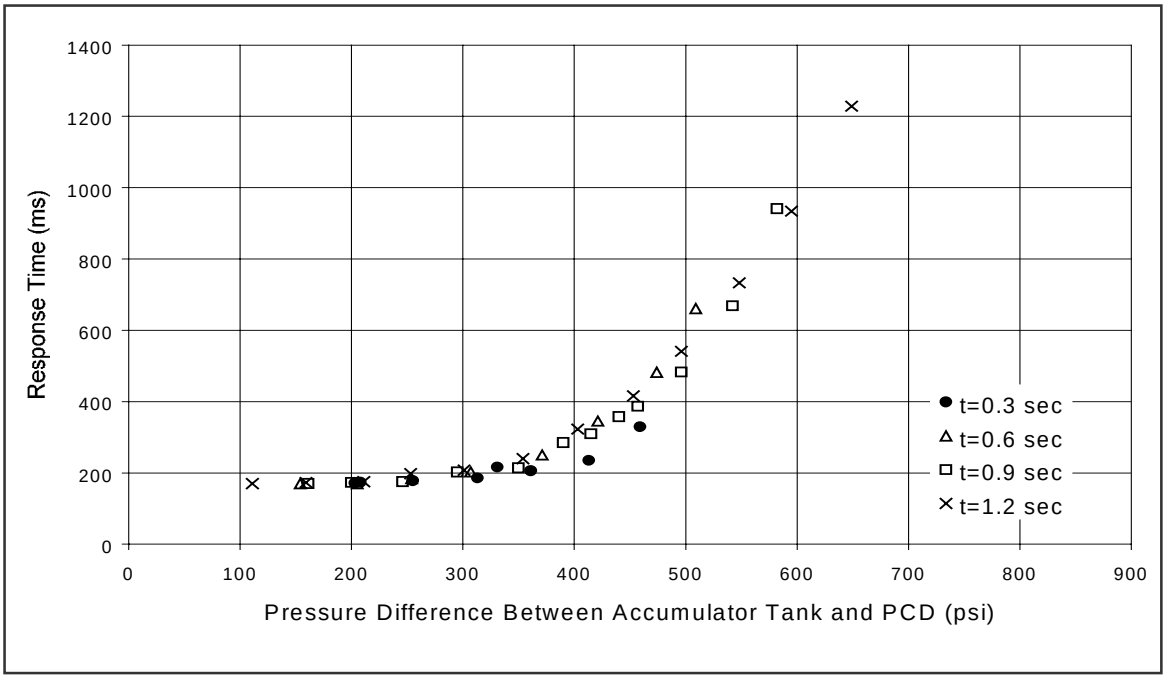


Figure 3.27.6-6 Response Time Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 120 psig

