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

Quarterly Progress Report for the Period July 1—September 30, 1982

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Morgantown, West Virginia

By
Westinghouse Electric Corporation
Synthetic Fuels Division
Madison, Pennsylvania

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

FOURTH QUARTER PROGRESS REPORT
FY-1982

Period July 1 to September 30, 1982

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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.
- An atmospheric pressure fluidized bed agglomerator, operating at design temperatures.
- 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

Single-stage, oxygen-blown gasifier test TP-033-1 was conducted in four operational phases from July 22, 1982 through August 22, 1982. The primary objective of this test was to obtain operating performance data for a hot solids injection device used for hot fines recycle. Though the first two startups were terminated early because of slagging of the grid area and excessive CO emissions around the recycle gas generator, the third startup achieved 99 hours of hot operation before a failed open check valve in the first water quench vessel caused shutdown. The fourth startup was successfully completed and ended upon depletion of the feedstock. In all, during test TP-033-1, 204 hours of hot operation were achieved, including 103 hours with Brookville seam coal and 68 hours with North Dakota lignite.

Fines recycle data from test TP-033-1 were reduced and indicated that up to 725 pounds per hour were recycled through the solids injection device at an eductor motive gas flow rate of 400 pounds per hour and at temperature of 600°F.

Construction, pretest and test planning activities were conducted during September in preparation for TP-033-2, a shakedown test of the non-mechanical valve to be conducted during the next quarterly report period.

2.2 PROCESS ANALYSIS

During test TP-033-1 the solids injection device was successfully operated for recycling char from the secondary cyclone. On-line temperature, pressure and isokinetic measurements showed the injection device was capable of pumping fines at a consistent rate over the range of operating conditions.

High carbon conversion efficiencies were obtained on both feedstocks as a result of improved fines collection and recycle and low carbon losses in the ash agglomerates.

During the planned set point conditions, medium-Btu gas combustion tests were conducted using 240 Btu/scf product gas. Combustion tests were completed at fuel preheat temperatures of 500, 750 and 950°F. The gas turbine temperature range was mapped for an 80 fps reference velocity at all fuel temperatures. These are contained herein as are those for a 60 fps reference velocity and fuel temperatures of 500 and 750°F.

2.3 PROCESS AND COMPONENT ENGINEERING AND DESIGN

Design, construction and procurement for the Phase II hot fines non-mechanical valve recycle system continued for test TP-033-2 scheduled during the next quarterly report period.

Resulting from the feedline erosion experienced in PDU test TP-032-1, it was decided to incorporate a double-wall feed pipe section for added safety and

test reliability. Design and installation of the double-wall feedline between the gasifier and the first block valve was completed prior to initiating TP-033-1.

Computer software development completed to improve the operational efficiency of the PDU and CFSF included:

- On-line PDU feed rate computations to give the operators a more accurate real-time measure of solids feeding into the gasifier.
- Means and standard deviations computations by playback to facilitate statistical error analysis of PDU heat/mass balances.
- A playback program for the new CFSF data acquisition system to provide quick analysis of collected data. This program will be used in analyzing the backlog of data accumulated at the CFSF.

2.4 COLD FLOW SCALEUP FACILITY

TP-M005, the shakedown test on the new 10-inch diameter air tube configuration, was completed August 2 and results indicate that the jet velocity could be increased up to 200 fps without severe particle entrainment from the bed. Complete analysis of TP-M005 data is continuing. TP-M007-1, a carbon dioxide tracer gas test whose objective is to develop an understanding of gas diffusion characteristics, was started August 6 and continued through September with approximately 60 percent of the test points completed.

Analyses of data from tests TP-M003-1, TP-M003-2, and TP-M004 were completed and are reported herein.

Design of the pneumatic solids transport loop, for studying saltation characteristics and pressure drop profiles at various test sections, was completed and this loop will be installed during the next quarterly reporting period.

CFSF multiple oxidant tube assembly design is on-going within the established schedule.

Preliminary development of alternate solids circulation probes was initiated to provide a method for measuring solids circulation velocities to map fluidization regimes in the CFSF model.

Pressure drop data obtained with the pitot tube during CFSF tests TP-M003-1 were analyzed, and part of the results are presented in this quarterly. A topical report will be issued to provide details of the analysis.

