ADVANCED DEVELOPMENT OF A PRESSURIZED ASH
AGGLOMERATING FLUIDIZED-BED COAL
GASIFICATION SYSTEM

Quarterly Progress Report: First Quarter—Fiscal Year 1983
Period October 1—December 31, 1982

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COAL GASIFICATION SYSTEM

FIRST QUARTER PROGRESS REPORT
FY-1983

Period October 1 to December 31, 1982

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TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1.0	OBJECTIVE AND SCOPE OF WORK	1
1.1	Operation and Maintenance of the PDU	1
1.2	PDU Modifications	1
1.3	Scaleup Design and Analysis	2
1.4	Laboratory Support Studies	2
2.0	TECHNICAL PROGRESS SUMMARY	3
2.1	PDU Test Operations and Results	3
2.2	Process Analysis	4
2.3	Cold Flow Scaleup Facility	4
2.4	Process and Component Engineering and Design	5
2.5	Laboratory Support Studies	5
2.5.1	Gas-Solids Flow Modeling	5
2.5.2	Coal/Ash Behavior	6
2.6	Summary Schedules	7
3.0	PDU TEST OPERATIONS AND RESULTS	9
3.1	Gasifier Test TP-033-2	9
3.2	Gasifier Test TP-033-3	32
4.0	PROCESS ANALYSIS	43
4.1	Temperature Profile of PDU Gasifier Combustion Zone	43
4.2	Western Coal High Temperature Gasifier Design	43
4.3	Fines Recycle	43
5.0	COLD FLOW SCALEUP FACILITY	46
5.1	Experimental Activity	46
5.2	Data Reduction	51
6.0	PROCESS AND COMPONENT ENGINEERING AND DESIGN	62
7.0	LABORATORY SUPPORT STUDIES	64
7.1	Gas Solids Flow Modeling	64
7.1.1	Jet Phenomena	64
7.1.2	Fine Particle History	64
7.1.3	Char/Ash Separation	66
7.2	Coal/Ash Behavior	66
7.2.1	Coal Gasification	66
7.2.2	Ash Behavior	66
7.2.3	Deposit Control	70

LIST OF TABLES

<u>Table</u>		<u>Page</u>
3-1	Chronology of Significant Events, PDU Test TP-033-2	12
3-2	Summary of Operating Data for Gasifier Test TP-033-2	17
3-3	Gasifier Heat and Material Balances, Test Point TP-033-2, Steady State 1A-1	19
3-4	Gasifier Heat and Material Balances, Test Point TP-033-2, Steady State 1B-1	22
3-5	Gasifier Heat and Material Balances, Test Point TP-033-2, Steady State 1B-2	25
3-6	Gasifier Heat and Material Balances, Test Point TP-033-2, Steady State 1B-3	28
3-7	Chronology of Significant Events, Test TP-033-3	34
3-8	Summary of Operating Data for Gasifier Test TP-033-3	37
3-9	Gasifier Heat and Material Balances, Test Point TP-033-3, Steady State 2A	39
3-10	Nominal Process Conditions During DOE/METC Quench Water Sampling, Test TP-033-3	42
5-1	Nominal Planned Conditions, TP-M007-1	47
5-2	Nominal Planned Conditions, FR-002	50
5-3	Simple Power Law Decay of the Maximum Jet Velocity at the Axis	52
5-4	Comparison of Calculated and Experimental Bubble Size -- TP-M003-1 and TP-M003-2	54
5-5	Comparison of Calculated and Experimental Jet Penetration Depth -- TP-M003-1 and TP-M003-2.	55
7-1	Reactivity of Wyoming Sub-C Coal in Different Gaseous Atmospheres	67
7-2	Effect of Temperature on the Reactivity of Wyoming Sub-C Coal	68
7-3	Summary of X-Ray Analyses of Samples of Cyclone Deposits	71
7-4	Summary of Proposed Mechanism of Deposit Formation in the PDU Cyclone	74

LIST OF FIGURES

<u>Figures</u>		<u>Page</u>
3-1	Heat and Material Balance Flow Schedule	31
4-1	Temperature Profile, Test TP-033-2, Wyoming Sub-C Coal	44
4-2	Temperature Profile, Test TP-033-3, Western Kentucky Coal	45
5-1	CO ₂ Probe Assembly	48
5-2	Schematic of the CFSF - 10" Airtube	49
5-3	Experimental Data on Gas Leakage from the Bubble to the Emulsion Phase	56
5-4	Definition of Jet Half Angle	58
7-1	Schematic Diagram of Humidity Control System for Fluidizing Air into 12-Inch Cold Flow Model	65
7-2	Wyoming Sub-C Char-Steam Reaction	69

SECTION 1.0

OBJECTIVE AND SCOPE OF WORK

The overall objective of the Westinghouse coal gasification program is to demonstrate the viability of the Westinghouse pressurized, fluidized bed, gasification system for the production of medium-Btu fuel gas for syngas, electrical power generation, chemical feedstocks, or industrial fuels and to obtain performance and scaleup data for the process and hardware.

1.1 OPERATION AND MAINTENANCE OF THE PDU

The Task 1 objective is operation of the process development unit (PDU) to evaluate the process feasibility and operability of the Westinghouse advanced, fluidized bed, coal gasification process and to provide data for scaleup and component hardware designs. Past work involved evaluation of the devolatilizer system for decaking and devolatilizing fresh coal feedstocks. Process feasibility of the devolatilizer was demonstrated through a series of tests with a variety of coal feedstocks, including highly caking Eastern bituminous coals. Following these tests, the gasifier-agglomerator system feasibility was demonstrated with chars produced in the devolatilizer and with other materials, including coke breeze, chars from another gasification process, and both non-caking and highly caking coals. These materials were successfully gasified, and ash agglomerates were successfully produced from feedstock. Testing of the gasifier-agglomerator reactor included direct coal feed, as well as oxygen-blown gasification of a char or coal bed. These tests were followed by evaluation of the integrated system consisting of the devolatilizer and gasifier-agglomerator.

Single-stage gasifier testing will continue under Task 1 with the gasifier operating at or near design temperature, pressure, and solids feed capacity using a variety of feedstocks, including a highly caking coal. Gasification will be accomplished with oxygen to produce medium-Btu synthesis gas and agglomerated ash at a high overall carbon utilization.

In addition, combustion testing in the Test and Development Center with medium-Btu gas from the PDU is also planned to determine combustion stability over a range of preheated gas temperatures.

1.2 PDU MODIFICATIONS

Under Task 2, present work involves the modification and upgrading of the PDU to achieve better performance as dictated by the results of prior testing efforts. One subtask includes modifications to upgrade the system to support the testing program. Specifically, this work involves the process piping, flow controls instrumentation and related process hardware. The PDU will also be modified to provide the capability of evaluating the equipment and subsystems necessary for fines recycle tests and deposit control methods. Modifications to the Test and Development Center were made to permit combustion evaluation tests of medium-Btu gas from the PDU.

1.3 SCALEUP DESIGN AND ANALYSIS

Scaleup design and analysis are performed as part of Task 3. The objective of this task is to conduct experimental and analytical work required to establish a data base for scaling up the components and subsystems of the fluidized bed gasification process. The cold flow scaleup facility (CFSF), a large 10-foot scale cold flow model, is the principal tool for providing this information. Initial operation is in the gasifier mode to determine operable geometries, measure and record operating characteristics, and develop empirical correlations to describe these characteristics.

1.4 LABORATORY SUPPORT STUDIES

This task consists of consultation and analytical and bench studies by the Westinghouse Research and Development Center in support of PDU operations and process analysis.

Support work has included studies and experiments in fuel processing, analysis of operating conditions for the PDU, obtaining data for PDU modifications, analysis and interpretation of results from PDU operation, development of process models for scaleup, and understanding of process phenomena to achieve reliable operation. Work has also been conducted in the areas of cold flow modeling, coal behavior, coal and chemical phenomena, environmental impact, and process and systems engineering consultation.

For the laboratory support experimental program, test facilities include:

- Two flexible 12-inch diameter semicircular units, which operate at atmospheric pressure and ambient temperature, for fluidization studies.
- A fluidized bed test unit, operating at design temperature and pressure, for devolatilization and gasification investigations.
- A pressurized, hot-stage microscope.
- A pressurized thermogravimetric analysis system, differential thermal analysis, and a pressurized high temperature fluidized bed test unit to conduct investigations in gas cleaning and gasification.

SECTION 2.0

TECHNICAL PROGRESS SUMMARY

2.1 PDU TEST OPERATIONS AND RESULTS

At the beginning of this quarter, mechanical work, commissioning, and startup activities were conducted in preparation for TP-033-2, a hot fines recycle test with a non-mechanical feed control device in the primary system. Prior to initiation of the test, the functional operation of the coal crusher-dryer was performed to assess its ability to achieve 10 percent moisture with Wyoming coal. Also, the deposit probe was installed in the PDU gasifier for test TP-033-2 to determine the metal wall temperatures at which deposit formation starts.

Single-stage, oxygen-blown test TP-033-2 was conducted from October 21, 1982 to November 22, 1982 using 75 tons of Wyoming Sub-C and 50 tons of Western Kentucky No. 9 coals as the feedstocks.

The test was conducted in five operational phases, with the first three terminated as a result of a flange leak in the dome of the C-110 cyclone. Following the third shutdown on November 11, the dome flange was resurfaced, the gasket was replaced, and the test was reinitiated on November 17. This fourth phase was terminated because of a hot spot on the barrel of the C-120 secondary cyclone, where eroded refractory exposed the shell to high temperature product gas. New refractory was installed in the inlet area of the secondary cyclone and the test was resumed on November 21, with the fifth and final phase of the test terminated on November 22 upon depletion of the Wyoming Sub-C feedstock.

Prior to conducting test TP-033-3 in December, some hardware modifications were implemented to correct the operational problems encountered during TP-033-2. These changes reduced skin heat loss from the dipleg, improved diagnostics capability, and enhanced cyclone performance. Furthermore, the test plan was formulated to focus on non-mechanical valve operation with set points to include air-blown (no steam) and oxygen-blown (with steam) operation using Western Kentucky No. 9 coal and one 48-hour oxygen-blown period (with steam) using Western Kentucky coal.

TP-033-3, the final test, was conducted from December 10, 1982 to December 16, 1982 using Western Kentucky No. 9 coal as the feedstock. The objective of this test demonstrated operability of the non-mechanical valve system for the continuous recycle of coal fines and evaluated the effect of hot fines recycle on fines consumption rate and carbon conversion.

TP-033-3 was an air/oxygen-blown test during which two set points were conducted. The first air-blown set point was utilized to functionally check out the operation of the non-mechanical valve dipleg and control system at operating conditions that did not permit moisture condensation in the dipleg. The second set point was an extended test run for 36 hours at "design" conditions in the oxygen-blown mode. A total of 111 hours of hot operation were achieved during this test.

2.2 PROCESS ANALYSIS

During operations with Wyoming Sub-C coal (TP-033-2) and Western Kentucky No. 9 coal (TP-033-3), a radial temperature profile of the PDU gasifier combustion zone was taken by a unique non-slugging thermocouple. Data obtained indicate that temperatures in the central jet exceed 2000°F, regardless of feedstock (Western or bituminous). For Western coal operation, the temperature near the wall was 1620°F and the internal temperature was 2050°F. For bituminous coal operation, the temperature near the wall was 1835°F and the internal temperature was 2180°F.

A preliminary design for a high temperature (1750°-1800°F), Western coal, PDU gasifier has been completed.

The non-mechanical valve primary fines recycle system was installed and used to recycle Wyoming Sub-C and Western Kentucky coal fines to the PDU gasifier.

2.3 COLD FLOW SCALEUP FACILITY

A CO₂ tracer gas test, TP-M007-1, similar to TP-M004 was conducted in the CFSF from August 9 to its completion on November 5, 1982. The test objective was to determine gas mixing within the fluidized bed and between different regions of the bed. To this end CO₂ was injected into the coaxial feedline, the air tube, the grid, the annulus, and the shroud. It differed from the earlier test in that TP-M004 used a 16-inch air tube and an 8-inch feedline; TP-M007-1 used a 10-inch air tube, a 4-inch feedline, a shroud, and a different grid configuration.

FR-002, a solids transport test was started on November 23, 1982. The objectives of the test are to study the acceleration length, the acceleration pressure drop, the pressure drop in the fully accelerated region, the pressure drop around the bends, and choking and saltation phenomena. This test using four different radius elbows was started with a 48-inch elbow. Set points 1 through 6, 8, 9, 10, 12, and 13 were completed on the 48-inch radius elbow. Set points 1, 3, 4, 8, 12, and 13 were completed on a 24-inch radius elbow.

Pitot tube data and information on bubble diameter, bubble frequency, bubble velocity, jet penetration depth, and jet half-angle obtained from frame-by-frame analysis of the motion pictures taken during TP-M003-1 and TP-M003-2 were analyzed. The pitot tube apparently sensed not only the gas momentum but also the solid particle momentum. Assumptions of particle velocity and voidage distribution in the jet permit the calculation of velocity profiles from the pitot tube data. These were reported in the last quarterly report. Comparison of experimental bubble diameter, bubble velocity, and jet penetration depth with that predicted from available correlations was generally favorable. A substantial amount of gas was found to leak out into the emulsion phase before the concentric jets degenerated into bubbles.