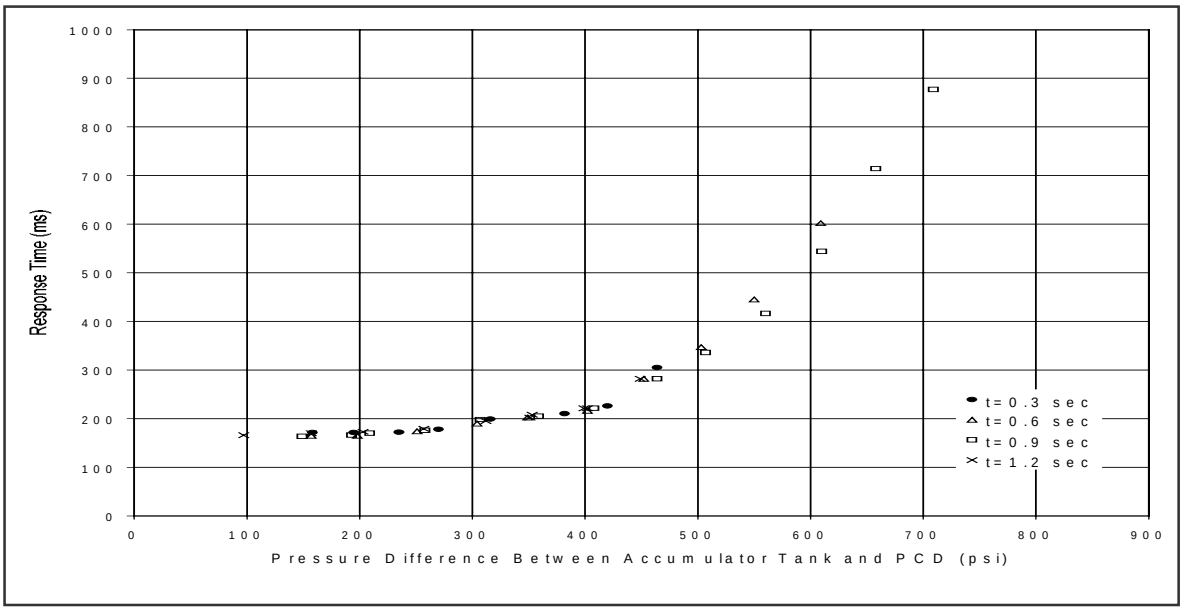


Figure 3.27.6-7 Response Time Vs Valve Differential Pressure for SV3112B With Pilot Pressure of 140 psig

3.27.7 Suggestions to Improve Valve Performance

From the test results it is evident that the Coax valve was not functioning properly at high-pressure difference across the valve. Modification or redesign of the valves would be necessary if the valves are desired to operate at high back-pulse pressures. Listed below are suggestions to improve valve performance.

1. Increase the piston size (see figure 3.27.6-1). The actuation force is proportional to A_3.

2. Replace the current pilot valve with one with a higher working pressure so that the pilot pressure can be further increased.

3. Reduce the spring stiffness. This may affect the sealing condition. However, if this is done together with increasing the piston size the sealing can be secured.

4. Modify the seat profile and outlet end of the cylinder to balance (or reduce) the force produced by ΔP. This modification may also improve the flow condition near the seat and the opening dynamic response.

5. Connect a large volume reservoir to the actuation line. The pressure decay during the back-pulse can be significantly reduced to a minimum.

In conclusion, parametric tests have been conducted for the Coax back-pulse valve. The testing results showed that mass discharge per pulse initially increased with differential pressure across the valve but decreased after the differential pressure exceeded a certain point while the valve was still fully open. The mass discharge turned to slightly increase again in the higher differential pressure region where the valve was no longer open. Generally, the fully open time decreased with increasing differential pressure and eventually went to zero. The response time increased with increasing differential pressure, whereas the time to open and time to close remained fairly constant. Longer electrical pulse duration or higher pilot pressure resulted in larger maximum mass per pulse and higher corresponding differential pressure. The fully open time increased with the electrical pulse duration or pilot pressure. The response time was only affected by the pilot pressure. These operating parameters did not affect the time to open and time to close.

3.28 FINES HANDLING SYSTEM

3.28.1 Operation Summary

During test campaign 01 (TC01) the spent fines transport system (FD0520) repeatedly forced the run to stop due to complications with the spheri valve seals. The system is manufactured by Clyde Pneumatic Conveying Ltd. of England; similar units are used for coal and limestone feed as well as for ash removal. Altogether, there are four Clyde units in the MWK system. Together, these units were responsible for over 700 hours of downtime from September to November. Figure 3.28.1-1 shows the FD0520 system. Because of the complications with the operation of the Clyde units a representative from Clyde Pneumatic Conveying visited the site in Wilsonville, Alabama, in October.

The spent fines screw cooler (FD0502) also experienced minor operational complications during TC01. The most pressing of the complications was the wear of the shaft and ceramic bushing and the ash inlet side of the screw. Figure 3.28.1-2 shows the FD0502 system. This unit, however, was never the sole reason the run was forced to stop. A representative from the manufacturer Christian Engineering was also brought in to evaluate these problems in January 1998.

Figure 3.28.1-1 FD0520

Figure 3.28.1-2 FD0502

3.28.2 Significant Observations and Major Events (FD0520)

A. FD0520 Plugged With Filter Element Pieces–September 01 at 2:00. Broken pieces of elements blocked the discharge line. This was usually characterized by a sustained increase in vessel pressure.

B. FD0520 Plugged With Filter Element Pieces–September 08 at 01:00.

C. FD0520 Plugged With Filter Element Pieces–September 19 at 20:00.

D. Spheri Valve Seal Failure–September 27 at 00:00. The silicone seal that seats on the dome valve ruptured forcing the run to end. The seal had experienced only 359 cycles.

E. Spheri Valve Seal Failure–October 15 at 00:00.

F. Spheri Valve Seal Leak–October 22 at 17:40. The o-ring seal on the middle spheri valve on FD0520 was allowing leak through of nitrogen. The valve on the nitrogen header was fluctuating between closed and fully open. The leaking o-ring recovered and the run continued.

G. Spheri Valve Seal Failure–October 23 at 21:45. The o-ring seal on the middle FD0520 spheri valve seal began leaking again and forced the end of the run. The leak was too great to continue.