2.5 LABORATORY SUPPORT STUDIES

2.5.1 GAS SOLIDS FLOW MODELING

Tests were completed to simulate PDU fines injection in the char/ash separator region below the oxidant jet. Visual observation on the jet interaction of

two jets of 5.4 cm (2-1/8 in.) and 1.1 cm (7/16 in.) i.d. in the 30-cm (1-foot) semicircular unit produced the following conclusion: total momentum in the jet, rather than the momentum flux, is responsible for jet interaction. Before the main jet was deflected, the secondary jet deflected toward the main jet and merged into it at very close to the top of the jet nozzle. After the main jet had been deflected, both the main and the secondary jets deflected in the same direction, rather than toward each other, and merged. When the secondary jet was located at 30.5 cm (1 foot) below the main jet, the total momentum required in the secondary jet to cause a deflection in the main jet was 1.2 times the momentum of the main jet; when the secondary jet location was 15.2 cm (6 in.) below the main jet, 0.5 times the momentum of the main jet was required. Results provide a basis for selecting design criteria.

Shakedown tests of the high-temperature unit were completed. Experiments will be carried out initially to measure the minimum fluidization velocity at different bed temperatures to investigate the temperature effect.

Work on the determination of fine particle history continued. During this quarter, an order of antistatic resin pellets was received and shipped to be crushed cryogenically by an outside contractor. A few additional modifications of the 30-cm semicircular test apparatus were completed and preliminary tests run to evaluate the proposed experimental concept and to resolve any problem areas. A series of fine tracer particle injection experiments were initiated, and the initial results were partially analyzed.

Probes were also developed to measure solids circulation in the CFSF. A solid circulation probe based on piezoelectric principles was constructed and tested in the 30-cm semicircular cold model with promising results. The probe also showed potential in detecting the jet boundaries in a three-dimensional bed and in detecting the presence of gas bubbles in fluidized beds. On the basis of the experimental findings, a new probe with high damping is being fabricated which will cut down the resonance produced during particle impaction and thus will provide a better quantitative measurement of the number of particle impactions in the probe.

2.5.2 COAL/ASH BEHAVIOR

Gasification - Several coals and PDU chars were characterized for reactivity on the thermogravimetric analyzer - North Dakota lignite, Brookville "A" seam coal, and char from the PDU Illinois No. 6 coal and West Virginia char from the PDU were characterized at 982°C (1800°F). Texas lignite was characterized at 815°C (1500°F) to correspond to the PDU operating temperature.

Ash Behavior - The sintering temperature of ash particles from Pittsburgh seam and Wyoming Sub C coals of -30 to +35 mesh size was determined on a hot-stage microscope. These results form part of the data base to permit understanding of ash agglomeration phenomena.

Deposit Control - A deposit probe was installed in the PDU gasifier for test TP-033-1 to determine the metal wall temperature at which deposit formation starts. Although there was a small decrease in the readings of two probe

thermocouples during the Brookville A seam coal feed (from around 1050°F and 1100°F to 900°F, which may indicate an accumulation of deposit) the gasifier was not opened and signs of deposit formation on the probe could not be observed after the test with Brookville A seam coal. The probe was left in the gasifier through shutdown, restart, and the test run with North Dakota lignite. At the end of the test, the gasifier was opened and the deposit probe examined. The probe appeared clean and free of any ash deposit.

Of the many possible reasons for the absence of ash deposit on the probe surface, the following seem the most obvious:

- Ash deposit would not adhere to stainless steel at surface temperature below 1300°F.
- Ash deposit was formed on the probe at surface temperatures around 1050 and 1100°F but spalled off when the gasifier was shut down and when it restarted.
- Ash deposit formed but was eroded away by nonsticky carry-over material in the effluent stream during the test with lignite.

The probe will be removed from the gasifier and observed carefully under the microscope for signs of remaining deposits or signs of spalling. Probe thermocouple readings obtained during the tests will be analyzed for consistent trends and correlations of these temperature measurements and deposit formation.

2.6 SUMMARY SCHEDULES

Task Description

Operation and Maintenance of the PDU

Single-Stage Gasifier Operation

Gasifier Oxygen-Blown Maintenance and Test Modification

Gas Characterization, Treatment and Utilization

Fines Recycle Deposit Control

PDU Modifications

Modification for Fines Recycle

Hot Rotary Feeder (D)
Hot Educator
Upgrade CO₂ 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

[illegible]

LEGEND:

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

Task Description

Scaleup Design and Analysis

• Operation of Cold Flow Scaleup Facility

Test Model Modifications

Process Systems and Data Analysis and Design

Laboratory Support Studies

Gas Solids Flow Modeling

Jet Phenomena in High Temperature Unit

Particle Dynamics
Fine Particle History

Particle Separation

CFSF Support
Solid Circulation
Probe Development
Data Analysis

Coal/Ash Behavior
Gasification

Ash Agglomeration

Deposit Control
PDU Data Analysis
PDU Deposit Probe Test
Study of Deposit Mechanism
(with hot stage microscope)