Data from tests TP-M003-1 and TP-M003-2 in the CFSF were analyzed, and a topical report was prepared. A test program scope was prepared for the pneumatic transport loop constructed at the CFSF which outlines the current test program scope and possible future test programs using this facility.

Four more piezoelectric solid circulation probes were constructed. These probes use different techniques to dampen the secondary oscillation of the piezoelectric element so that every collision of a solid particle will generate only one response from the element. These probes will be evaluated in the 12-inch diameter semicircular unit first.

2.4 PROCESS AND COMPONENT ENGINEERING AND DESIGN

Major modifications completed prior to test TP-033-2 were the relocation of the C-110 primary cyclone and the installation of the "through-trap" in the outlet pipe of the gasifier.

Additional refractory and a new type gasket were installed in the primary cyclone dome to rectify leakage problems prior to startup of the gasifier test TP-033-3. Also, an additional nuclear densitometer (K-ray) level indicator was installed on the non-mechanical valve standpipe.

Failure analysis of the nuisance leakage problems on the PDU primary cyclone was completed. After the November PDU test (TP-033-2), the insulation in the flange area of the leak was inspected, and it was found that significant areas had eroded causing the flange to overheat and the gasket to fail. The erosion was caused by product gas flow around the support plate of the downcomer, which is supported in this flange area.

Work was initiated on the procurement package to modify the PDU structure and elevate the primary cyclone two more floors (approximately 20 feet). The specification for the structure modification and the relocation of the cyclone was completed.

2.5 LABORATORY SUPPORT STUDIES

2.5.1 GAS SOLIDS FLOW MODELING

Experimental programs on particle separation and high-temperature jet phenomena were reinitiated. The gas tracer conservation equation was solved numerically to fit the tracer gas concentration profiles observed experimentally in the 12-inch diameter semicircular unit. Preliminary conclusions indicated that the gas mixing between the jetting region and the emulsion region was due primarily to the convection. Diffusion of tracer gas played a negligible role. Tracer gas concentration profiles obtained in the 12-inch diameter model will be analyzed next.

Tracer particle injection experiments were reinitiated and the new results were examined.

The need to install an air-humidity control and monitoring system in the 12-inch diameter cold flow model was identified, and the limiting design conditions and required equipment components for such a system determined. Manufacturers of hygrometers and water-atomizing spray nozzles were contacted and cost estimates obtained. Detailed mechanical drawings of the components that need to be fabricated were completed and relevant purchase orders were submitted for approval and competitive bidding.

2.5.2 COAL/ASH BEHAVIOR

Characterization of Texas lignite was extended to include the effect of particle size on reactivity. The same reactivity was obtained for both 10 x 12 and 18 x 60 mesh particles.

Wyoming Sub C coal was thermogravimetrically analyzed in two different atmospheres with the reactivities roughly equal in both. Reactivity of this coal was also studied at three temperatures in addition to the reference temperature to determine the activation energy.

Behavior of Pittsburgh Seam coal ash, -12 +14 and 30 x 35 mesh, and of West Virginia coal ash, -6 +8 mesh, was studied in an oxidizing atmosphere. In the Pittsburgh Seam ash the sintering temperature was considerably lower than for the West Virginia particles, which sintered only slightly at a temperature 278 to 361°C (531 to 682°F) above the sintering temperatures of the Pittsburgh Seam particles and 194 to 232°C (381 to 450°F) above the melting temperatures. This result confirmed earlier findings indicating the difficulty of agglomerating the West Virginia coal ash.

In studies of white particles of 10 x 12 mesh of Indiana No. 7 coal ash, initial sintering took place at 1116°C, (2040°F) but no melting took place up to 1260°C (2300°F). Gray particles of the same sample sintered at 1177°C (2150°F).

A report containing available analytical data on PDU cyclone deposits has been prepared. Deposit analyses included: x-ray; microprobe; and physical and chemical analyses. Proposed mechanisms of deposit formation were described, along with alternative deposit prevention options.

A deposit probe was installed in the PDU gasifier for tests TP-033-2 and TP-033-3 to determine the metal wall temperatures at which deposit formation starts. In TP-033-2 there was no indication of deposit formation on the probe during the Wyoming coal feed, at a freeboard temperature of 899°C (1650°F) and at probe temperatures between 93 and 149°C (200 to 300°F). In test TP-033-3, however, with Western Kentucky coal feed, there was a decrease in probe thermocouple readings from between 149 and 288°C (300-550°F) and 116 - 221°C (240 - 430°F) during the air-blown mode, and between 149 - 260°C (300 - 500°F) and 99 - 171°C (210 - 340°F) during the oxygen-blown mode), indicating ash accumulation or deposit on the probe surface. The deposit probe will be observed for signs of ash deposit when the gasifier is opened.

2.6 SUMMARY SCHEDULES

FY 1983					
Task Description	OCT	NOV	DEC	JAN	FEB
<u>Operation and Maintenance of the PDU</u>					
Single-Stage Gasifier Operation					
Gasifier Oxygen-Blown Maintenance and Test Modification	—	—	—	—	—
Gas Characterization, Treatment and Utilization	—	—	—	—	—
Fines Recycle	—	—	—	—	—
Deposit Control	—	—	—	—	—
<u>PDU Modifications</u>					
Modification for Fines Recycle					
Hot Rotary Feeder (D)					
Hot Educator					
Upgrade CO ₂ System					
Hot Dipleg and Non-Mechanical Valve	—	—	—	—	—
Modifications for Deposit Control					
Cold Wall (for side exit from gas)	—				
Cold Wall (standby system)	—				
Through-Trap	—				
Deposit Probe	—				
Modification for Gas Characterization, Treatment and Utilization					
Gas Characterization Upgrading					
Conversion of Propane-Fired Components to Natural Gas					
Gas Preheater for Combustion Tests					

LEGEND:

Task Complete ▼	Design/Approval		Construction/
Test ———	Procurement	— — —	Modification
Eval./Test -- --	Deleted or	(D)	
Planning	Deferred		

Results of PDU Probe Tests and Deposit Mechanism/Control

3

SECTION 3.0

PDU TEST OPERATIONS AND RESULTS

At the beginning of this quarter, mechanical work, commissioning, and startup activities were conducted in preparation for TP-033-2, a hot fines recycle test with a non-mechanical feed control device in the primary system. Prior to initiation of the test, the following were accomplished.

- Functional operation of the coal crusher-dryer was performed to assess its ability to achieve 10 percent moisture with Wyoming coal. The moisture content of the test feedstock, however, could not be dried below 18 percent, which is identical to the prior Wyoming coal tests.
- Seventy-five tons of Wyoming Sub-C and 50 tons of Western Kentucky No. 9 coal were crushed and dried.
- Orientation and training sessions were held with PDU operating personnel to review the hot fines recycle operating procedures and the relevant CFSF solids recycle experience.
- Installation and functional checkout of the following instrumentation and control units were completed.
 - New isokinetic sampling train for the gasifier outlet.
 - Experimental traversing thermocouple to measure combustion zone temperatures in the gasifier.
 - Auburn meter modified for measuring solids in transport line from the C-102 lockhopper.
 - K-ray, nuclear densitometer measurement device and control loops for level control in the dipleg.
 - Accelerometer on the gasifier shell to measure frequency of oscillation for correlating with bubble frequency.
 - Alkali probe to obtain one set of samples for each set point.
- The deposit probe was installed in the PDU gasifier for test TP-033-2 to determine the metal wall temperatures at which deposit formation starts.

3.1 GASIFIER TEST TP-033-2

Single-stage, oxygen-blown test TP-033-2 was conducted from October 21 to November 22 using Wyoming Sub-C and Western Kentucky No. 9 coals as the feedstocks. The objectives of test TP-033-2 were to:

- Demonstrate operability of the non-mechanical valve system for the recycle of primary fines to the gasifier.
- Evaluate the collection efficiency of the new design for the primary cyclone.
- Evaluate the effectiveness of the modified particle "through-trap" for preventing cyclone deposition.

- Continue the evaluation of the hot solids injection device used for secondary fines recycle.
- Analyze the product gas for EPA-defined priority pollutants.
- Measure the temperature at which cyclone deposits may form using a deposit probe located in the freeboard section of the gasifier.
- Evaluate the effect of hot fines recycle on fines consumption rate and carbon conversion.

The test was conducted in five operational phases, with the first three terminated as a result of a flange leak in the dome of the C-110 cyclone. Following the third shutdown on November 11, the dome flange was resurfaced, the gasket was replaced, and the test was reinitiated on November 17. This fourth phase was terminated because of a hot spot on the barrel of the C-120 secondary cyclone, where eroded refractory exposed the shell to high temperature product gas. New refractory was installed in the inlet area of the secondary cyclone and the test was resumed on November 21, with the fifth and final phase of the test terminated on November 22 upon depletion of the Wyoming Sub-C feedstock.

During the test, 114 hours of hot operation were achieved, including 76 hours with Wyoming Sub-C coal, as well as four steady states described below:

Steady State 1A-1 - Wyoming Sub-C coal; 1635°F freeboard temperature; 230 psig; 284 Btu/scf product gas heating value; 74 percent oxygen in oxidant tube; 65 percent ash in withdrawal.

Steady State 1B-1 - Wyoming Sub-C coal; 1603°F freeboard temperature; 230 psig; 263 Btu/scf product gas heating value; 71 percent oxygen in oxidant tube; 48 percent ash in withdrawal.

Steady State 1B-2 - Wyoming Sub-C coal; 1605°F freeboard temperature; 230 psig; 270 Btu/scf product gas heating value; 72 percent oxygen in oxidant tube; 50 percent ash in withdrawal.

Steady State 1B-3 - Wyoming Sub-C coal; 1636°F freeboard temperature; 230 psig; 270 Btu/scf product gas heating value; 70 percent oxygen in oxidant tube; 60 percent ash in withdrawal.

Notable accomplishments include the following:

- A shakedown and operational checkout of the non-mechanical valve fines recycle system was conducted with Wyoming Sub-C coal. The non-mechanical valve system successfully recycled fines during coke breeze and coal operation for short periods (2-10 hours). During these times:
 - The solids level was established in the detectable range by fines collection.
 - The solids level was monitored by the K-ray device.

- Fines collection and recycle was confirmed by the changes in the K-ray reading and standpipe temperatures.
- Automatic control was used to maintain the solids level in the standpipe.
- Primary fines were collected and recycled during periods of coke breeze and coal feed.
- The secondary fines recycle system was operational during steady state 1A-1 and provides a good diagnostic tool for qualitatively evaluating the performance of the primary cyclone.

A chronology of significant events for test TP-033-2 is given in Table 3-1, the operating data are presented in Table 3-2, and heat and material balances are presented in Tables 3-3 to 3-6. Figure 3-1 depicts a flow schematic for the heat and material balance schematic.

Prior to conducting test TP-033-3 in December, some hardware modifications were implemented to correct the operational problems encountered during TP-033-2. These changes reduced skin heat loss from the dipleg, improved diagnostics capability, and enhanced cyclone performance. Furthermore, the test plan was formulated to focus on non-mechanical valve operation with set points to include air-blown (no steam) and oxygen-blown (with steam) operation using Western Kentucky No. 9 coal and one 48-hour oxygen-blown period (with steam) using Western Kentucky coal.

TABLE 3-1
CHRONOLOGY OF SIGNIFICANT EVENTS, TEST TP-033-2

<u>Date</u>	<u>Time</u>	<u>Event</u>
<u>STARTUP NO. 1</u>		
10-21-82	2115	Initiated air flow to gasifier
10-24-82	2130	Completed atmospheric cure of refractory
10-25-82	0640	Completed pressurization at 230 psig
	1300	Achieved acceptable leak rate
	1900	Developed leak on primary cyclone (C-110) dome flange. Depressurized. Replaced gasket
10-26-82	0845	Completed pressurization at 230 psig. Primary cyclone dome flange leak. Depressurized. Replaced gasket.
	2345	Completed pressurization at 230 psig
	0045	Achieved acceptable leak rate
	0445	Initiated coke breeze feed to gasifier
	1200	Initiated coke breeze feed to C-110 standpipe
	1245	Secured coke breeze feed line to C-110 standpipe. Solids level in K-ray range. Began cold flow test of C-110 non-mechanical valve.
10-28-82	0130	Completed cold flow test of non-mechanical valve
	0600	Achieved autogeneous ignition
	1023	Decreased system pressure to 200 psig to dislodge apparent plug in non-mechanical valve.
	1450	Dislodged restriction in non-mechanical valve by cycling aeration and fluffing flows. Filled C-110 standpipe with coke breeze
	1615	Completed repressurization at 230 psig
	1910	Initiated oxygen flow to gasifier
	1935	Air flow out of system
	2200	Initiated Wyoming coal feed to gasifier
10-29-82	0255	Initiated shutdown - leak from C-110 dome flange. Removed 1/2 inch refractory from C-110 dome/barrel interface to prevent sealing interference from refractory. Installed new gasket.