H. FD0520 Plugged With Filter Element Pieces–November 02 at 13:30. Following a severe thermal event in the particulate control device (PCD) broken filter element pieces clogged the discharge from FD0520 forcing an end to the run TC01G.

3.28.3 Fines Transporter System (FD0520)

The current design for the lock vessel has a volumetric capacity of 2.0 ft^3. Actual working volume is 1.4 ft^3 as set by the level probe. Theoretically, it should be adequate for stable combustion operations. However, due to consistent problems with the unstable operations and some design defects this unit has been the major "bottle-neck" in the process. Major problems includeD:

1. The sealing system of the spheri valves was inadequately designed. The seals ruptured many times.

2. Bridging and packing in the drop pipe, lock vessel, and dispense vessel were a persistent problems. The current aeration system seems insufficient. Striking and manual aeration have to be used to solve the problem.

3. The sensitivity of the level probe was difficult to adjust and often caused an incorrect indication.

4. When elements broke the ceramic pieces often blocked the discharge line downstream of the dispense vessel.

5. Since FD0520 is an in-line piece of equipment with no means to isolate it from the system these problems with the unit often forced the plant to shut down.

The representative from Clyde Pneumatic Conveying visited the plant site in October of 1997 to discuss these problems. The primary reason for this visit was to troubleshoot problems with all the Clyde systems including FD0520. A majority of the seal problems with the Clyde system involved the high-temperature and high-pressure applications on the FD0520 systems. Consequently, the seals were failing often. Figure 3.28.3-1 shows a typical failed seal. As the seals fit snugly to the dome valve, the valve dome also showed signs of wear. Figure 3.28.3-2 shows the wear of the dome valve. Clyde has experience with high-pressure applications as well as with high-temperature applications; however, their knowledge of these two specific applications is limited. It was speculated that the silicone seals were extruding, therefore contributing to wear of the seal material from the excess friction on the dome valve. An extrusion test was conducted to prove this hypothesis. The results are displayed in table 3.28.3-2.

The silicone seals showed extensive extrusion at ambient conditions and only 200 psig (13.8 bar g). In operation, the seal could be expected to withstand pressures as great as 300 psig (20.7 bar g). The decision was made to use neoprene seals and carefully monitor the temperature limits this would place on the system. Neoprene is not recommended for use above 212°F (100°C). The replacement of the silicone seals with neoprene showed significant improvement for operation of the unit. Figure 3.28.3-3 shows the improved cycle life of neoprene as compared with silicone.

Other complications in the operation of FD0520 involve the quick dump valve for the spheri valve seal. When the actuator arm closes the dome valve a position switch is contacted. This

switch signals that the dome is in position and ready for the seal inflation. Similarly, a quick dump valve is opened prior to the movement of the actuator arm to release the seal pressure. Movement of the housing for the actuator arm often caused the failure of the contact switch to engage fully. Consequently, nitrogen for the seal escaped through the quick dump valve, which remained open while inflation of the seal was attempted. Other Clyde systems on the nitrogen header would see the resulting pressure loss, often tripping these units off line as well. This was especially the case with the coal feeder (FD0210). It was speculated that the housing was moving enough with the cover plate removed to hinder the proper contact with the contact switch. The other minor problem encountered was failure of the poppet valves on the nitrogen supply line to the spheri valve seal. This had the same effect as the failure of the quick dump valve.

The level probe in the lock hopper vessel of FD0520 often malfunctioned due to bridging in the vessel as well as inherent difficulties with the level probe technology. The unit often ran on a timed cycle without using the level probe. Additionally, there was no way to fluff the lock hopper vessel to remedy the ash bridging and caking problems. Operators were often forced to strike the side of the vessel to dislodge the bridged ash. Each vessel had a volume of only 2.0 ft^3 and bridging of the lock hopper hindered its effectiveness. Broken filter element pieces also plugged the exit line from the discharge vessel, forcing manual intervention. These and other improvements were made to the system during run TC01 to remedy some of the operational complications. Some of these improvements were a result of the Clyde recommendations while others were the result of SCS employee ideas. Recommendations include:

1. Conveying gas pressure for the discharge line from the lock hopper vessel was increased to 85 psig (5.9 bar g).

2. The surface of the domes on FD0520 were coated with a hardened surface deposit of belzone to reduce friction with the spheri seal as well as to reduce wear on the dome.

3. A control sequence modification was added to the lower seal (between the lock hopper and dispense vessel) on the FD0520 unit to ensure that the seal is fully deflated before the dome moves. There has previously been concern that the seal was not fully deflated when the dome moved.