FY 1982					
JULY	AUG	SEPT	OCT	NOV	DEC
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SECTION 3.0

PDU TEST OPERATIONS AND RESULTS

3.1 GASIFIER TEST TP-033-1

Single-stage, oxygen-blown gasifier test TP-033-1 was initiated on July 22 using Brookville A seam coal (Pennsylvania Allegheny group) and North Dakota lignite as the feedstocks. The objectives of this test were to:

- Obtain performance assessment data for a hot solids injection device used for hot fines recycle.
- Evaluate the effect of hot fines recycle on the fines consumption rate.
- Analyze the product gas for EPA-defined priority organic pollutants.
- Measure the temperature at which cyclone deposits form using a deposit probe located just upstream of the full cyclone cold wall.
- Continue the evaluation of the full cyclone cold wall.
- Develop a PDU feedstock characterization data base for Brookville seam coal and North Dakota lignite.
- Measure the alkali content of the product gas using a hot alkali sampling probe (DOE Contract No. DE-AC21-81MC16024).

Test TP-033-1 was conducted in four startups. The first was terminated when, in an attempt to reach the prescribed freeboard temperature, coal and oxygen feeds were increased. The ash concentration of the bed and annulus were in an elevated condition (45 and 85 percent, respectively), which did not allow sufficient time to respond to the increasing ash feed to the gasifier. The ash annulus quickly filled up to the grid area, causing a decreased carbon inventory. Slagging of the grid ensued to a point where recovery was not possible, and a decision was made to initiate shutdown. The second was terminated 14 hours into the first set point, when severe CO emissions were detected around the recycle gas compressor. After shutdown, an inspection of the recycle gas compressor revealed the shaft seals had worn and the cylinder cooling jacket was leaking.

Upon completion of a detailed inspection and repair of the compressor, the test was reinitiated on August 10. After 99 hours of hot operation, a third abort of the test occurred. A failed open check valve in the first water quench vessel resulted in liquid effluents escaping the system. The fourth startup, initiated on August 20, was successfully completed and ended upon depletion of the North Dakota lignite feedstock.

During test TP-033-1, 204 hours of hot operation were achieved, including 103 hours with Brookville A seam coal and 68 hours with North Dakota lignite. Set points obtained with both feedstocks are as follows:

Brookville Seam Coal

- Set point 1A - 1741°F freeboard temperature, 55 percent oxygen in oxidant tube, 232 Btu/scf product gas heating value, 63 percent ash in withdrawal, full fines recycle.
- Set point 1B - 1756°F freeboard temperature, 63 percent oxygen in oxidant tube, 241 Btu/scf product gas heating value, 65 percent ash in withdrawal, full fines recycle.
- Set point 2A - 1780°F freeboard temperature, 66 percent oxygen in oxidant tube, 247 Btu/scf product gas heating value, 77 percent ash in withdrawal, secondary fines recycle only using the solids injection device.

North Dakota Lignite

- Set point 3 - 1498°F freeboard temperature, 61 percent oxygen in oxidant tube, 256 Btu/scf product gas heating value, 81 percent ash in withdrawal, full fines recycle.
- Set point 3A - 1528°F freeboard temperature, 62 percent oxygen in oxidant tube, 260 Btu/scf product gas heating value, 79 percent ash in withdrawal, secondary fines recycle only using the solids injection device.
- Set point 3B - 1493°F freeboard temperature, 62 percent oxygen in oxidant tube, CO₂ in place of steam in the gasifier, 91 percent ash in withdrawal, secondary fines recycle only using the solids injection device.
- Set point 3C - An attempt was made to achieve set point 3C test conditions using a limited amount of North Dakota lignite char, made in the gasifier, and CO₂ in place of process steam to evaluate the absence of process steam and feedstock moisture on reactor performance. Steady state condition was unable to be achieved before exhausting the feedstock; however, during the attempt (approximately 1-1/2 hours) an increase in gasifier bed temperature (from 1567 to 1641°F) was observed. Further evaluations are planned later this year using Montana Sub-B coal having a 5% moisture content.

Notable accomplishments of test TP-033-1 include the following:

- The solids injection device was successfully operated for recycling char from the secondary cyclone. Performance data were obtained over a range of solids loadings by purposely operating the primary cyclone in both collecting and non-collecting modes. The pressure seal between the gasifier and the secondary cyclone was successfully maintained throughout the duration of the test. On-line temperature, pressure and isokinetic measurements showed the injection device was capable of pumping fines at a consistent rate over the range of operating conditions. Fines were reinjected back to the gasifier at 600°F as compared with 250°F with the original lockhopper system.