TABLE 3-1 (continued)

<u>Date</u>	<u>Time</u>	<u>Event</u>
<u>STARTUP NO. 2</u>		
10-30-82	0210	Completed pressurization at 230 psig
	0245	Recycle gas aftercooler severely restricted
	1530	Completed recycle gas aftercooler cleaning
	1847	Initiated coke breeze feed to gasifier
	2130	Initiated coke breeze feed to C-110 standpipe
	2200	C-110 standpipe solids level in K-ray range. Secured feed line
	2230	Controlling level in non-mechanical valve on K-ray
10-31-82	2355	Achieved autogeneous ignition
	0302	Initiated oxygen flow to gasifier
	0420	Completed oxygen flow switchover, no air flow to gasifier
	0445	Level in non-mechanical valve dropped below K-ray detection level because of excess aeration flow. Shut off aeration flow
	0447	C-110 standpipe level in K-ray detection range. No coke breeze was added to standpipe
	0530	Initiated Wyoming coal feed to gasifier
	0543	Level in C-110 standpipe dropped below K-ray detection level. Initiated coke breeze feed to gasifier
	0623	C-110 standpipe level in K-ray detection range. No coke breeze was added to standpipe
	0815	Initiated shutdown - C-110 dome flange leak. Reworked surfaces of C-110 dome and barrel flanges in place. Additional refractory was removed (2 inches below flange) to provide clearance for the resurfacing machine. Reevaluated piping stress analysis. Replaced gasket.

TABLE 3-1 (continued)

<u>Date</u>	<u>Time</u>	<u>Event</u>
<u>STARTUP NO. 3</u>		
11-8-82	1930	Completed pressurization at 230 psig
	2037	Achieved acceptable leak rate
11-9-82	1830	Completed hot air dryout
	2040	Completed repressurization at 230 psig
	2115	C-120 feed line plugged
11-10-82	0100	Initiated coke breeze feed to gasifier
	0755	Achieved autogeneous ignition
	1020	Solids level in C-110 standpipe built to K-ray detection range by collecting fines.
	1330	Initiated oxygen feed to gasifier
	1400	Initiated Wyoming Sub-C coal feed to gasifier
	1025-1400	C-110 standpipe level repeatedly dropped below K-ray detection range because of excess deaeration and rebuilt by fines collection.
	2120	C-109 feed line plugged
	2125	Initiated coke breeze feed
	2225	C-109 system on line. Found broken ceramic insert
	11-11-82 0150	All feed lines plugged. Initiated CO ₂ flow to gasifier. Shut off air flow.
	0235	Initiated coke breeze feed to gasifier
	0305	Initiated oxygen flow to gasifier
	0600	Initiated shutdown - gas leak on C-110 dome flange. Dome flange was sent to a machine shop and resurfaced. Replaced gasket. Performed additional pipe stress analysis.

TABLE 3-1 (continued)

<u>Date</u>	<u>Time</u>	<u>Event</u>
<u>STARTUP NO. 4</u>		
11-17-82	1130	Completed pressurization at 230 psig
	1230	Achieved acceptable leak rate
11-18-82	0415	Completed hot air dryout
	0607	Completed repressurization system at 230 psig
	1007	Initiated coke breeze feed to gasifier
	1440	Achieved autogeneous ignition
	1730	Solids level in C-110 standpipe in K-ray detection range. Solids accumulated from fines collection
	1920	Initiated oxygen feed to gasifier
	1935	Completed oxygen flow switchover - no air flow to gasifier
	2005	Initiated Wyoming coal feed to gasifier
11-19-82	0200	<u>Achieved Set point 1 conditions</u>
	0340	Controlling non-mechanical valve in manual mode. Suspected incorrect K-ray reading
	0930-1155	Level in C-110 standpipe repeatedly dropped below detectable level due to high aeration flow. Shut off aeration flow. Level in C-110 standpipe reestablished in detectable range.
	1155	Maximum reading on C-110 standpipe K-ray 10 percent of chart.
	1200	Upset in grid area - high fines feed to that area.
	1250	Initiated shutdown because of hot spot on C-120 barrel. Installed new refractory in area of C-120 inlet, where poor seal allowed gas to erode insulating refractory.

TABLE 3-1 (continued)

<u>Date</u>	<u>Time</u>	<u>Event</u>
<u>STARTUP NO. 5</u>		
11-21-82	0020	Completed pressurization at 230 psig
	0120	Achieved acceptable leak rate
	1210	Initiated coke breeze feed to gasifier
	1430	C-120 feed line plugged
	1700	Achieved autogeneous ignition
	1900	Solids level in C-110 standpipe in detectable range. Solids accumulated from fines collection
	1935	Initiated oxygen flow to gasifier
	1955	Completed oxygen flow switchover - no air flow to gasifier
	2015	Initiated Wyoming coal feed to gasifier
11-22-82	0220	Maximum reading on C-110 K-ray 12 percent of chart
	0230	<u>Achieved Set point 1 conditions</u>
	0315	Small gas leak from C-110 dome flange
	0350	Small gas leak from C-110 gas outlet flange
	0410	Developed gas leak on T-124, coal starwheel feeder shaft packing
	0540	Initiated coke breeze feed to gasifier
	0645	Depleted Wyoming Coal inventory
	0910	Initiated shutdown

TABLE 3-2
SUMMARY OF OPERATING DATA FOR GASIFIER TEST TP-033-2

STEADY STATE		1A-1	1B-1	1B-2	1B-3
		Hours	Hours	Hours	Hours
		11-19	11-22	11-22	11-22/23
TEST RUN DATE & TIME (1982)	UNIT	0545 to 1030	0230 to 1330	1330 to 2100	2100 to 0340
<u>MEASURED GASIFIER PARAMETERS</u>					
Freeboard Temperature	°F	1635	1603	1605	1636
Gasifier Bed Temperature	°F	1680	1635	1636	1680
Ash Annulus Temperature	°F	997	832	635	1405
Average Bed Height*	feet	10.83	10.68	10.81	10.90
System Pressure	psig	231	230	231	231
Average Gasifier Bed Density	lb/ft ³	20.47	19.96	19.34	19.33
Average Annulus Density	lb/ft ³	19.32	20.10	18.62	18.97
Freeboard Gas Velocity	fps	1.223	1.223	1.252	1.278
Oxidant Tube Velocity	fps	89.09	85.56	87.55	90.31
Oxygen Concentration	%	73.9	71.5	71.8	70.1
Coal Feed Material		Wyoming	Wyoming	Wyoming	Wyoming
Coal Feed Rate	lb/hr	2323	2271	2377	2256
Carryover to Water System**	lb/hr	351	356	346	353
Ash Withdrawal Rate	lb/hr	45	46	32	23
<u>PRODUCT GAS ANALYSIS, DRY BASIS</u>					
Carbon Monoxide	%	45.56	39.97	41.10	42.65
Carbon Dioxide	%	20.72	28.29	26.14	24.86

TABLE 3-2 (continued)

STEADY STATE		1A-1	1B-1	1B-2	1B-3
		Hours	Hours	Hours	Hours
		11-19	11-22	11-22	11-22/23
TEST RUN DATE & TIME (1982)	UNIT	0545 to 1030	0230 to 1330	1330 to 2100	2100 to 0340
Methane	%	4.62	5.09	4.99	4.50
Nitrogen	%	0.71	0.67	0.57	0.56
Sulfur	%	0.10	0.13	0.14	0.17
Hydrogen	%	28.30	25.84	27.06	27.27
HHV, Dry Basis (Gas Chromatograph)	Btu/scf	284	263	270	270
<u>OVERALL PROCESS RATES</u>					
Carbon Mass Velocity ⁺	lb/hr-ft ²	472.212	490.673	513.576	482.964
Gas Make/Coal	SCF/lb	29.392	31.203	31.826	34.371
Steam/Coal Ratio, MAF ⁺⁺	lb/lb	0.208	0.216	0.212	0.241
Oxygen/Coal Ratio, MAF	lb/lb	0.689	0.646	0.636	0.682
Total Moisture/Coal Ratio MAF	lb/lb	0.427	0.415	0.412	0.451
Recycle Gas/Coal Ratio, MAF	lb/lb	1.425	1.473	1.319	1.374
<u>SOLIDS ANALYSIS</u>					
Ash Content - Fines (secondary)	%		23.00	34.25	
Ash Content - Feedstock	%	7.59	7.41	7.69	
Ash Content - Bed	%	22.79	19.84	21.76	31.12
Ash Content - Agglomerate	%	71.83	47.62	58.87	52.89

* From jet inlet to top of bed

**Estimated from isokinetic probe or ash samples

+ Referenced at the 20" I.D. section

++Moisture and ash free

TABLE 3-3

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1A-1

STREAM NO.	1	2	3	4	5	6
STREAM DESCRIPTION	STEAM TO GRID	STEAM TO AIR TUBE	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL LB/HR	0.00	367.00	0.00	100.00	385.48	781.93
TEMPERATURE F	0.0	416.0	0.0	114.0	150.0	587.0
GAS LB/HR	0.00	367.00	0.00	100.00	385.48	781.93
SOLID LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
LIQUID LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT	0.000	18.016	0.000	44.011	23.364	23.364
CO VOLUME %	0.00	0.00	0.00	0.00	44.87	44.87
CO2 VOLUME %	0.00	0.00	0.00	100.00	20.66	20.66
H2 VOLUME %	0.00	0.00	0.00	0.00	20.23	20.23
CH4 VOLUME %	0.00	0.00	0.00	0.00	4.83	4.83
N2 VOLUME %	0.00	0.00	0.00	0.00	0.70	0.70
O2 VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00
H2O VOLUME %	0.00	100.00	0.00	0.00	0.52	0.52
GAS CHARACTERIZATION						
H2S PPM	0.000	0.000	0.000	0.000	1681.246	1681.246
COS PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS						
CARBON LB/HR	0.000	0.000	0.000	27.291	139.449	282.863
HYDROGEN LB/HR	0.000	41.067	0.000	0.000	12.835	26.035
OXYGEN LB/HR	0.000	325.932	0.000	72.709	228.914	464.337
NITROGEN LB/HR	0.000	0.000	0.000	0.000	3.232	6.557
SULFUR LB/HR	0.000	0.000	0.000	0.000	0.889	1.804
ASH LB/HR	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT						
KBTU/HR	0.000	56.456	0.000	0.774	1796.036	3758.974

TABLE 3-3, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1A-1

STREAM NO.	7	8	9	10	11	12
STREAM DESCRIPTION	BOOSTER GAS	COAL FEED AND TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G	LIQUID WATER INJECTION	PRODUCT GAS
TOTAL LB/HR	294.14	3370.75	1214.00	153.00	0.00	6351.73
TEMPERATURE F	150.0	140.0	512.0	114.0	0.0	1302.0
GAS LB/HR	294.14	1047.75	1214.00	153.00	0.00	6000.84
SOLID LB/HR	0.00	2323.00	0.00	0.00	0.00	350.89
LIQUID LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT	23.364	23.364	31.862	44.011	0.000	22.928
CO VOLUME %	44.87	44.87	0.00	0.00	0.00	41.30
CO2 VOLUME %	20.66	20.66	0.00	100.00	0.00	18.78
H2 VOLUME %	28.23	28.23	0.00	0.00	0.00	25.66
CH4 VOLUME %	4.83	4.83	0.00	0.00	0.00	4.19
N2 VOLUME %	0.70	0.70	0.00	0.00	0.00	0.65
O2 VOLUME %	0.00	0.00	99.57	0.00	0.00	0.00
H2O VOLUME %	0.52	0.52	0.00	0.00	0.00	9.36
GAS CHARACTERIZATION						
H2S PPM	1681.246	1681.246	0.000	0.000	0.000	924.569
CO S PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS						
CARBON LB/HR	106.404	1690.356	0.000	44.484	0.000	2219.862
HYDROGEN LB/HR	9.794	133.846	0.000	0.000	0.000	231.557
OXYGEN LB/HR	174.669	1324.201	1214.000	113.516	0.000	3694.377
NITROGEN LB/HR	2.466	31.087	0.000	0.000	0.000	49.733
SULFUR LB/HR	0.679	14.497	0.000	0.000	0.000	11.654
ASH LB/HR	0.000	176.316	0.000	0.000	0.000	143.128
HEAT CONTENT						
KBTU/HR	1370.436	25362.348	119.704	1.261	0.000	31462.998

TABLE 3-3, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1A-1

STREAM NO.		13	14		
STREAM DESCRIPTION		ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	45.00	3.79	0.00	4.13
TEMPERATURE	F	249.0	1622.0	0.0	0.0
GAS	LB/HR	0.00	0.00	0.00	0.00
SOLID	LB/HR	45.00	3.79	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION					
	H2S PPM	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000
ELEMENTS					
CARBON	LB/HR	12.636	2.844	0.000	2.423
HYDROGEN	LB/HR	0.049	0.014	0.000	-3.597
OXYGEN	LB/HR	0.023	0.000	0.000	5.834
NITROGEN	LB/HR	0.117	0.021	0.000	-15.062
SULFUR	LB/HR	0.365	0.047	0.000	32.482
ASH	LB/HR	32.324	0.864	0.000	0.000
HEAT CONTENT					
	KBTU/HR	185.321	42.973	425.000	1.077