4. In order to minimize the tendency for seal extrusion the pressure to the seal was set at approximately 30 psi (~2.0 bar) above the operating pressure of the system. The seal was previously set with header pressure, which was greater than 300 psig (20.7 bar G).

5. Restriction orifices were added to the nitrogen supply lines to each seal. This limited the flow of nitrogen in case of a seal failure and helped preserve header pressure.

6. An isolation valve was added to the drop pipe to the FD0520 unit. This will allow repairs to the unit to be conducted without the need to bring the plant down.

Table 3.28.3-1

FD0520 Significant Events

Event	Description	Date at Time
A	FD0520 Plugged With Filter Element Pieces	September 1 at 2:00
B	FD0520 Plugged With Filter Element Pieces	September 8 at 1:00
C	FD0520 Plugged With Filter Element Pieces	September 19 at 20:00
D	Spheri Valve Seal Failure	September 27 at 0:00
E	Spheri Valve Seal Failure	October 15 at 0:00
F	Spheri Valve Seal Leak	October 22 at 17:40
G	Spheri Valve Seal Failure	October 23 at 21:45
H	FD0520 Plugged With Filter Element Pieces	November 2 at 13:30

Table 3.28.3-2

FD0520 Extrusion Test Results

Silicone Seal				
Test No.	**Seal To Dome Gap at Positions (thousandths of inch)**			
	A	**B**	**C**	**D**
1	18	18	15	20
4	4	< 2	< 2	2
Neoprene Seal				
Test No.	**Seal To Dome Gap at Positions (thousandths of inch)**			
	A	**B**	**C**	**D**
1	25	27	25	27
5	25	25	25	25
New Silicone Seal				
Test No.	**Seal To Dome Gap at Positions (thousandths of inch)**			
	A	**B**	**C**	**D**
1	25	25	25	27
3	< 2	< 2	< 2	< 2