- Fines recycle data from test TP-033-1 were reduced, and the performance of the solids injection device was evaluated. Results indicate that up to 725 pounds per hour of fines were recycled through the solids injection device at an eductor motive gas flow rate of 400 pounds per hour and a temperature of 600°F. The operational and process performance results from this test are being summarized.
- High carbon conversion efficiencies were obtained on both feedstocks as a result of improved fines collection and recycle and low carbon losses in the ash agglomerates (typical ash content 80-90 percent).
- Fines deposition measurement for both feedstocks were performed utilizing the deposit probe in the gasifier freeboard section.
- The product gas was sampled for alkali metals using a hot alkali sampling probe.
- The product gas was sampled for EPA-defined priority organic pollutants.
- During air-blown holding operation of the test, the Test and Development Center (TDC) fuel gas preheater was commissioned. Several attempts at igniting low-Btu gas (70 Btu/scf) were made with 500°F fuel preheat and 800°F combustion air preheat. Ignition could not be achieved at these conditions.
- During the planned set point conditions, medium-Btu fuel gas combustion tests were conducted in Test Passage 1 at the TDC for 11 hours of operation using 240 Btu/scf product gas. Successful combustion tests were completed at fuel preheat temperatures of 500, 750, and 950°F. The gas turbine temperature range was mapped for an 80-feet-per-second reference velocity at all fuel temperatures. At a 60-feet-per-second reference velocity, fuel temperatures of 500 and 750°F were investigated.

Preliminary analysis of the combustion data indicates a high combustion efficiency greater than 99.5 percent, and at a combustor exit temperature of 2000°F, a 20 to 30 ppm increase in measured NO_x for preheated fuel gas vs. the cold (32°F) fuel gas test conducted in 1980/81.

Combustor wall or fuel nozzle overheating did not occur. The iron oxide coating previously observed inside the combustor was not present for these tests.

A chronology of significant events for test TP-033-1 is given in Table 3-1, the nominal operating data are presented in Table 3-2, and heat and material balances are reported in Tables 3-3 to 3-5. Figure 3-1 depicts a flow schematic for the heat and material balance envelope.

3.2 MAINTENANCE AND MODIFICATIONS

Construction, pretest and test planning activities were conducted during September in preparation for TP-033-2, a shakedown test of the non-mechanical valve to be conducted in October.

Construction activities included:

- Fabrication of inlet and outlet pipe sections for the primary cyclone and installation of refractory.
- Fabrication of dipleg piping between the primary cyclone and the gasifier non-mechanical valve and installation of refractory.
- Relocation of the primary cyclone to a higher elevation.
- Installation of the modified through-trap in the gasifier dome section.
- Modification of the PDU vent header to the thermal oxidizer.

The preliminary test plan for TP-033-2, as well as operating procedures, were developed. Feedstocks planned for the test are Powder River, Wyoming and Western Kentucky No. 9 coals.

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

<u>Date</u>	<u>Time</u>	<u>Event</u>
		<u>Startup No. 1</u>
7/22/82	1730	Completed pressurization at 230 psig.
7/24/82	0135	Completed hot air dryout.
	0500	Initiated coke breeze feed to gasifier.
	1645	Achieved autogenous ignition.
7/25/82	0105	Initiated Brookville coal feed to gasifier in air-blown mode for low-Btu combustion testing with gas preheat.
	0540	Continued setup of slipstream flow to TDC. Problems encountered in pressurizing TDC pipe line because of in-line restriction.
	0600	Bed height decreased 1.5 feet to 20-foot level to increase freeboard temperature to 1800°F.
	0910	Cleared TDC pipe line restriction and initiated slipstream flow to TDC.
	1215	Initiated and completed pressure recovery evaluation test on solids injection device.
	1300	Aborted gas preheat combustion test at TDC - could not sustain combustion.
	1715	Began transition from air-blown to oxygen-blown mode.
	1830	Annulus control temperature TE-507-4 too cold. Unable to control temperature interface in automatic - switched to operator control.