TABLE 3-4

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1B-1

STREAM NO.	1	2	3	4	5	6
STREAM DESCRIPTION	STEAM TO GRID	STEAM TO AIR TUBE	AIR	CO2 FURGE	GRID GAS	SPARGER RING
TOTAL LB/HR	0.00	378.00	0.00	102.00	399.70	561.28
TEMPERATURE F	0.0	421.0	0.0	130.0	145.0	569.0
GAS LB/HR	0.00	378.00	0.00	102.00	399.70	561.28
SOLID LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
LIQUID LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT	0.000	18.016	0.000	44.011	25.000	25.000
CO VOLUME %	0.00	0.00	0.00	0.00	40.67	40.67
CO2 VOLUME %	0.00	0.00	0.00	100.00	27.25	27.25
H2 VOLUME %	0.00	0.00	0.00	0.00	26.04	26.04
CH4 VOLUME %	0.00	0.00	0.00	0.00	5.03	5.03
N2 VOLUME %	0.00	0.00	0.00	0.00	0.67	0.67
O2 VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00
H2O VOLUME %	0.00	100.00	0.00	0.00	0.18	0.18
GAS CHARACTERIZATION						
H2S PPM	0.000	0.000	0.000	0.000	1567.233	1567.233
COS PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS						
CARBON LB/HR	0.000	0.000	0.000	27.837	140.092	196.724
HYDROGEN LB/HR	0.000	42.298	0.000	0.000	11.746	16.494
OXYGEN LB/HR	0.000	335.702	0.000	74.163	243.908	342.509
NITROGEN LB/HR	0.000	0.000	0.000	0.000	3.004	4.219
SULFUR LB/HR	0.000	0.000	0.000	0.000	0.803	1.128
ASH LB/HR	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT						
KBTU/HR	0.000	59.036	0.000	1.135	1626.800	2361.711

TABLE 3-4, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1B-1

STREAM NO.		7	8	9	10	11	12
STREAM DESCRIPTION		BOOSTER GAS	COAL FEED AND TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G	LIQUID WATER INJECTION	PRODUCT GAS
TOTAL	LB/HR	304.26	3589.16	1132.00	158.00	0.00	6427.11
TEMPERATURE	F	145.0	131.0	509.0	130.0	0.0	1355.0
GAS	LB/HR	304.26	1318.16	1132.00	158.00	0.00	6070.91
SOLID	LB/HR	0.00	2271.00	0.00	0.00	0.00	356.20
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		25.000	25.000	31.862	44.011	0.000	24.506
CO	VOLUME %	40.67	40.67	0.00	0.00	0.00	35.98
CO2	VOLUME %	27.25	27.25	0.00	100.00	0.00	25.47
H2	VOLUME %	26.04	26.04	0.00	0.00	0.00	23.26
CH4	VOLUME %	5.03	5.03	0.00	0.00	0.00	4.59
N2	VOLUME %	0.67	0.67	0.00	0.00	0.00	0.60
O2	VOLUME %	0.00	0.00	99.57	0.00	0.00	0.00
H2O	VOLUME %	0.18	0.18	0.00	0.00	0.00	9.98
GAS CHARACTERIZATION							
	H2S PPM	1567.233	1567.233	0.000	0.000	0.000	1251.292
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON	LB/HR	106.642	1824.604	0.000	43.120	0.000	2167.177
HYDROGEN	LB/HR	8.941	139.796	0.000	0.000	0.000	214.626
OXYGEN	LB/HR	185.670	1411.869	1132.000	114.880	0.000	3840.377
NITROGEN	LB/HR	2.287	29.212	0.000	0.000	0.000	43.924
SULFUR	LB/HR	0.612	14.913	0.000	0.000	0.000	13.893
ASH	LB/HR	0.000	168.281	0.000	0.000	0.000	145.294
HEAT CONTENT							
	KBTU/HR	1238.368	27311.762	110.817	1.758	0.000	28279.840

TABLE 3-4, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1B-1

STREAM NO.		13	14		
STREAM DESCRIPTION		ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	46.00	5.45	0.00	2.20
TEMPERATURE	F	220.0	1569.0	0.0	0.0
GAS	LB/HR	0.00	0.00	0.00	0.00
SOLID	LB/HR	46.00	5.45	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION					
	H2S PPM	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000
ELEMENTS					
CARBON	LB/HR	22.926	4.261	0.000	6.184
HYDROGEN	LB/HR	0.106	0.021	0.000	2.063
OXYGEN	LB/HR	0.681	0.000	0.000	-0.009
NITROGEN	LB/HR	0.106	0.021	0.000	-13.760
SULFUR	LB/HR	0.276	0.065	0.000	18.458
ASH	LB/HR	21.905	1.081	0.000	0.000
HEAT CONTENT					
	KBTU/HR	330.281	64.142	425.000	11.042

TABLE 3-5

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1B-2

STREAM NO.		1	2	3	4	5	6
STREAM DESCRIPTION		STEAM TO GRID	STEAM TO AIR TUBE	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL	LB/HR	0.00	390.00	0.00	105.00	389.33	562.99
TEMPERATURE	F	0.0	416.0	0.0	120.0	162.0	669.0
GAS	LB/HR	0.00	390.00	0.00	105.00	389.33	562.99
SOLID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	18.016	0.000	44.011	24.407	24.407
CO	VOLUME %	0.00	0.00	0.00	0.00	41.61	41.61
CO2	VOLUME %	0.00	0.00	0.00	100.00	25.34	25.34
H2	VOLUME %	0.00	0.00	0.00	0.00	27.15	27.15
CH4	VOLUME %	0.00	0.00	0.00	0.00	4.95	4.95
N2	VOLUME %	0.00	0.00	0.00	0.00	0.58	0.58
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	100.00	0.00	0.00	0.19	0.19
GAS CHARACTERIZATION							
	H2S PPM	0.000	0.000	0.000	0.000	1527.052	1527.052
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON	LB/HR	0.000	0.000	0.000	28.655	137.749	199.191
HYDROGEN	LB/HR	0.000	43.641	0.000	0.000	12.024	17.387
OXYGEN	LB/HR	0.000	346.359	0.000	76.345	236.033	341.313
NITROGEN	LB/HR	0.000	0.000	0.000	0.000	2.600	3.760
SULFUR	LB/HR	0.000	0.000	0.000	0.000	0.781	1.129
ASH	LB/HR	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT							
	KBTU/HR	0.000	59.995	0.000	1.123	1659.929	2475.870

TABLE 3-5, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1B-2

STREAM NO.		7	8	9	10	11	12
STREAM DESCRIPTION		BOOSTER GAS	COAL FEED AND TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G	LIQUID WATER INJECTION	PRODUCT GAS
TOTAL	LE/HR	303.43	3542.19	1167.00	162.00	0.00	6411.81
TEMPERATURE	F	163.0	104.0	508.0	128.0	0.0	1438.0
GAS	LE/HR	303.43	1165.19	1167.00	162.00	0.00	6065.74
SOLID	LE/HR	0.00	2377.00	0.00	0.00	0.00	346.07
LIQUID	LE/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		24.407	24.407	31.862	44.011	0.000	23.944
CO	VOLUME %	41.61	41.61	0.00	0.00	0.00	37.10
CO2	VOLUME %	25.34	25.34	0.00	100.00	0.00	23.59
H2	VOLUME %	27.15	27.15	0.00	0.00	0.00	24.42
CH4	VOLUME %	4.95	4.95	0.00	0.00	0.00	4.50
N2	VOLUME %	0.58	0.58	0.00	0.00	0.00	0.51
O2	VOLUME %	0.00	0.00	99.57	0.00	0.00	0.00
H2O	VOLUME %	0.19	0.19	0.00	0.00	0.00	9.74
GAS CHARACTERIZATION							
	H2S PPM	1527.052	1527.052	0.000	0.000	0.000	1435.054
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON	LB/HR	107.358	1038.456	0.000	44.211	0.000	2165.724
HYDROGEN	LB/HR	9.371	141.761	0.000	0.000	0.000	222.996
OXYGEN	LB/HR	183.958	1342.247	1167.000	117.789	0.000	3810.954
NITROGEN	LB/HR	2.027	27.986	0.000	0.000	0.000	37.979
SULFUR	LB/HR	0.609	15.173	0.000	0.000	0.000	15.948
ASH	LB/HR	0.000	176.136	0.000	0.000	0.000	156.078
HEAT CONTENT							
	KBTL/HR	1293.710	27911.672	113.968	1.733	0.000	29354.139

TABLE 3-5, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1B-2

STREAM NO.		13	14		
STREAM DESCRIPTION		ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	32.00	5.60	0.00	2.61
TEMPERATURE	F	215.0	1585.0	0.0	0.0
GAS	LB/HR	0.00	0.00	0.00	0.00
SOLID	LB/HR	32.00	5.60	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION					
	H2S PPM	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000
ELEMENTS					
CARBON	LB/HR	12.634	4.229	0.000	7.346
HYDROGEN	LB/HR	0.112	0.025	0.000	0.469
OXYGEN	LB/HR	0.150	0.027	0.000	-0.002
NITROGEN	LB/HR	0.093	0.028	0.000	-4.747
SULFUR	LB/HR	0.173	0.072	0.000	8.475
ASH	LB/HR	18.838	1.219	0.000	0.001
HEAT CONTENT					
	KBTU/HR	186.921	63.919	425.000	10.406

TABLE 3-6

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1B-3

STREAM NO.	1	2	3	4	5	6
STREAM DESCRIPTION	STEAM TO GRID	STEAM TO AIR TUBE	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL LB/HR	0.00	414.00	0.00	122.00	388.97	747.06
TEMPERATURE F	0.0	416.0	0.0	128.0	182.0	569.0
GAS LB/HR	0.00	414.00	0.00	122.00	388.97	747.06
SOLID LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
LIQUID LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT	0.000	18.016	0.000	44.011	24.175	24.175
CO VOLUME %	0.00	0.00	0.00	0.00	42.94	42.94
CO2 VOLUME %	0.00	0.00	0.00	100.00	24.11	24.11
H2 VOLUME %	0.00	0.00	0.00	0.00	27.47	27.47
CH4 VOLUME %	0.00	0.00	0.00	0.00	4.68	4.68
N2 VOLUME %	0.00	0.00	0.00	0.00	0.57	0.57
O2 VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00
H2O VOLUME %	0.00	100.00	0.00	0.00	0.06	0.06
GAS CHARACTERIZATION						
H2S PPM	0.000	0.000	0.000	0.000	1549.121	1549.121
COS PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS						
CARBON LB/HR	0.000	0.000	0.000	33.295	135.759	266.221
HYDROGEN LB/HR	0.000	46.327	0.000	0.000	11.766	23.074
OXYGEN LB/HR	0.000	367.673	0.000	0.000	229.986	450.996
NITROGEN LB/HR	0.000	0.000	0.000	0.000	2.528	4.958
SULFUR LB/HR	0.000	0.000	0.000	0.000	0.783	1.535
ASH LB/HR	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT						
KBTU/HR	0.000	63.687	0.000	1.305	1657.537	3346.435

TABLE 3-6, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-2, STEADY STATE 1B-3

STREAM NO.		7	8	9	10	11	12
STREAM DESCRIPTION		BOOSTER GAS	COAL FEED AND TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G	LIQUID WATER INJECTION	PRODUCT GAS
TOTAL	LB/HR	301.06	3190.76	1173.00	164.00	0.00	6391.54
TEMPERATURE	F	182.0	112.0	508.0	128.0	0.0	1378.0
GAS	LB/HR	301.06	934.76	1173.00	164.00	0.00	6038.19
SOLID	LB/HR	0.00	2256.00	0.00	0.00	0.00	353.35
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		24.175	24.175	31.862	44.011	0.000	23.794
CO	VOLUME %	42.94	42.94	0.00	0.00	0.00	38.68
CO2	VOLUME %	24.11	24.11	0.00	100.00	0.00	22.54
H2	VOLUME %	27.47	27.47	0.00	0.00	0.00	24.73
CH4	VOLUME %	4.68	4.68	0.00	0.00	0.00	4.08
N2	VOLUME %	0.57	0.57	0.00	0.00	0.00	0.51
O2	VOLUME %	0.00	0.00	99.57	0.00	0.00	0.00
H2O	VOLUME %	0.06	0.06	0.00	0.00	0.00	9.32
GAS CHARACTERIZATION							
	H2S PPM	1549.121	1549.121	0.000	0.000	0.000	1559.765
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON	LB/HR	107.283	1674.299	0.000	44.757	0.000	2176.583
HYDROGEN	LB/HR	9.298	132.421	0.000	0.000	0.000	218.601
OXYGEN	LB/HR	181.745	1168.012	1173.000	119.243	0.000	3779.479
NITROGEN	LB/HR	1.998	27.184	0.000	0.000	0.000	38.121
SULFUR	LB/HR	0.619	15.005	0.000	0.000	0.000	17.073
ASH	LB/HR	0.000	173.486	0.000	0.000	0.000	159.361
HEAT CONTENT							
	KBTU/HR	1309.859	25857.115	114.554	1.755	0.000	29468.869

TABLE 3-6, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-03E-2, STEADY STATE 1B-3

STREAM NO.		13	14		
STREAM DESCRIPTION		ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	23.00	6.30	0.00	1.11
TEMPERATURE	F	365.0	1598.0	0.0	0.0
GAS	LB/HR	0.00	0.00	0.00	0.00
SOLID	LB/HR	23.00	6.30	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION					
	H2S PPM	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000
ELEMENTS					
CARBON	LB/HR	10.555	4.217	0.000	3.107
HYDROGEN	LB/HR	0.048	0.023	0.000	1.891
OXYGEN	LB/HR	0.000	0.000	0.000	-0.003
NITROGEN	LB/HR	0.071	0.028	0.000	-4.233
SULFUR	LB/HR	0.166	0.071	0.000	3.521
ASH	LB/HR	12.165	1.961	0.000	0.000
HEAT CONTENT					
	KBTU/HR	154.654	64.075	425.000	6.923

Figure 3-1. Heat and Material Balance Flow Schematic

3.2 GASIFIER TEST TP-033-3

TP-033-3, the final test in the 1982 PDU test program, was conducted from December 10 to December 16 using Western Kentucky No. 9 coal as the feedstock. The objectives of this test were to:

- Demonstrate operability of the non-mechanical valve system for the continuous recycle of coal fines.
- Evaluate the primary cyclone performance.
- Evaluate the effectiveness of the modified particle "through-trap" for preventing deposition in the transfer pipe.
- Continue the evaluation of the hot solids injection device used for secondary fines recycle.
- Analyze the product gas for EPA-defined priority pollutants.
- Measure the temperature at which deposits form using a deposit probe located in the freeboard section of the gasifier.
- Evaluate the effect of hot fines recycle on fines consumption rate and carbon conversion.