Figure 3.28.3-1 Failed Silicone Seal

Figure 3.28.3-2 Wear on FD0520 Dome Valve

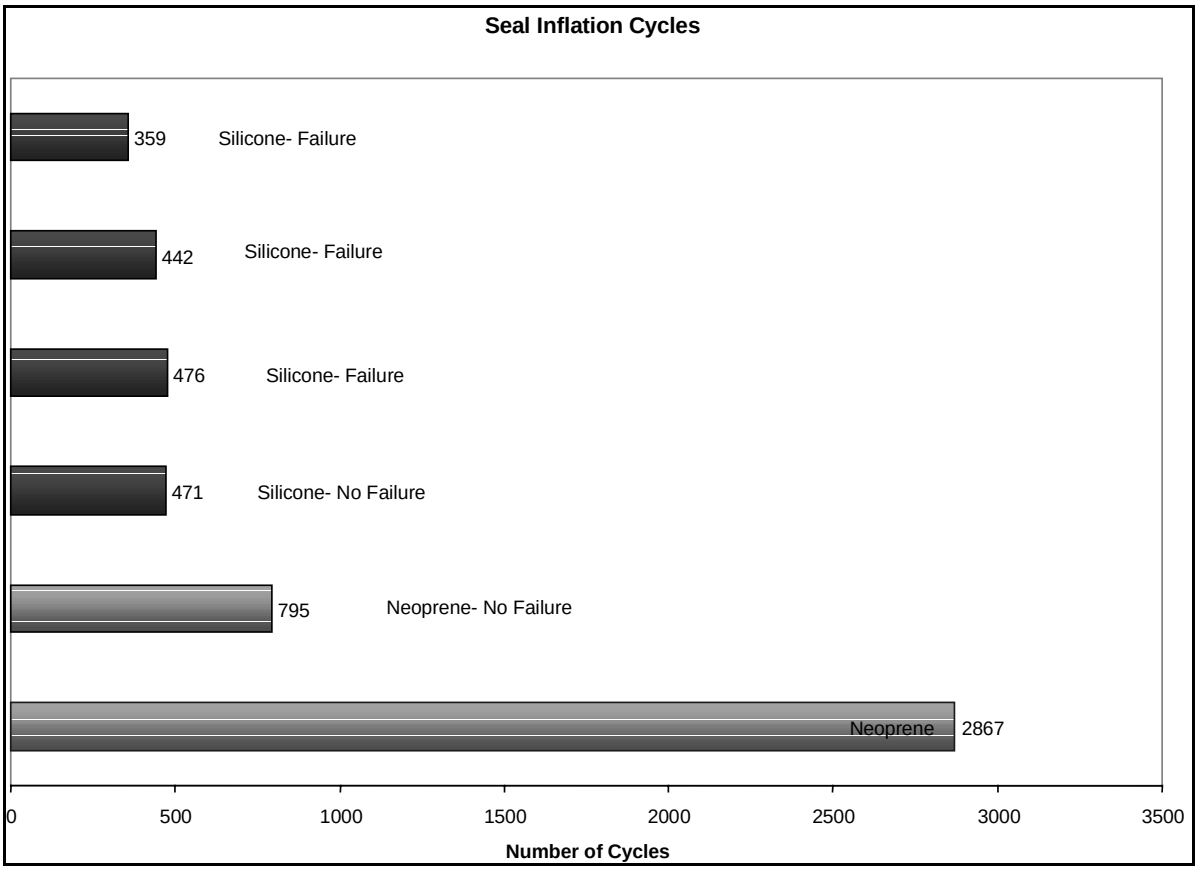


Figure 3.28.3-3 FD0520 Seal Cycle Life

3.28.4 Spent Fines Screw Cooler (FD0502)

The spent fines screw cooler operated well during most of TC01. This and previous operations have not been directly disturbed by ash removal from FD0502 with the exception of minor mechanical failures such as leakage of packing or heat transfer fluid. In other words, FD0502 is not "bottle-necking" the spent fines transport system, and since January 1, 1997, the unit has experienced over 3,000 hours of operation. Design specifications show that the volume per revolution is 0.066 ft^3/rev. At the maximum speed (12 rev/min) FD0502 can convey 47.5 ft^3/hr. Normal operations indicated that the screw of FD0502 did not convey ash in a fully loaded condition. The void ratio varied widely and was close to 0.8 in most cases. Actually, the void ratio will be reduced at larger loading, resulting in a larger conveying rate. However, even in a typical situation where the PCD cone was filled with solids the void ratio could not reach below 0.3 to ~0.5. By considering this factor the effective conveying rate should be lower than the nominal capacity. If the void ratio of 0.5~0.8 is considered the maximum effective capacity is about 10 ~24 ft^3/hr. This volumetric capacity is large enough for the stable operation of combustion mode. However, the capacity could not cover the ash loading range in gasification mode. A potential problem is that the ash will accumulate in the PCD cone at a larger loading and eventually bridge between elements. In a worst scenario with 27.4 ft^3/hr ash loading and 0.8 void ratio the PCD cone (67.7 ft^3) will be filled in 3.9 hours.

Regarding the mechanical issues, it was found from previous runs that FD0502 could efficiently crush the broken filter element pieces. The screw material seems hard enough to easily handle large filter element pieces. By varying the RPM of the unit it has also been demonstrated that it can reliably control ash temperature. However, challenges have surfaced occasionally during the operation of the unit. The most critical of these involved the ceramic bushing wear noticed in November 1997. Figure 3.28.4-1 shows the worn ceramic bushing from the ash inlet in of the unit. The shaft of the screw also showed visible signs of wear. Figure 3.28.4-2 shows the worn shaft. Wearing of the shaft and bushing is speculated to be the result of ash abrasion. Consequently, as the two wore the flights of the screw cooler encountered the side of the housing. Figure 3.28.4-3 shows the wear in the housing. This is suspected of causing the noticed noise and slight vibration of the unit. In preparation for the next run (TC01H) the shaft was reworked and the bushing replaced. The unit was put back in operation for the remainder of the TC01 run. At the conclusion of the TC01 run in January 1998, the screw was pulled again and inspected. Visible signs of wear were present again and a representative from Christian Engineering came to the site. Figures 3.28.4-4 and -5 show the worn shaft and bushing from January 1998. The shaft was reworked in preparation for the TC02 run while Christian Engineering designs a system to isolate the ceramic bushing from the process ash. Plans are to have the unit modified after the TC02 run.

Other operational challenges included leaking heat transfer fluid fittings and leaking packing for the nitrogen seal system. Operators tightened the packing many times to help eliminate the leak and inadvertently contributed to some wear of the shaft. Figure 3.28.4-6 shows this wear as detailed for the January 1998 Christian Engineering visit.

In general, FD0502 is working properly for the combustion mode but will likely encounter potential problems in normal gasification operations due to insufficient capacity. Table 3.28.4-1 details past as well as predicted ash loading data. Appropriate redesign should be made to accommodate the larger ash loading in gasification mode. The redesign for FD0520 combustion mode also requires appropriate modifications for the FD0502 capacity to fully utilize the new capacity of the whole spent fines transport system.