<u>Date</u>	<u>Time</u>	<u>Event</u>
	1850	Annulus temperature interface level increasing rapidly. Increased ash withdrawal rate - could not maintain bed level. Reduced temperature from 1850°F to 1830°F. Increased flow through annulus. Unable to stabilize control of annulus.
	1855	Temperature (TE-126) excursion diagnosed at top of oxidant tube to 2400°F. Initiated failure recovery action plan to prevent slagging in grid region.
	2100	No ash withdrawal, continued failure action plan.
	2120	Switched from steam to CO ₂ in shroud - could not obtain flow. Initiated shutdown.
	2124	Backed out air to quench combustion.
	2126	Completed shutdown - initiated depressurization ramp.
<u>Startup No. 2</u>		
7/29/82	2130	Completed pressurization at 230 psig.
7/30/82	1805	Completed hot air dryout.
	2235	Initiated coke breeze feed to gasifier.
7/31/82	1035	Achieved autogenous ignition.
	1700	Initiated air to oxygen transition.
	1910	Initiated Brookville coal feed to gasifier.
8/1/82	0450	Placed solids injection device (SID) on line.
	0630	<u>Achieved Set Point 1A test conditions.</u>
	1640	Recycle gas leaking into oil reservoir of recycle gas compressor.
	2025	Initiated shutdown. Measured carbon monoxide level on lower levels of structure unacceptably high because of recycle gas leak into oil reservoir of recycle gas compressor.

<u>Date</u>	<u>Time</u>	<u>Event</u>
		<u>Startup No. 3</u>
8/9/82	2300	Completed hot air dryout.
8/20/82	0340	Initiated coke breeze feed to gasifier.
	1040	Achieved autogenous ignition.
	1920	Initiated air to oxygen transition.
	2015	Initiated Brookville coal feed to gasifier.
	2255	Heat recovery system on line.
8/11/82	0530	<u>Achieved Set Point 1B test conditions.</u>
8/12/82	0800	<u>Achieved Set Point 2 test conditions.</u>
	1040	Initiated gas flow to Test and Development Center (TDC).
	2135	Completed gas flow to TDC.
8/13/82	0210	Exhausted Brookville coal supply.
	0345	Initiated North Dakota lignite feed.
	1500	<u>Achieved Set Point 3 test conditions.</u>
	1600	Mechanical problems with belt weigher systems. Initiated coke breeze feed to gasifier.
	1950	Resumed North Dakota lignite coal feed.
8/14/82	0300	<u>Redeclared Set Point 3 test conditions.</u>
	0710	Heat recovery system shutdown - leak in product gas line.
	1235	Check valve failure on water quench vessel.
	1300	Initiated shutdown.
		<u>Startup No. 4</u>
8/18/82	2035	Completed pressurization at 230 psig.
8/19/82	0730	Completed hot air dryout.
	2105	Initiated coke breeze feed to gasifier.
8/20/82	0830	Achieved autogenous ignition.
	1235	Initiated air to oxygen transition.

<u>Date</u>	<u>Time</u>	<u>Event</u>
	1430	Initiated North Dakota lignite coal feed to gasifier.
	2000	<u>Achieved Set Point 3A test conditions.</u>
8/21/82	0700	Replaced steam in gasifier with carbon dioxide for transition to set point 3B.
	0730	<u>Achieved Set Point 3B test conditions.</u>
8/22/82	0000	D-101 storage bin empty.
	0245	Depleted coal inventory. Initiated shutdown.