TP-033-3 was an air/oxygen-blown test during which two set points were conducted. The first air-blown set point was utilized to functionally check out the operation of the non-mechanical valve dipleg and control system at operating conditions that did not permit moisture condensation in the dipleg. The second set point was an extended test run for 36 hours in the oxygen-blown mode. These set points are described below.

Set Point 1 - Western Kentucky No. 9 seam coal, 1755°F freeboard temperature, 230 psig, 61 Btu/scf product gas heating value, air blown, 56 percent ash in withdrawal.

Set Point 2 - Western Kentucky No. 9 seam coal, 1835°F freeboard temperature, 230 psig, 250 Btu/scf product gas heating value, 68 percent oxygen in oxidant tube, 83 percent ash in the withdrawal.

A total of 111 hours of hot operation were achieved during this test. Notable accomplishments included:

- Operationally evaluated the non-mechanical valve fines recycle system with Western Kentucky No. 9 seam coal during air-blown and oxygen-blown operation. Primary fines were collected and recycled for up to 7 continuous hours of coal feed. During this time, the solids level was maintained automatically within the control range (plus or minus 2 feet), and fines collection and recycle were confirmed by changes in K-ray readings, standpipe temperatures, and secondary recycle system operation.
- Demonstrated recovery from non-mechanical valve system upsets (loss of standpipe leg or pressure seal, bridging).

- Operation of the solids injection device in parallel with non-mechanical valve operation was demonstrated.
- Demonstrated the particle through-trap device in the exit of the gasifier as effective in preventing solids deposition with Western Kentucky coal. No deposition occurred on the through-trap, gasifier outlet piping, or primary cyclone after 94 hours of coal feed.
- Optimal operation of the gasifier ash agglomerator to produce agglomerates from Western Kentucky coal was demonstrated for ash concentrations ranging from 80 to 90 percent.
- Operation of primary cyclone vessel and interconnecting piping was achieved without any of the gas leakage problems that hampered the previous gasifier test.

A chronology of significant events for test TP-033-3 is given in Table 3-7, the operating data are presented in Table 3-8, and heat and material balances are presented in Table 3-9.

During the course of PDU test TP-033-3, a large volume (approximately 475 gallons of liquid) sample from the quench scrubber system was obtained to be used by DOE, Morgantown, for preliminary waste water management studies. Nominal process conditions during the sampling period are shown in Table 3-10.

WORK FORECAST FOR NEXT QUARTER

- Perform scheduled activities for the annual PDU maintenance program and winterization.
- Install Radian Corporation environmental sampling equipment trains for the screening test program.
- Conduct PDU test TP-034-1 to evaluate the hot fines recycle system using Wyoming coal as the feedstock.

TABLE 3-7

CHRONOLOGY OF SIGNIFICANT EVENTS, TEST TP-033-3

<u>Date</u>	<u>Time</u>	<u>Event</u>
12/10/82	1710	Initiated pressurization and leak check.
12/11/82	0530	Achieved acceptable leak rate.
	1030	Began hot air dryout at 130 psig.
	2230	Completed hot air dryout. Increased system pressure to 230 psig.
12/12/82	0500	Initiated coke breeze feed to gasifier.
	0815	Secondary fines collection and recycle system on-line.
	1300	Achieved autogenous ignition.
	1305	Sample streams to product and recycle gas chromatographs frozen. Thawed gas chromatograph GC 1.
	1740	Initiated Western Kentucky coal feed to gasifier.
	1925	Discovered gas leak on C-111 water box flange.
	2010	Decreased system pressure to 200 psig.
	2100	Re-torqued C-111 water box flange. Leak stopped.
12/13/82	0315	Began collecting and recycling fines through primary cyclone (C-110).
	0330	<u>Achieved Set Point No. 1 conditions.</u>
	0340	C-110 standpipe level dropped below K-ray levels. Temperatures in standpipe increased to 1300°F.
	0424	Cooled C-110 standpipe using CO ₂ fluffing flow.
	0431	Shut off CO ₂ fluffing flow to C-110 standpipe.
	0438	C-110 standpipe level established in K-ray detection level.
	0448	C-110 standpipe aeration tap plugged.
	0508	Unplugged C-110 standpipe aeration tap. Standpipe bridged.
	0550-1330	Continually lost and rebuilt C-110 standpipe level in K-ray detection ranges.

<u>Date</u>	<u>Time</u>	<u>Event</u>
	1330	C-110 standpipe temperature at 1400°F. Used CO ₂ fluffing flow to cool standpipe.
	1335	C-110 standpipe level reestablished in K-ray detection range. Maintained level while recycling fines.
	1730	C-110 standpipe bridged. Increased aeration flow. Level dropped below detectable range.
	1740	C-110 standpipe level reestablished in detectable range. Operation continued as described with periods of good control and periods of upsets.
	2145	All feed lines plugged.
	2155	Feed lines on-line.
	2230	Discovered bad sample injection solenoid on gas chromatograph for product and recycle gas.
12/14/82	1240	Shut down gas chromatograph because of leak.
	1255	Idled C-110 cyclone for control valve change.
	1300	Repaired gas chromatograph.
	1415	C-110 standpipe level control in automatic using new control mode.
	1530	Completed set point No. 1.
	1700	Initiated steam flow to gasifier.
	1720	Initiated oxygen flow to gasifier.
	2355	All feed lines plugged. Oxygen flow replaced with CO ₂ .
12/15/82	0027	Cleared C-102 feed line. Initiated coke breeze feed to gasifier.
	0050	Cleared C-103 feed line.
	0120	Initiated oxygen flow to gasifier.
	0135	Initiated Western Kentucky coal feed to gasifier. No coke breeze feed to gasifier.
	0515	<u>Achieved set point No. 2 conditions.</u>
	0900-1200	Sampled quench water for DOE/METC.
	1000	Achieved good automatic control of C-110 standpipe.

<u>Date</u>	<u>Time</u>	<u>Event</u>
12/16/82	0055	C-110 standpipe level reestablished in detectable range.
	0625	All feed lines plugged.
	0641	All feed lines cleared.
	1805	Depleted Western Kentucky coal inventory supply. Began coke breeze feed to gasifier.

TABLE 3-8
SUMMARY OF OPERATING DATA FOR GASIFIER TEST TP-033-3 ▲

		2A
		Hours
		12-15-82
		0630
		to
		12-16-82
TEST RUN DATE AND TIME (1982)	UNIT	1800
<u>MEASURED GASIFIER PARAMETERS</u>		
Freeboard Temperature	°F	1835
Gasifier Bed Temperature	°F	1919
Ash Annulus Temperature	°F	396
Average Bed Height*	feet	12.01
System Pressure	psig	230
Average Gasifier Bed Density	lb/ft ³	15.01
Average Annulus Density	lb/ft ³	15.13
Freeboard Gas Velocity	fps	1.323
Oxidant Tube Velocity	fps	96
Oxygen Concentration	%	69.17
Coal Feed Material		W. Kentucky
Coal Feed Rate	lb/hr	1458
Carryover to Water System**	lb/hr	296
Ash Withdrawal Rate	lb/hr	57
<u>PRODUCT GAS ANALYSIS, DRY BASIS</u>		
Carbon Monoxide	%	50.73
Carbon Dioxide	%	24.86
Methane	%	2.28

* From jet inlet to top of bed

** Estimated from isokinetic probe or ash samples

▲ Since equipment was not running properly, no data were taken during Set Point No. 1A

TABLE 3-8 (continued)

TEST RUN DATE AND TIME (1982)	UNIT	2A Hours 12-15-82 0630 to 12-16-82 1800
Nitrogen	%	1.397
Sulfur	%	0.658
Hydrogen	%	20.00
HHV, Dry Basis (Gas Chromatograph)	Btu/scf	250
<u>OVERALL PROCESS RATES</u>		
Carbon Mass Velocity ⁺	lb/hr-ft ²	379.02
Gas Make/Coal	scf/lb	33.151
Steam/Coal Ratio, MAF ⁺⁺	lb/lb	0.323
Oxygen/Coal Ratio, MAF	lb/lb	0.834
Total Moisture/Coal Ratio MAF	lb/lb	0.375
Recycle Gas/Coal Ratio, MAF	lb/lb	2.181
<u>SOLIDS ANALYSIS</u>		30.00
Ash Content - Fines (secondary)	%	29.67
Ash Content - Feedstock	%	9.14
Ash Content - Bed	%	28.92
Ash Content - Agglomerate	%	71.83

+ Referenced at the 20" I.D. section

++ Moisture and ash free

TABLE 3-9

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-3, STEADY STATE 2A

STREAM NO.		1	2	3	4	5	6
STREAM DESCRIPTION		STEAM TO GRID	STEAM TO AIR TUBE	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL	LB/HR	0.00	407.00	0.00	126.00	441.89	777.45
TEMPERATURE	F	0.0	415.0	0.0	131.0	117.0	587.0
GAS	LB/HR	0.00	407.00	0.00	126.00	441.89	777.45
SOLID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	18.016	0.000	44.011	26.643	26.643
CO	VOLUME %	0.00	0.00	0.00	0.00	50.67	50.67
CO2	VOLUME %	0.00	0.00	0.00	100.00	25.11	25.11
H2	VOLUME %	0.00	0.00	0.00	0.00	19.94	19.94
CH4	VOLUME %	0.00	0.00	0.00	0.00	2.26	2.26
N2	VOLUME %	0.00	0.00	0.00	0.00	1.37	1.37
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	100.00	0.00	0.00	0.06	0.06
GAS CHARACTERIZATION							
	H2S PPM	0.000	0.000	0.000	0.000	5946.160	5946.160
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON	LB/HR	0.000	0.000	0.000	34.387	155.455	273.504
HYDROGEN	LB/HR	0.000	45.544	0.000	0.000	8.395	14.770
OXYGEN	LB/HR	0.000	361.456	0.000	91.613	267.913	471.361
NITROGEN	LB/HR	0.000	0.000	0.000	0.000	6.384	11.233
SULFUR	LB/HR	0.000	0.000	0.000	0.000	3.162	5.563
ASH	LB/HR	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT							
	KBTU/HR	0.000	62.419	0.000	1.428	1602.144	2927.788

TABLE 3-9, Continued.

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-Q33-3, STEADY STATE 2A

STREAM NO.		7	8	9	10	11	12
STREAM DESCRIPTION		BOOSTER GAS	COAL FEED AND TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G	LIQUID WATER INJECTION	PRODUCT GAS
TOTAL	LB/HR	338.49	2647.10	1050.00	166.00	0.00	5756.34
TEMPERATURE	F	117.0	130.0	548.0	131.0	0.0	1412.0
GAS	LB/HR	338.49	1189.10	1050.00	166.00	0.00	5460.52
SOLID	LB/HR	0.00	1458.00	0.00	0.00	0.00	295.82
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		26.643	26.643	31.862	44.011	0.000	25.606
CO	VOLUME %	50.67	50.67	0.00	0.00	0.00	44.99
CO2	VOLUME %	25.11	25.11	0.00	100.00	0.00	22.05
H2	VOLUME %	19.94	19.94	0.00	0.00	0.00	17.74
CH4	VOLUME %	2.26	2.26	0.00	0.00	0.00	2.02
N2	VOLUME %	1.37	1.37	0.00	0.00	0.00	1.24
O2	VOLUME %	0.00	0.00	99.57	0.00	0.00	0.00
H2O	VOLUME %	0.06	0.06	0.00	0.00	0.00	11.31
GAS CHARACTERIZATION							
	H2S PPM	5946.160	5946.160	0.000	0.000	0.000	5835.802
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON	LB/HR	119.079	1470.851	0.000	45.303	0.000	1965.826
HYDROGEN	LB/HR	6.431	97.240	0.000	0.000	0.000	145.397
OXYGEN	LB/HR	205.222	857.408	1050.000	120.697	0.000	3425.596
NITROGEN	LB/HR	4.891	39.050	0.000	0.000	0.000	76.413
SULFUR	LB/HR	2.422	47.292	0.000	0.000	0.000	48.038
ASH	LB/HR	0.000	133.699	0.000	0.000	0.000	87.770
HEAT CONTENT							
	KBTU/HR	1227.250	23402.762	112.486	1.882	0.000	23688.857

TABLE 3-9, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST POINT TP-033-3, STEADY STATE 2A

STREAM NO.		13	14		
STREAM DESCRIPTION		ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	57.00	5.22	0.00	2.27
TEMPERATURE	F	238.0	1835.0	0.0	0.0
GAS	LB/HR	0.00	0.00	0.00	0.00
SOLID	LB/HR	57.00	5.22	0.00	0.00
LICUID	LB/HR	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION					
	H2S PPM	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000
ELEMENTS					
CARBON	LB/HR	10.630	3.557	0.000	5.650
HYDROGEN	LB/HR	0.029	0.007	0.000	15.632
OXYGEN	LB/HR	0.000	0.000	0.000	0.002
NITROGEN	LB/HR	0.131	0.054	0.000	-24.433
SULFUR	LB/HR	1.796	0.093	0.000	14.567
ASH	LB/HR	44.420	1.510	0.000	-0.001
HEAT CONTENT					
	KBTU/HR	163.486	53.798	425.000	17.067

TABLE 3-10

NOMINAL PROCESS CONDITIONS DURING DOE/METC
QUENCH WATER SAMPLING, TEST TP-033-3

Coal feedstock:	Western Kentucky No. 9
Freeboard temperature (°F):	1838
System pressure (psig):	230
Oxidant:	Oxygen

Product gas composition (vol.%)

CO ₂	24.52
H ₂ S	0.61
H ₂	20.11
N ₂	1.45
CH ₄	2.05
CO	51.27

SECTION 4.0

PROCESS ANALYSIS

4.1 TEMPERATURE PROFILE OF PDU GASIFIER COMBUSTION ZONE

During operations with Wyoming Sub-C coal (TP-033-2) and Western Kentucky No. 9 coal (TP-033-3), a radial temperature profile of the PDU gasifier combustion zone was taken by a unique non-slagging thermocouple. Data obtained indicate that temperatures in the central jet exceed 2000°F, regardless of feedstock (Western or bituminous). For Western coal operation, the temperature near the wall was 1620°F and the internal temperature was 2050°F. For bituminous coal operation, the temperature near the wall was 1835°F and the internal temperature was 2180°F. Figures 4-1 and 4-2 show the temperature profile. Both tests indicated peak temperatures 2 inches past the center line of the gasifier. This could possibly be explained by the fact the feed tube leans slightly toward the west wall. Also, the transversing thermocouple could deflect the jet off center.