Table 3.28.4-1

Ash Loading Data

	Combustion	Gasification
Total Flow, lb/hr (from RFP)	24744	18735
Flow Rate, acfm (from RFP)	1000	1000
Particulate Loading (design)	4000~16000	4000~20000
Ash Loading, lb/hr	100~400	75~375
Maximum Obtainable Particulate Loading, ppmw (from RFP)	15600	41000
Ash Loading, lb/hr	386	768
Particulate Loading in CCT4 (max), ppmw	95700	
Ash Loading, lb/hr	2368	
Particulate Loading in CCT5, ppmw	25000	
Ash Loading, lb/hr	619	
Particulate Loading in CCT6, ppmw	41100	
Ash Loading, lb/hr	1017	
Ash Bulk Density, lb/ft^3:		
TC01B	39.3	
TC01C	33.7~36.8	
TC01D	37.4	
TC01E	33.1	
TC01F	30.0~36.2	
TC01G	35.0	
Average	35.2	
Ash Bulk Density, lb/ft^3:		
SRI measurement for UNDERC Sample		13.7

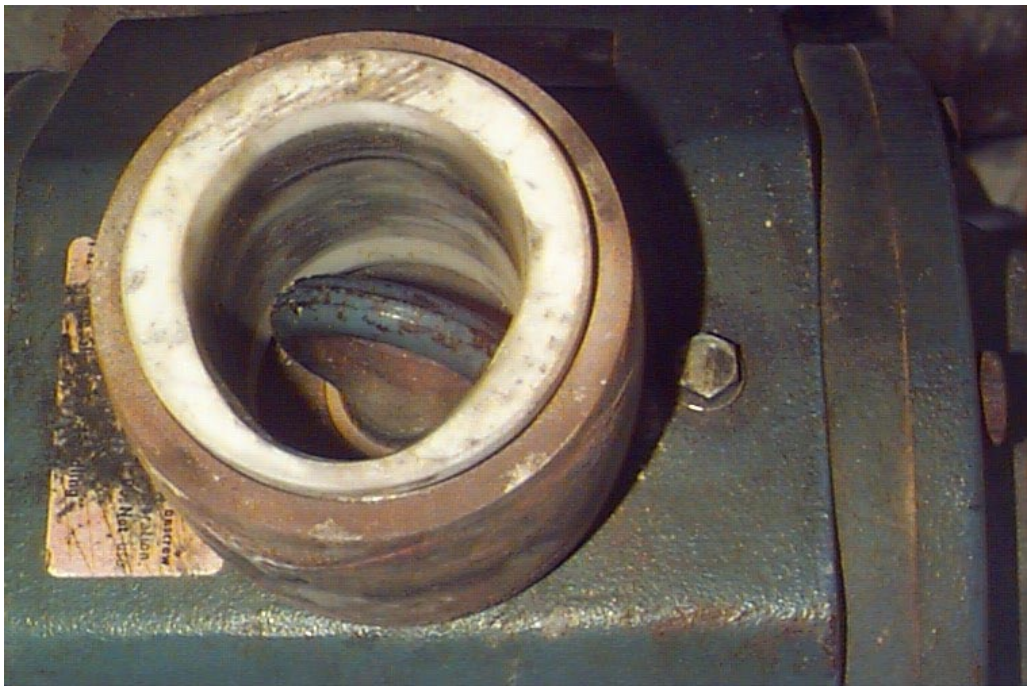


Figure 3.28.4-1 Worn Ceramic Bushing From FD0502 in November 1997