TABLE 3-2
SUMMARY OF OPERATING DATA FOR GASIFIER TEST TP-033-1

STEADY STATE		1B-1	1B-2	2A	3A	3A-1	3B-1
		Hours	Hours	Hours	Hours	Hours	Hours
TEST RUN DATE AND TIME (1982)	Unit	8/11 0600 - 1400	8/11-12 1400 - 0530	8/12-13 1400 - 0200	8/14 0345 - 1230	8/20-21 2000 - 0700	8/21 0900 - 1300
<u>MEASURED GASIFIER PARAMETERS</u>							
Freeboard Temperature	°F	1736	1768	1780	1506	1531	1488
Gasifier Bed Temperature	°F	1871	1896	1904	1555	1587	1541
Ash Annulus Temperature	°F	457	444	429	520	778	429
Average Bed Height**	feet	13.69	13.67	13.44	11.23	11.61	11.48
System Pressure	psig	231	231	230	231	232	233
Average Gasifier Bed Density	lb/ft ³	12.25	10.70	11.54	15.06	14.19	14.26
Average Annulus Density	lb/ft ³	12.71	13.68	16.37	13.20	14.67	15.87
Freeboard Gas Velocity	fps	1.30	1.32	1.35	1.28	1.28	1.11
Oxidant Tube Velocity	fps	80.57	85.19	85.58	104.89	95.18	96.84
Oxygen Concentration	%	62	63	66	61	62	61
Coal Feed Material		Brookville	Brookville	Brookville	N. Dakota Lignite	N. Dakota Lignite	N. Dakota Lignite
Coal Feed Rate	lb/hr	1414	1424	1385	2471	2358	2272
Fines Feed Material		Recycle Fines	Recycle Fines	--	Recycle Fines	--	--
Fines Feed Rate	lb/hr	550	479	0	572	0	0
Carryover to Water System*	lb/hr	140	140	344	273	286	365
Ash Withdrawal Rate	lb/hr	217	130	127	164	176	140
<u>PRODUCT GAS ANALYSIS, DRY BASIS</u>							
Carbon Monoxide	%	50.88	50.88	53.07	40.84	40.78	41.11
Carbon Dioxide	%	26.13	26.13	23.31	29.54	27.60	42.24
Methane	%	2.20	2.20	2.09	4.59	4.14	2.38
Nitrogen	%	1.05	1.05	0.98	0.36	0.56	0.43
Sulfur	%	0.857	0.857	0.738	0.212	0.184	0.128
Hydrogen	%	18.82	20.05	19.83	24.47	26.72	13.68
HHV, Dry Basis (Gas Chromatograph)	Btu/scf	246.0	250.0	255.2	256.3	256.9	199.9
<u>OVERALL PROCESS RATES</u>							
Carbon Mass Velocity ^a	lb/hr-ft ²	375.57	376.23	352.66	463.41	441.37	441.23
Gas Make/Coal	SCF/lb	43.61	42.24	42.80	36.24	36.56	32.14
Steam/Coal Ratio, MAF**	lb/lb	0.356	0.349	0.344	0.292	0.290	0
Oxygen/Coal Ratio, MAF	lb/lb	0.763	0.781	0.834	0.662	0.631	0.629
Total Moisture/Coal Ratio, MAF	lb/lb	0.381	0.366	0.369	0.553	0.556	0.219
Recycle Gas/Coal Ratio, MAF	lb/lb	2.39	2.38	2.62	1.65	1.56	1.92
<u>SOLIDS ANALYSIS</u>							
Ash Content - Fines	%	32.37	28.23	0	37.42	0	0
Ash Content - Feedstock	%	13.01	13.42	13.21	12.27	10.38	9.58
Ash Content - Bed	%	28.38	35.97	43.43	37.55	30.33	33.39
Ash Content - Agglomerate	%	63.45	50.97	76.98	81.61	78.10	88.80

*Estimated from isokinetic probe or ash samples.

**From jet inlet to top of bed.

++Moisture and ash free.

aReferenced at the 20" I.D. section.

Figure 3-1. Heat and Material Balance Flow Schematic

TABLE 3-3

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

STREAM NO.		1	2	3	4	5	6	7
STREAM DESCRIPTION		STEAM TO GRID	STEAM TO AIR TUBE	BOOSTER STEAM	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL	LB/HR	0.00	427.00	0.00	0.00	149.00	504.93	803.57
TEMPERATURE	F	0.0	445.0	0.0	0.0	118.0	143.0	594.0
GAS	LB/HR	0.00	427.00	0.00	0.00	149.00	504.93	803.57
SOLID	LB/HR	0.00	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	0.00
MOLECULAR WEIGHT		0.000	18.016	0.000	0.000	44.011	27.021	27.021
CO	VOLUME %	0.00	0.00	0.00	0.00	0.00	50.94	50.94
CO2	VOLUME %	0.00	0.00	0.00	0.00	100.00	25.83	25.83
H2	VOLUME %	0.00	0.00	0.00	0.00	0.00	18.93	18.93
CH4	VOLUME %	0.00	0.00	0.00	0.00	0.00	2.25	2.25
N2	VOLUME %	0.00	0.00	0.00	0.00	0.00	1.04	1.04
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	100.00	0.00	0.00	0.00	0.22	0.22
GAS CHARACTERIZATION								
	H2S PPM	0.000	0.000	0.000	0.000	0.000	7763.148	7763.148
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	0.000	0.000	0.000	0.000	40.663	177.369	282.272
HYDROGEN	LB/HR	0.000	47.782	0.000	0.000	0.000	9.203	14.646
OXYGEN	LB/HR	0.000	379.218	0.000	0.000	108.337	307.403	489.213
NITROGEN	LB/HR	0.000	0.000	0.000	0.000	0.000	5.453	8.679
SULFUR	LB/HR	0.000	0.000	0.000	0.000	0.000	4.651	7.403
ASH	LB/HR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT								
	KBTU/HR	0.000	71.516	0.000	0.000	1.279	1800.007	2971.948

TABLE 3-3, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST TP-G33-1, STEADY STATE 1B-1