4.2 WESTERN COAL HIGH TEMPERATURE GASIFIER DESIGN

A preliminary design for a high temperature (1750-1800°F), Western coal, PDU gasifier has been completed. The current PDU gasifier geometry and coal feed capability is limited to a maximum operating temperature of approximately 1640°F. Future work includes the mechanical design and a design review.

4.3 FINES RECYCLE

The non-mechanical valve primary fines recycle system was installed and used to recycle Wyoming Sub-C and Western Kentucky coal fines to the PDU gasifier. Fines were recycled at temperatures up to 800°F. The automatic control system was not properly installed to handle upset or transient conditions. These conditions were handled in the manual operating mode. Automatic control was demonstrated during steady state conditions. Bridging of the solids occurred whenever aeration flow was stopped or the solids level rose into the cyclone.

WORK FORECAST FOR NEXT QUARTER

Analysis of the data from tests TP-033-2 and TP-033-3, with respect to the non-mechanical valve, is under way and results will be reported in the next quarterly progress report.

Figure 4-1. Temperature Profile, Test TP-033-2, Wyoming Sub-C Coal

Figure 4-2. Temperature Profile, Test TP-033-3, Western Kentucky Coal

SECTION 5.0

COLD FLOW SCALEUP FACILITY (CFSF)

5.1 CFSF OPERATIONS

A CO₂ tracer gas test, TP-M007-1, similar to TP-M004 was conducted in the CFSF from August 9 to its completion on November 5, 1982. The test objective was to determine gas mixing within the fluidized bed and between different regions of the bed. To this end CO₂ was injected into the coaxial feedline, the air tube, the grid, the annulus, and the shroud. It differed from the earlier test in that TP-M004 used a 16-inch air tube and an 8-inch feedline; TP-M007-1 used a 10-inch air tube, a 4-inch feedline, a shroud, and a different grid configuration. Nominal planned set point conditions for TP-M007-1 are shown in Table 5-1.

All the set points were completed with the exception of one or two of the eight probe locations for approximately 10 set points. Recorder failures were responsible for the lost data. Specifically:

- Set points 13, 14, 15, and 16 were completed with CO₂ injected into the coaxial feedline.
- Set points 1 through 6, 8 through 12, 15, and 16 were completed with CO₂ injected into the shroud.
- Set points 13 through 16 were completed with CO₂ injected into the air tube.
- Set points 12 through 16 were completed with CO₂ injected into the annulus.

Figures 5-1 and 5-2 show the CO₂ probe assembly and the schematic of the CFSF using the 10-inch air tube for TP-M007-1.

Concurrently with TP-M007-1, tests were also conducted on the non-mechanical value. During these tests, on October 4, 8, 14, and November 3 and 8, fines were recycled directly into the bed and into the coaxial feedline.

FR-002, a solids transport test was started on November 23, 1982. The objectives of the test are to study the acceleration length, the acceleration pressure drop, the pressure drop in the fully accelerated region, the pressure drop around the bends, and choking and saltation phenomena. This test, using four different radius elbows, was started with a 48-inch elbow.

Set points 1 through 6, 8, 9, 10, 12, and 13 were completed on the 48-inch radius elbow. Set points 1, 3, 4, 8, 12, and 13 were completed on a 24-inch radius elbow.

Table 5-2 shows the planned set point conditions for FR-002.

TABLE 5-1

NOMINAL PLANNED CONDITIONS, TP-M007-1

<u>Set Point</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>
Air Tube Velocity (ft/sec)	50	100	150	200	50	100	150	200	50	100	150	200	50	100	150	200
Shroud (scfm)	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Annulus Velocity (ft/sec)	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*	1.5*
Grid Flow (scfm)																
Chamber 1	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Chamber 3	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Chamber 5	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Solid Transport Velocity (ft/sec)	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Solid Feed Rate (lb/hr)	0	0	0	0	3000	3000	3000	3000	6000	6000	6000	6000	9000	9000	9000	9000
Bed Height (ft)	18+	18+	18+	18+	18+	18+	18+	18+	18+	18+	18+	18+	18+	18+	18+	18+

*Adjust the gas flow to keep the annulus slightly bubbling.

+It is essential that the bed height be maintained at 18 feet to prevent large entrainment due to periodical jet penetration.

Figure 5-1. CO₂ Probe Assembly

Figure 5-2. Schematic of the CFSF - 10" Airtube

TABLE 5-2

NOMINAL PLANNED CONDITIONS, FR-002

<u>Set Point</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>
Transport Velocity (ft/sec)	40	40	40	50	50	50	50	75	75	75	75
Solid Feed	0	3000	6000	0	3000	6000	9000	0	3000	6000	9000
<u>SET POINT</u>	<u>12</u>	<u>13</u>	<u>14</u>	<u>15</u>	<u>16</u>	<u>17</u>	<u>18</u>				
Transport Velocity (ft/sec)	100	100	100	100	100*	100*	100*				
Solid Feed Rate (lb/hr)	0	3000	6000	9000	3000	6000	9000				

*Start the feed rate and then gradually decrease the velocity to determine the saltation point.

Note: When changing from one setpoint to another setpoint with a higher feed rate, the data should be continuously recorded and the rate of change noted on the chart. This process should be repeated for various rates of change and will be defined on a daily test plan.

5.2 CFSF ANALYSIS

Pitot tube data and information on bubble diameter, bubble frequency, bubble velocity, jet penetration depth, and jet half-angle obtained from frame-by-frame analysis of the motion pictures taken during TP-M003-1 and TP-M003-2 were analyzed. The pitot tube apparently sensed not only the gas momentum but also the solid particle momentum. Assumptions of particle velocity and voidage distribution in the jet permit the calculation of velocity profiles from the pitot tube data. These were reported in the last quarterly report. Comparison of experimental bubble diameter, bubble velocity, and jet penetration depth with that predicted from available correlations was generally favorable. A substantial amount of gas was found to leak out into the emulsion phase before the concentric jets degenerated into bubbles. These results are reported herein.

For a single, pure gas or gas-solid, two-phase jet in a fluidized bed, it was found that the gas velocity profiles in the jet could be approximated by Tollmien similarity as in a homogeneous turbulent jet in a homogeneous medium (Yang and Keairns, 1980). Attempts to analyze the present data with the same method were unsuccessful because the jet velocities at the jet boundaries could not be clearly identified. Dissipation of the maximum velocity was analyzed, however, on the basis of simple power law decay characteristics commonly observed for a homogeneous jet in a homogeneous medium (Abramovich, 1963). The maximum velocity at the axis was assumed to decay according to the following equation:

$$\frac{U_m}{(U_j)_c} = a \left(\frac{h}{d_o}\right)^b \quad (1)$$

Compound jet velocity at the two concentric jet nozzles, $(U_j)_c$, was calculated in the following manner:

$$\rho_f (U_j)_c \frac{2}{c} = \frac{(M_g)_i (U_g)_i + (M_s)_i (U_s)_i + (M_g)_o (U_g)_o}{A_t} \quad (2)$$

Particle velocity at the exit of the solid feed line, $(U_s)_i$, was also assumed to be the difference between the gas velocity and the terminal velocity of a single particle. Parameters a and b in Equation (1) for all data are summarized in Table 5-3. Although the pitot tube data were available at five different elevations from the top of the jet nozzle, only data collected at locations 1 to 3 are suitable for jet velocity profile analysis. Locations 5 and 6 are beyond the jet penetration region, as indicated by the motion picture analysis. In addition, location 1, which is only 0.134 m (5.28 in.) from the top of the jet nozzle, may still be in the potential core region of the jet.

Equation (1), with $a = 0.516$ and $b = -0.238$, correlates all data with a high correlation coefficient of -0.8788 (see Table 5-3). This indicates that equation (1) with the compound jet velocity, $(U_j)_c$, calculated following equation (2), can be employed to project the effect of solid loading and relative jet velocities between the two concentric jets on the decay of the maximum velocity at the jet axis.

TABLE 5-3

SIMPLE POWER LAW DECAY OF THE MAXIMUM JET VELOCITY AT THE AXIS

<u>Set Point No.</u>	<u>a</u>	<u>b</u>	<u>Correlation Coefficient</u>
1	0.569	-0.311	-0.9934
2	0.616	-0.278	-0.9859
3	0.579	-0.238	-0.9755
4	0.534	-0.316	-0.9935
5	0.504	-0.254	-0.9879
6	0.452	-0.100	-0.9982
7	0.475	-0.157	-0.9932
8	0.428	-0.251	-0.9999
All Data	0.516	-0.238	-0.8788

Motion pictures taken during TP-M003-1 and TP-M003-2 were analyzed frame-by-frame to extract information on jet penetration depth, bubble size, bubble velocity, bubble frequency and jet half-angle. The fraction of time when the jet penetrates through the bed observed at View 3 was also noted. For bubble frequency analysis, the period of time when the jet penetrates the bed was excluded. Results of motion picture analyses are presented in Table 5-4 for TP-M003-1 and in Table 5-5 for T-M003-2.

The average bubble size and the average bubble frequency observed in the motion pictures can be used to estimate the percentage of the gas supplied via the concentric jets that eventually goes to form the visible bubbles. They are shown in Figure 5-3. There is substantial gas leakage from the bubble before it is pinched off from the jet, a fact consistent with earlier observations of TP-M002-1 and TP-M002-2 (Yang et al., 1982). The line in Figure 5-3 can be expressed as:

$$V_B = 0.301 \text{ G/n} \quad (3)$$

Equation (3) is comparable with that obtained for TP-M002-2 as shown in equation (4):

$$V_B = 0.303 \text{ G/n} \quad (4)$$

Change of grid flow location from Sections 1 and 2 in TP-M003-1 to Section 5 in TP-M003-2 does not seem to affect the magnitude of gas leakage from the bubbles.

Experimentally observed average bubble sizes are compared with those calculated from the model developed earlier (Yang, et al., 1982) in Table 5-4 and they compare reasonably well. The experimentally observed bubble frequencies were used during those calculations. If the bubble frequency or the amount of gas leakage is unknown, the bubble size cannot be predicted a priori using the model.

Bubble velocity was obtained by following a gas bubble in the motion pictures for a distance over 0.6 to 1.2 m with a frame counter. The average bubble velocity reported in Tables 5-4 and 5-5 is an average value typically of up to 40 bubbles.

The experimental average bubble velocities are compared with those calculated from the following equation:

$$U_B = 0.711 \sqrt{gDB} \quad (5)$$

Equation (5) applies to a single bubble in a fluidized bed without wall effect. Considering that so many other mechanisms, such as jetting, bubble coalescence, and pressure fluctuation, occur in the 3-meter model, besides the wall effect, the agreement in Tables 5-4 and 5-5 is reasonable. Further refinement in bubble velocity comparison may not be constructive at this point because the wall effect and the effect of those other mechanisms cannot be properly quantified.

TABLE 5-4
COMPARISON OF CALCULATED AND EXPERIMENTAL BUBBLE
SIZE -- TP-M003-1 AND TP-M003-2

<u>Set Point</u>	<u>Experimental Bubble Size, m</u>	<u>Calculated* Bubble Size, m</u>	<u>Calculated Maximum* Bubble Size, m</u>
TP-M003-1			
1	1.27	1.42	1.55
2	1.21	1.39	1.48
3	1.23	1.50	1.63
4	1.45	1.56	1.88
5	1.41	1.67	1.87
6	1.44	1.61	1.83
7	1.30	1.57	1.86
8	1.22	1.51	1.83
TP-M003-2			
1	1.54	1.49	1.60
2	1.44	1.48	1.59
3	1.39	1.47	1.59
4	1.54	1.80	2.04
5	1.46	1.65	1.84
6	1.37	1.69	1.92
7	1.37	1.67	1.93
8	1.45	1.65	1.91

*Calculated using equations (8) and (9) of Yang (1982).