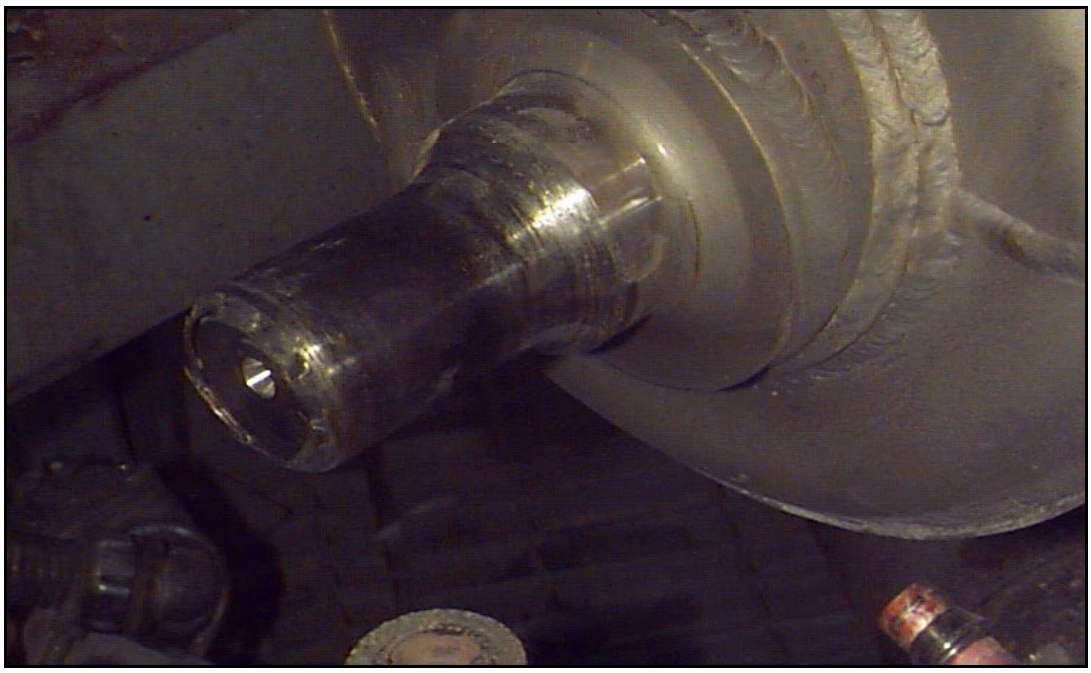


Figure 3.28.4-2 Worn Screw Shaft for FD0502 in November 1997

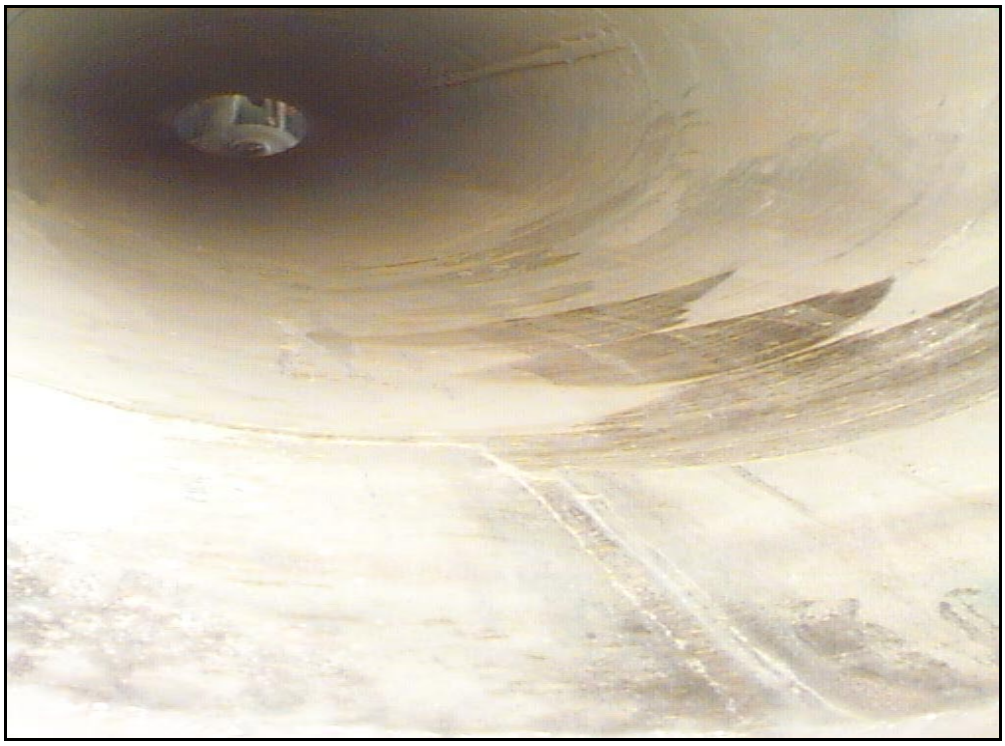


Figure 3.28.4-3 Worn Housing for FD0502 in November 1997

Figure 3.28.4-4 Shaft Wear on FD0502 in January 1998

Figure3.28.4-5 Worn Ceramic Bushing From FD0502 in January 1998

Figure 3.28.4-6 Shaft Wear From Packing in January 1998

3.28.5 Evaluation and Redesign Possibilities (FD0520/FD0502)

The FD0520 and FD0502 spent fines transport systems experienced a variety of problems during operation. The problems were a result of smaller capacity, inefficient conveying and fluffing design, inability to handle broken elements, and an insensitive level probe. Additionally, limited space for access to the system was a problem for maintenance.