STREAM NO.		8	9	10	11	12	13	14
STREAM DESCRIPTION		BOOSTER GAS	TRANSPORT GAS (FV-33)	TRANSPORT GAS (FV-29)	COAL FEED & TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G.	C119 FEED & TRANS. G.
TOTAL	LB/HR	355.61	1138.55	0.00	2249.98	916.00	389.00	922.31
TEMPERATURE	F	143.0	143.0	0.0	152.0	516.0	118.0	223.0
GAS	LB/HR	355.61	1138.55	0.00	835.98	916.00	389.00	372.31
SOLID	LB/HR	0.00	0.00	0.00	1414.00	0.00	0.00	550.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		27.021	27.021	0.000	27.021	31.862	44.011	27.021
CO	VOLUME %	50.94	50.94	0.00	50.94	0.00	0.00	50.94
CO2	VOLUME %	25.83	25.83	0.00	25.83	0.00	100.00	25.83
H2	VOLUME %	18.93	18.93	0.00	18.93	0.00	0.00	18.93
CH4	VOLUME %	2.25	2.25	0.00	2.25	0.00	0.00	2.25
N2	VOLUME %	1.04	1.04	0.00	1.04	0.00	0.00	1.04
O2	VOLUME %	0.00	0.00	0.00	0.00	99.57	0.00	0.00
H2O	VOLUME %	0.22	0.22	0.00	0.22	0.00	0.00	0.22
GAS CHARACTERIZATION								
	H2S PPM	7763.148	7763.148	0.000	7763.148	0.000	0.000	7763.148
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	124.917	399.942	0.000	1336.526	0.000	106.162	473.214
HYDROGEN	LB/HR	6.481	20.751	0.000	71.555	0.000	0.000	8.051
OXYGEN	LB/HR	216.498	693.152	0.000	564.302	916.000	282.838	226.665
NITROGEN	LB/HR	3.841	12.297	0.000	25.431	0.000	0.000	6.661
SULFUR	LB/HR	3.276	10.488	0.000	66.399	0.000	0.000	29.940
ASH	LB/HR	0.000	0.000	0.000	183.961	0.000	0.000	178.035
HEAT CONTENT								
	KBTU/HR	1267.709	4058.770	0.000	21386.576	91.186	3.338	6418.286

TABLE 3-3, Continued

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

STREAM NO.		15	16	17	18	19	HEAT LOSS	TOTAL CLOSURE
STREAM DESCRIPTION		LIQUID WATER INJECTION	PRODUCT GAS	C119 COLLEC. & TRANS.G.	ASH WITH-DRAWAL	BED SAMPLE (SC-22)		
TOTAL	LB/HR	0.00	6675.81	1475.14	217.00	5.25	0.00	-6.58
TEMPERATURE	F	0.0	1192.0	424.0	292.0	1750.0	0.0	0.0
GAS	LB/HR	0.00	6535.81	994.14	0.00	0.00	0.00	0.00
SOLID	LB/HR	0.00	140.00	481.00	217.00	5.25	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	26.507	27.021	0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	47.45	50.94	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	24.37	25.83	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	17.55	18.93	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	2.05	2.25	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.98	1.04	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	6.75	0.22	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION								
	H2S PPM	0.000	7991.611	7763.148	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	0.000	2281.005	648.687	60.218	3.587	0.000	-1.779
HYDROGEN	LB/HR	0.000	145.595	19.225	0.304	0.012	0.000	7.522
OXYGEN	LB/HR	0.000	4060.658	605.237	0.000	0.000	0.000	-11.514
NITROGEN	LB/HR	0.000	68.222	13.046	0.499	0.028	0.000	-31.162
SULFUR	LB/HR	0.000	66.445	32.342	18.293	0.132	0.000	3.812
ASH	LB/HR	0.000	43.288	155.700	137.687	1.490	0.000	6.584
HEAT CONTENT								
	KBTU/HR	0.000	25703.953	8090.090	976.872	54.623	425.000	7.407