TABLE 5-5

COMPARISON OF CALCULATED AND EXPERIMENTAL JET
PENETRATION DEPTH - TP-M003-1 AND TP-M003-2

Set Point	Experimental m	Yang(1981)* m	Yang and Keairns(1978) m	Merry(1975) m	Wen et al. (1982) m	Modified Hirsan m
TP-M003-1						
1	2.98	2.33	3.86	3.46	6.67	2.03
2	2.91	2.30	3.91	3.52	6.85	2.07
3	2.94	2.65	4.34	4.11	8.79	2.63
4	2.96	2.79	4.25	4.08	8.67	2.59
5	3.06	3.05	4.59	4.43	9.94	2.95
6	2.94	2.94	4.44	4.31	9.50	2.82
7	2.63	2.68	4.29	4.10	8.75	2.61
8	2.72	2.66	4.36	4.20	9.12	2.71
TP-M003-2						
1	2.74	2.98	3.98	3.62	7.16	2.17
2	2.72	2.65	4.08	3.75	7.57	2.29
3	2.69	2.70	4.21	3.93	8.15	2.45
4	2.69	3.11	4.53	4.47	10.07	2.97
5	2.80	3.00	4.49	4.28	9.37	2.79
6	2.78	3.02	4.62	4.56	10.40	3.07
7	2.72	2.85	4.42	4.28	9.38	2.79
8	2.71	3.01	4.51	4.40	9.84	2.92

*Based on the predictions by Yang (1981) plus one bubble diameter height.

+All calculations used the properties of the median particle diameter.

Figure 5-3. Experimental Data on Gas Leakage from the Bubble to the Emulsion Phase

Jet half-angles reported in Tables 5-4 and 5-5 were calculated from equation (6) developed on the basis of Figure 5-4. The jet-half angles, under those operating conditions,

$$\sigma = \tan^{-1} (D_B - d_o/2L) \quad (6)$$

are generally around 10°.

A considerable amount of bubble coalescence was observed even after the bubbles were pinched off at the end of the jet in TP-M003-1 and TP-M003-2. Those coalescence phenomena above the jet were not generally observed during TP-M002-1 and TP-M002-2. If this coalescence process occurred often above the jet, the jet penetration depth was defined as the height at which this coalescence process had just finished, rather than as the height at which the gas bubbles first were pinched off at the end of the jet. As a result, the jet penetration depths reported in Tables 5-4 and 5-5 are substantially higher than those reported earlier for TP-M002-1 and TP-M002-2. The depth of jet penetration was also insensitive to the changes in jet momentum caused by changes in gas flow rate and solids feed rate. This difference in coalescence phenomena observed in TP-M003 and TP-M002 might be due to the difference in particle size and/or distribution. Tests in TP-M002 have median particle diameters ranging from 0.11 to 0.23 cm (0.05 to 0.10 in.), as compared to 0.10 to 0.11 cm (0.05 in.) in tests TP-M003.

A comparison of jet penetration depth calculations obtained from various correlations is presented in Table 5-5. Four of the correlations, those by Merry (1975), Wen et al. (1982), Hirsan et al. (1980), and Yang (1981), were used in a previous report (Yang 1982). A new correlation by Yang and Keairns (1979) developed for jet penetration involving multiple jets where bubble coalescence may be a dominant phenomenon is also included for comparison:

$$\frac{L}{d_o} = 15.0 \left(\frac{\rho_f}{\rho_p - \rho_f} \frac{U_o^2}{g d_o} \right)^{0.187} \quad (7)$$

This correlation shows jet penetration to depend substantially less on the momentum of the jet. The correlation by Hirsan et al. (1980) shown in the following,

$$\frac{L}{d_o} = 19.3 \left(\frac{\rho_f U_o}{\rho_p \sqrt{g d_p}} \right)^{0.83} \left(\frac{U_f}{U_{cf}} \right)^{-0.54} \quad (8)$$

was also modified to assume that $U_f/U_{cf} = 1$. Equation (8) becomes:

$$\frac{L}{d_o} = 19.3 \left(\frac{\rho_f U_o}{\rho_p \sqrt{g d_p}} \right)^{0.83} \quad (9)$$

The modified correlation by Hirsan et al. (1980), as shown in Equation (9), correlates the data surprisingly well. The correlation by Yang (1981), which performs satisfactorily for data in TP-M002-1 and TP-M002-2 where bubble coalescence above the jet was not dominant, underpredicts the jet penetration

Figure 5-4. Definition of Jet Half Angle

depth defined in the present context. If the larger momentum flux of the two concentric jets, rather than the average momentum flux, was used the correlation improved somewhat. If we assume that the observed jet penetration depth is that predicted by Yang (1981) plus one bubble diameter, because of additional coalescence above the jet observed in TP-M003, the predictions in Table 5-5 and the other correlations all overpredict the jet penetration depth to a different degree.

A test program scope was prepared for the pneumatic transport loop constructed at the CFSF using the bed material now available at the CFSF. Primary variables to be changed in the test program are transport velocity, 26 to 98 fps (8 to 30 m/s), and solid transport rate, 15,000 lb/hr (up to 6800 kg/hr). This gives a solid-to-gas weight ratio of up to 6 at 30 m/s or up to 12 at 15 m/s (50 fps). The secondary variable to be changed is the radius of the elbow, from 0 to the dead-end tee) to 12 inches. The phenomena to be studied are the line pressure drop under different operating conditions, saltation, and other solid transport flow patterns.

Four more piezoelectric solid circulation probes were constructed. These probes used different techniques to dampen the secondary oscillation of the piezoelectric element so that every collision of a solid particle will generate only one response from the element. These probes are being evaluated in the 12-inch diameter semicircular unit. The first piezoelectric probe is also being adapted for tests in the CFSF.

Gas traces concentration profiles obtained during tests TP-M004 are being analyzed by solving the tracer gas conservation equation numerically. The axial gas velocity profiles in the jet were assumed to be similar to those obtained through Tollmien's solution, and the radial gas velocity profiles were forced to reproduce the gas tracer concentration profiles observed experimentally. Preliminary conclusions using data from the 12-inch diameter laboratory unit indicated that the gas mixing between the jet region and the emulsion phase was primarily due to convection. The diffusion of the tracer gas played a negligible role.

5.3 NOMENCLATURE

A_t	total cross-sectional area of the concentric jets
D_B	diameter of the gas bubble
d_o	jet nozzle diameter
d_p	particle diameter
g	gravitational acceleration
G	volumetric flow through the jet nozzle
L	jet penetration depth
$(M_g)_i$	mass flow rate of gas in the inner jet

$(M_q)_o$	mass flow rate of solids in the outer jet
$(M_s)_i$	mass flow rate of solids in the inner jet
$(M_s)_o$	mass flow rate of solids in the outer jet
n	bubble frequency
U_B	bubble velocity
U_{cf}	complete fluidization velocity
U_f	superficial fluidization velocity
U_g	interstitial gas velocity
$(U_g)_i$	jet velocity in the inner jet
$(U_g)_o$	jet velocity in the outer jet
$(U_j)_c$	compound jet velocity of the concentric jets defined in equation (7)
U_m	maximum gas velocity at the jet axis
U_o	average jet nozzle velocity
$(U_s)_i$	solid particle velocity in the inner jet
V_B	volume of the gas bubble
ρ_f	fluid density
ρ_p	particle density
μ	fluid viscosity

5.4 REFERENCES

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WORK FORECAST FOR NEXT QUARTER

- Complete CFSF test FR-002.
- Complete data reduction for CFSF tests TP-M007-1 and FR-002.
- Conduct CFSF tests TP-M009-1 and TP-M008-1.

SECTION 6.0

PROCESS AND COMPONENT ENGINEERING AND DESIGN

Major modification completed prior to test TP-033-2 are as follows:

- The C-110 primary cyclone was relocated.
- The 18-inch diameter piping connecting the gasifier to the primary cyclone and the primary cyclone to the secondary cyclone was installed.
- The 12-inch diameter dipleg piping from the primary cyclone to the connecting tee on the gasifier was installed.
- The "through-trap" was installed in the outlet pipe of the gasifier. A water-cooled pipe section was fabricated for installation at the gasifier exit to replace the through-trap, if necessary.
- An auxiliary feed line was installed between the feed lockhopper and the primary cyclone dipleg to fill the dipleg during startup and upset recovery conditions.

In addition to the above, a data report on test TP-033-1 was completed, including performance assessment of the secondary recycle solids injection device and the effect of hot fines recycle on gasifier heat load. The MCOAL computer program for measuring the secondary fines recycle rate through the solids injection device was updated for TP-033-2, based on the results obtained from test TP-033-1. Also, an on-line computer program was developed to provide an instantaneous readout of the surface metal temperature of the "through-trap" device to be evaluated in test TP-033-2.

A number of modifications and changes were implemented prior to startup of gasifier test TP-033-3. These are described below.

- Additional refractory and a new type gasket were installed in the primary cyclone dome to rectify leakage problems.
- An additional nuclear densitometer (K-ray) level indicator was installed on the non-mechanical valve standpipe. This was located below the existing K-ray instrument and increased the span of fines level monitoring from 4 to 12 feet of the standpipe.
- The K-ray level instruments were pretest calibrated with two materials of different densities to develop a range of operating characteristics for diagnostic assessment during the test.
- The non-mechanical valve standpipe thermocouples were inserted 1/4-inch into the standpipe to better measure the fines temperature.
- Sintered metal filters were added to the pressure taps on the standpipe to reduce line plugging.

- Insulation was added to the standpipe to maintain higher fines temperature above the gas dew point. Skin temperature thermocouples were added to the standpipe to monitor the metal temperature for over-temperature control.
- A shell-and-tube steam heat exchanger was added to the non-mechanical valve aeration flow supply line to provide an auxiliary heat supply for the dew point problem.
- Fine and coarse flow control valves in parallel arrangement were added to the non-mechanical valve aeration flow for improved control over a wider range of operation.
- Representative sampling of the non-mechanical valve standpipe solids was modified. Because of the length of the sample leg, seven samples are discarded before a representative sample is obtained.

Failure analysis of the nuisance leakage problems on the PDU primary cyclone was completed. After the November PDU test (TP-033-2), the insulation in the flange area of the leak was inspected, and it was found that significant areas had eroded causing the flange to overheat and the gasket to fail. The erosion was caused by product gas flow around the support plate of the downcomer, which is supported in this flange area.

Work was initiated on the procurement package to modify the PDU structure and elevate the primary cyclone two more floors (approximately 20 feet). The specification for the structure modification and the relocation of the cyclone was completed.

WORK FORECAST FOR NEXT QUARTER

- Upgrade PDU oxygen and steam systems.
- Modify solids injection device to provide blowdown capability.
- Recast C-120 cyclone barrel refractory to prevent the erosion bypass flow.
- Relocate K-ray level control and reorient pressure tap nozzles.

SECTION 7.0

LABORATORY SUPPORT STUDIES

7.1 GAS-SOLIDS FLOW MODELING

7.1.1 JET PHENOMENA

The objective of this task is to investigate different jetting phenomena in a fluidized bed: jet penetration depth, gas and solids entrainment into jets, and different jetting regimes. A two-dimensional, high-temperature unit was operated to measure the minimum fluidization velocity of sand particles approximately 750 μm (0.030 in.) in size at different bed temperatures. These data will then serve as the base line for subsequent studies of jet penetration at different bed temperatures.

7.1.2 FINE PARTICLE HISTORY

This subtask objective is to study the fate of fines that are injected either concentrically or radially into the gasifier as a function of flow-field characteristics. Knowledge about the mixing and residence time of the fines in an operating fluidized-bed reactor is necessary to predict fines consumption rate and reactor performance and to design the fines recapturing and recirculation systems.

When the tracer particle injection experiments were reinitiated, some of the earlier experiments were repeated. The mean residence time obtained from these experiments was repeatedly longer than the previously obtained mean residence times by an order of magnitude. This difference was attributed to static electricity caused by increased dryness of the fluidizing air in the winter. As a result, it was considered necessary to install a humidity control system for the fluidizing air to increase our confidence in the results obtained from the fine tracer particle injection experiments. Other investigators have found the same effect of the relative humidity of the fluidizing medium on the behavior of fines.

A flow diagram of the designed air-humidity control system to be incorporated into the 12-inch diameter semicircular cold flow unit is shown in Figure 7-1. Its active element is an ultrasonic spray nozzle activated by compressed air at about 207 kPa (30 psi). As water is fed into the spray nozzle at a controlled rate through a metering pump, it becomes atomized and is injected as a fine, evenly dispersed cloud of extremely small droplets into a spray chamber. Dry compressed air from the main air line is fed through this chamber, becomes humidified, and is subsequently channeled into the cold-flow unit. The relative humidity and temperature of the humidified air stream is measured at the exit to the spray chamber, before it enters the cold flow unit, by means of a microprocessor-based aluminum oxide hygrometer.

Detailed drawings of the spray chamber and the included distributor plate for the incoming dry air were completed and submitted for approval and competitive bidding along with the purchase orders for the spray nozzles, the metering pump, and the hygrometer.

Figure 7-1. Schematic Diagram of Humidity Control System for Fluidizing Air into 12-Inch Cold Flow Model

7.1.3 CHAR/ASH SEPARATION

The objective of this task is to determine the effect of different particle characteristics on the rate and effectiveness of particle separation. Experimental work on particle separation was resumed, continuing studies on separation of particles of similar density but of different sizes, using crushed acrylic particles.