3.28.5.1 Ash Loading

Combustion mode. The original design was based on 1,000 acfm gas flow and 4,000~16,000 ppmw particulate loading. This design specification yielded 100~400 lb/hr ash loading to the PCD. The maximum obtainable steady-state ash loading from the reactor to the PCD is 386 lb/hr. Actually, the PCD has experienced ash loading of up to 2,368 lb/hr (95,700 ppmw) in previous runs under very unusual situations. The volumetric rates of ash loading are 2.8~11.4, 11.0 and 67.3 ft^3/hr, respectively, for these loading levels using average bulk density of 35.2 lb/ft^3 (TC01 run data).

Gasification mode. The design specification is 1,000 acfm gas flow with 4,000~20,000 ppmw particulate loading. The corresponding ash loading is 75~375 lb/hr or 5.5~27.4 ft^3/hr (bulk density is 13.7 lb/ft^3) to the PCD. The maximum obtainable steady-state ash loading from the reactor to the PCD is 768 lb/hr or 56 ft^3/hr. If the PCD experiences the same unusual variation of loading level as in the combustion mode the ash loading can be projected to be 1,776 lb/hr or 130 ft^3/hr.

3.28.5.2 FD0520 Redesign

The major aspects of redesign should include the following:

1. Increase the capacity of the lock and dispense vessels to 5 times their current size (i.e., 10 ft^3 in the new design). This increase will significantly reduce the number of cycles and mechanical wear on the system.

2. With the larger size described above, an effective way to fluff/convey the ash is even more important. Introducing a bypass pipe (with uniformly distributed openings) inside it could solve packing in the drop pipe. Bridging in the lock vessel could be alleviated with a way to directly blow through the lock vessel during the discharge from the lock vessel to dispense vessel.

3. Improve the spheri valve sealing system. New seal material and/or configuration as well as corresponding control issue should be elaborated.

4. Install another ash level measuring mechanism to replace the level probe. A weigh cell might work. This could also serve as a useful device for research. If the level probe has to be used a blowing system may help clean the residual ash on the probe and improve the sensitivity.

5. Install a filter element catcher downstream of the dispense vessel where atmospheric pressure and low temperatures permit on-line removal of filter element pieces. An additional reducer should be installed downstream of the filter element catcher to prevent the filter element pieces from being conveyed to the downstream equipment (FD0530).

6. Increase spaces between vessels to facilitate maintenance. The minimum space should be larger than 18 inches. The system should be close to the floor and the control panel should be placed at the operator eye level. The orientation of the system should also permit the access of SRI sampling devices.

3.28.5.3 FD0502 Redesign

The ash loading data indicate that doubling its current capacity is needed in the redesign for gasification. This change will give about 20~48 ft^3/hr effective conveying rate. The redesign should consider the following:

1. The length/diameter ratio should yield good heat exchange efficiency.

2. The outlet temperature should be well below the allowable limit for the spheri valve seal material.

3. The rotation rate can be adjusted in a wider range.

4. Modify the bearing set (may be wider in support region or consider other bearing types) to minimize wear and repair.

5. The material of construction should be appropriate for process conditions.

TERMS

Listing of Abbreviations

AAS	Automated Analytical Solutions
ADEM	Alabama Department of Environmental Management
APC	Alabama Power Company
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.
HP	High Pressure
HRSG	Heat Recovery Steam Generator
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
PRB	Powder River Basin
PSD	Particle Size Distribution
PSDF	Power Systems Development Facility
ΔP	Pressure Drop
PT	Pressure Transmitter
RFQ	Request for Quotation
RO	Restriction Orifice
RSSE	Reactor Solid Separation Efficiency
SCS	Southern Company Services, Inc
SRI	Southern Research Institute
SUB	Start-up Burner
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
VFD	Variable Frequency Drive
VOCs	Volatile Organic Compounds
WPC	William's Patent Crusher
XXS	Extra, Extra Strong

Listing of Units

acfm	Actual Cubic Feet Per Minute
Btu	British Thermal Units
°F	Degrees Fahrenheit
ft	Feet
FPS	Feet Per Second
gpm	Gallons Per Minute
hp	Horsepower
hr	Hour
inWg	Inches, Water Gauge
MB	Megabytes
MW	Megawatts
m/s	Meters per second
μ or μm	Microns or Micrometers
dp_{50}	Particle Size Distribution at 50 Percentile
ppm	Parts Per Million
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