7.2 COAL/ASH BEHAVIOR

The objective of this task is to develop an understanding of the critical factors that determine gasification kinetics and ash agglomeration and to characterize coals for reactivity and ash sintering characteristics in support of the PDU operation.

7.2.1 COAL GASIFICATION

The characterization of Texas lignite was extended by studying the effect of particle size on reactivity. The average relative reactivity determined for 10 x 12 mesh size was 129. The same reactivity was obtained for the size distribution of 18 x 60 mesh ($-1.0 +0.25$ mm), indicating no particle size effect. Two additional sizes will be investigated.

A series of tests were performed on a thermogravimetric analyzer to characterize Wyoming Sub C coal for reactivity in a fuel gas containing H_2 , H_2O , CO , and CO_2 and also in a mixture of CO , CO_2 , and N_2 . This coal had been characterized in a mixture of H_2 , H_2O , and N_2 in earlier tests. Reactivities obtained in these three series of tests are shown in Table 7-1. Note that the reactivity of Wyoming Sub C coal in the fuel gas mixture is approximately equal to the sum of reactivities in the CO_2 - CO - N_2 mixture and the H_2O - H_2 - N_2 mixture, showing the additivity of the two carbon gasification reactions (C - CO_2 and C - H_2O). Additional tests are needed to confirm this observation. The reactivity in a CO_2 atmosphere is nearly the same as the reactivity obtained in an H_2O atmosphere. These tests were conducted to extend the characterization of Wyoming Sub C coal and to develop a coal characterization test for western coals.

The reactivity of Wyoming Sub C coal was studied at temperatures of 926, 871, and 815°C, (1700, 1600, and 1500°F, respectively) in addition to the reference temperature of 983°C (1800°F) to determine the activation energy. The results are shown in Table 7-2. The reaction rate data are plotted in Figure 7-2, and an activation energy of 9.6×10^4 J/g mole (23,050 cal/g mole) is obtained. This information was developed for analyzing PDP data obtained with Wyoming Sub C coal.

7.2.2 ASH BEHAVIOR

The objective of this task is to study the behavior of coal ashes. Following the installation of the hot-stage microscope facility for pressurized use, the hot-stage chamber was tested hydrostatically both at 3443 kPa (500 psi) with the sapphire window in place and at 5171 kPa (750 psi) with a metal disc in the place of the sapphire window and found to be satisfactory. All the lines connected to the hot-stage chamber were tested for leaks, and the facility is ready for use at pressure.

TABLE 7-1

REACTIVITY OF WYOMING SUB C COAL IN DIFFERENT GASEOUS ATMOSPHERES

Gas Composition for Pyrolysis and Gasification	P.A. ^a -N ₂ H ₂ , & CO ₂ H ₂ /H ₂ O = 0.5 CO/CO ₂ = 1.0	P.A.-N ₂ H ₂ , and CO CO/CO ₂ = 1.0	P.A.-N ₂ CO/CO ₂ = 0.5	P.A.-N ₂ and H ₂ H ₂ /H ₂ O = 0.5	P.A.-N ₂ H ₂ /H ₂ O = 0.5
<u>Reactivity Data^b</u>					
Average reaction rate x 10 ² , min ⁻¹	69.89	32.42	29.73	26.60	36.2
Average relative reactivity	233.0	108.1	99.1	88.7	120.0
<u>Proximate Analysis, Wt. %</u>					
Moisture	21.66	22.94	16.22	17.57	17.15
Volatile Matter	32.35	32.22	39.81	35.05	35.27
Ash	4.49	5.23	5.09	5.72	5.72
Fixed Carbon	41.51	39.61	38.89	41.66	41.86
<u>Analysis of Char, Wt. %</u>					
Carbon	90.17	88.30	88.37	87.98	88.03
Ash	9.83	11.70	11.63	12.02	11.97

^a P.A. - Pyrolysis Atmosphere^b Average of three or more tests

TABLE 7-2

EFFECT OF TEMPERATURE ON THE REACTIVITY OF WYOMING SUB C COAL

<u>Temperature, °C</u>	<u>982</u>	<u>926</u>	<u>871</u>	<u>815</u>
<u>Reactivity Data*</u>				
Average reaction rate $\times 10^2$, min ⁻¹	26.6	21.29	13.80	6.47
Average relative reactivity	88.7	71.0	46.0	21.6
<u>Proximate Analysis, Wt. %</u>				
Moisture	17.57	15.24	15.83	12.27
Volatile Matter	35.05	39.43	40.48	36.11
Ash	5.72	4.31	6.26	10.42
Fixed Carbon	41.66	41.03	37.43	41.20
<u>Analysis of Char, Wt. %</u>				
Carbon	87.98	90.46	85.63	79.88
Ash	12.02	9.54	14.37	20.12

* Average of three or more tests.

Figure 7-2. Wyoming Sub C Char-Steam Reaction

Behavior of Pittsburgh seam coal ash of -12 +14 mesh was studied in an oxidizing atmosphere. On the basis of two experiments, the initial sintering temperature varied from 982 to 1010°C (1800 to 1850°F), while the initial melting temperature varied from 1028 to 1071°C (1900 to 1960°F). Particle size of 30 x 35 mesh was also studied. Initial sintering temperature was about 899°C (1650°F), while the initial melting temperature was about 1066°C (1950°F) for this distribution. Results of the later test will be verified.

Behavior of West Virginia coal ash, -6 +8 mesh in size, was studied in an oxidizing atmosphere. The ash particle was heated to a temperature of 1260°C (2300°F). The particle showed slight sintering at this temperature, confirming earlier observations. From these tests, it appears that West Virginia coal ash is difficult to agglomerate.

To improve the temperature measurement in the hot stage, two thermocouple junctions were spot-welded to the platinum strip. Thus, the temperature gradient across the platinum strip and the temperature at the point of contact of the platinum strip and the particle could be determined more accurately.

The temperature gradient across the platinum strip was found to be small (<10°F over a distance of 0.5 cm) and, hence, the points of contact of several ash particles placed near a thermocouple junction can be expected to be close to the temperature indicated by the T.C.

The sintering behavior of Indiana No. 7 coal ash particles, 10 x 12 mesh and white in appearance, was studied. An initial sintering temperature of 1116°C (2040°F) was observed. No melting was noticed even though the platinum strip was heated to a temperature of 1260°C (2300°F). Three grey ash particles from the same ash sample were examined and found to sinter at a temperature of approximately 1177°C (2150°F). The ash sample consisted of both white and grey particles. During the next test, the sintering behavior of 30 x 35 mesh ash particles will be studied.

7.2.3 DEPOSIT CONTROL

A report containing available analytical data on PDU cyclone deposits has been prepared. Deposit analyses included x-ray, microprobe, and physical and chemical analyses.

Table 7-3 is a summary of x-ray results for deposits obtained with various coals. For coals with high pyritic sulfur contents, such as Pittsburgh Seam or Western Kentucky, the deposit samples contain FeS₂ or FeS or Fe_{1-x}S in the major phase. For coals low in pyritic sulfur, such as Indiana No. 7, West Virginia, or RSA, the deposit samples do not show iron sulfides, and most of the iron is bound in the silicates or aluminates.

Microprobe results agree with x-ray results. For coals rich in pyritic sulfur, systems of Fe-S, Ca-Al-Si, K-Si-Al, and Fe-Al-Si could be identified. FeS was predominant in the bulk of the deposit. At the surface close to the cyclone wall, some particles of Fe-S were seen scattered among other ash material. At the surface exposed to the gas stream, the patterns for Fe and S were dispersed and did not exactly coincide with each other. The absence of FeS was also noted in micrographs of deposit samples from low pyritic sulfur coals, the iron being tied up mainly in Fe-Al-Si systems.

TABLE 7-3

SUMMARY OF X-RAY ANALYSES OF SAMPLES OF CYCLONE DEPOSITS

- With Pittsburgh Seam Coal (TP-018-2; TP-022-2; TP-023-3)

Major - SiO_2 ; Fe_{1-x}S ; FeS ; Fe_2O_3 ; $(\text{Mg.Fe})_2\text{SiO}_4$ - ring woodite; $(\text{Fe})_2\text{SiO}_4$ - fayalite; $(\text{Al}_{1.96}\text{Fe}_{0.04})\text{O}_4$ - spinel

Minor - FeS_2 ; $(\text{Fe})_2\text{SiO}_4$; $(\text{Mg.Fe})_2\text{SiO}_4$; $\text{CaAl}_2\text{Si}_2\text{O}_8$ - Anorthite

Trace - CaSO_4 and MgO

- With Western Kentucky Coal (TP-027-4)

Major - FeS

Minor - Fe_2O_3

- With Ohio No. 9 coal and water injection (TP-023-1)

Major - Fe_2O_3

Minor - SiO_2

Trace - $(\text{Fe})_2\text{SiO}_4$; $(\text{Mg.Fe})_2\text{SiO}_4$

- With Indiana No. 7 coal (TP-028-2) - Primary and secondary cyclone deposits

Major - $(\text{Fe})_2\text{SiO}_4$; SiO_2 ; FeS (only in through-trap deposit)

Minor - $(\text{Fe, Mg})\text{SiO}_3$; $(\text{Mg, Fe})\text{Si}_2\text{O}_4$ - spinel

TABLE 7-3 (continued)

- With West Virginia Coal (TP-030-3) - Primary and secondary cyclone deposits

Major - $\text{Fe}_2(\text{SiO}_4)$ or FeAl_2O_4 - spinel; SiO_2

Minor - $\text{Fe}_2(\text{SiO}_4)_i \text{Al}_2\text{SiO}_5$

Trace - $\text{Mg}_{.17} \text{Fe}_{.83} (\text{SiO}_3)$ - ortho-ferrosilite

Possible mechanisms of deposit formation were proposed, as summarized in Table 7-4. Alternative deposit prevention options were discussed, including water injection, cold-wall cyclone, and through-trap.

The deposit probe was installed in the PDU gasifier for tests TP-033-2 and TP-033-3 to determine the metal wall temperatures at which deposit formation starts. In TP-033-2, with Wyoming coal feed, the CO₂ cooling gas flow was maintained at 45.4 kg/hr (100 lb/hr) for about 24 hours, and the temperature readings along the length of the probe were between 93 and 166°C (200 and 330°F). Gasifier freeboard temperature was around 899°C (1650°F). There was no indication of deposit formation on the probe, since the probe thermocouple readings remained constant during the test. The gasifier was not opened after TP-033-2, and the deposit probe was not examined.

In TP-033-2, with Western Kentucky coal feed, the probe cooling gas flow (CO₂) was maintained at 23 kg/hr (50 lb/hr). During set point 1, in the air-blown mode, gasifier freeboard temperature was around 954°C (1750°F), and temperature readings along the probe length were between 149 and 288°C (300 and 550°F). Over a period of 39 hours, there was a constant decrease in probe temperature readings, indicating ash accumulation or deposit on the probe surface. The probe thermocouple readings at the end of set point 1 were between 116 and 221°C (240 and 430°F).

During set point 2, in the oxygen-blown mode, the gasifier freeboard temperature was 1004°C (1840°F), and the probe temperatures were between 149 and 260°C (300 and 500°F). Over a period of 29 hours, the temperature readings constantly decreased to values between 99 and 171°C (210 and 340°F), indicating ash accumulation on the probe. The gasifier was not opened after TP-033-3. The deposit probe remained in place during test TP-033-4. When the gasifier is opened, after TP-033-4, the probe will be examined for signs of ash deposits.

WORK FORECAST FOR NEXT QUARTER

- Proceed with installing the air-humidity control and monitoring system in the 30-cm cold-flow model to ensure reliability of results obtained from fine tracer particle injection experiments.
- Reinitiate fine tracer particle injection experiments following equipment modification to study effect of variation in flow conditions and injection location on fines residence time.
- Continue modeling effort on solid circulation and fines entrainment and collection rates.
- Continue tests to increase the understanding of carbon gasification reactions, particularly with respect to western coals.
- Continue reactivity characterization of coals on the TGA.
- Continue ash behavior studies on the hot-stage microscope facility.

TABLE 7-4

SUMMARY OF PROPOSED MECHANISM OF DEPOSIT FORMATION
IN THE PDU CYCLONE

<u>Conclusions</u>	<u>Supporting Analyses</u>
Mechanism of particle arrival at the cyclone wall: inertial flight and impaction	<ul style="list-style-type: none"> ● Particle size analysis ($dp > 5\mu m$)* ● Deposit pattern (buildup appears to have started from opposite wall to the inlet pipe and grown back towards the inlet)
Mechanism of particle adhesion: molten, sticky FeS and low-melting eutectics of K-Al-Si oxide systems acting as binding matrix for ash buildup	<ul style="list-style-type: none"> ● X-ray, microprobe, and chemical analyses of deposit samples ● Phase diagrams of FeO-FeS and K_2O-SiO_2 systems ● Thermodynamic calculations indicating the presence of K_2SiO_3 and $KAlSi_3O_8$ in the gasifier

* Although most of the deposit (TP-018-3; TP-022-2) consisted of a cohesive mass, individual spherical particles could be microscopically observed in the more loosely bonded layers of the deposit closest to the cyclone wall. Nearly all observed particles were five microns or larger in diameter.

- Continue the experimental program to verify the proposed mechanisms of deposit formation.
- Analyze deposit probe data from TP-033-2 and TP-033-3.