TABLE 3-4

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

STREAM NO.	1	2	3	4	5	6	7
STREAM DESCRIPTION	STEAM TO GRID	STEAM TO AIR TUBE	BOOSTER STEAM	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL LB/HR	0.00	423.00	0.00	0.00	158.00	498.53	863.47
TEMPERATURE F	0.0	489.0	0.0	0.0	119.0	140.0	626.0
GAS LB/HR	0.00	423.00	0.00	0.00	158.00	498.53	863.47
SOLID LB/HR	0.00	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	0.00
MOLECULAR WEIGHT	0.000	18.016	0.000	0.000	44.011	26.238	26.238
CO VOLUME %	0.00	0.00	0.00	0.00	0.00	51.98	51.98
CO2 VOLUME %	0.00	0.00	0.00	0.00	100.00	23.52	23.52
H2 VOLUME %	0.00	0.00	0.00	0.00	0.00	20.15	20.15
CH4 VOLUME %	0.00	0.00	0.00	0.00	0.00	2.38	2.38
N2 VOLUME %	0.00	0.00	0.00	0.00	0.00	0.98	0.98
O2 VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O VOLUME %	0.00	100.00	0.00	0.00	0.00	0.20	0.20
GAS CHARACTERIZATION							
H2S PPM	0.000	0.000	0.000	0.000	0.000	5688.586	5688.586
COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON LB/HR	0.000	0.000	0.000	0.000	43.120	177.735	307.844
HYDROGEN LB/HR	0.000	47.334	0.000	0.000	0.000	9.833	17.030
OXYGEN LB/HR	0.000	375.666	0.000	0.000	114.880	301.662	522.491
NITROGEN LB/HR	0.000	0.000	0.000	0.000	0.000	5.201	9.008
SULFUR LB/HR	0.000	0.000	0.000	0.000	0.000	3.466	6.003
ASH LB/HR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT							
KBTU/HR	0.000	79.667	0.000	0.000	1.389	1881.609	3385.954

TABLE 3-4, Continued

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

STREAM NO.		8	9	10	11	12	13	14
STREAM DESCRIPTION		BOOSTER GAS	TRANSPORT GAS (FV-33)	TRANSPORT GAS (FV-29)	COAL FEED & TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G.	C119 FEED & TRANS. G.
TOTAL	LB/HR	351.39	1185.83	0.00	2232.30	947.00	380.00	846.85
TEMPERATURE	F	140.0	140.0	0.0	150.0	550.0	119.0	233.0
GAS	LB/HR	351.39	1185.83	0.00	808.30	947.00	380.00	367.85
SOLID	LB/HR	0.00	0.00	0.00	1424.00	0.00	0.00	479.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		26.238	26.238	0.000	26.238	31.862	44.011	26.238
CO	VOLUME %	51.98	51.98	0.00	51.98	0.00	0.00	51.98
CO2	VOLUME %	23.52	23.52	0.00	23.52	0.00	100.00	23.52
H2	VOLUME %	20.15	20.15	0.00	20.15	0.00	0.00	20.15
CH4	VOLUME %	2.38	2.38	0.00	2.38	0.00	0.00	2.38
N2	VOLUME %	0.98	0.98	0.00	0.98	0.00	0.00	0.98
O2	VOLUME %	0.00	0.00	0.00	0.00	99.57	0.00	0.00
H2O	VOLUME %	0.20	0.20	0.00	0.20	0.00	0.00	0.20
GAS CHARACTERIZATION								
	H2S PPM	5688.586	5688.586	0.000	5688.586	0.000	0.000	5688.586
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	125.277	422.768	0.000	1332.962	0.000	103.705	452.218
HYDROGEN	LB/HR	6.931	23.388	0.000	79.880	0.000	0.000	8.213
OXYGEN	LB/HR	212.628	717.546	0.000	544.354	947.000	276.295	222.586
NITROGEN	LB/HR	3.666	12.370	0.000	33.494	0.000	0.000	6.520
SULFUR	LB/HR	2.443	8.244	0.000	49.478	0.000	0.000	21.621
ASH	LB/HR	0.000	0.000	0.000	191.101	0.000	0.000	135.222
HEAT CONTENT								
	KBTU/HR	1326.260	4475.672	0.000	21908.285	101.902	3.341	6118.750

TABLE 3-4, Continued

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

STREAM NO.		15	16	17	18	19		
STREAM DESCRIPTION		LIQUID WATER INJECTION	PRODUCT GAS	C119 COLLEC. & TRANS.G.	ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	0.00	6813.79	1362.33	130.00	5.33	0.00	-5.39
TEMPERATURE	F	0.0	1212.0	433.0	318.0	1771.0	0.0	0.0
GAS	LB/HR	0.00	6673.79	928.33	0.00	0.00	0.00	0.00
SOLID	LB/HR	0.00	140.00	434.00	130.00	5.33	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	26.515	26.238	0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	47.36	51.98	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	24.32	23.52	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	18.67	20.15	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	2.05	2.38	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.98	0.98	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	6.91	0.20	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION								
	H2S PPM	0.000	7977.813	5688.586	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	0.000	2322.612	621.878	58.175	3.228	0.000	-1.358
HYDROGEN	LB/HR	0.000	155.079	19.178	0.221	0.005	0.000	9.410
OXYGEN	LB/HR	0.000	4144.842	561.736	0.000	0.000	0.000	-11.132
NITROGEN	LB/HR	0.000	69.508	12.115	0.481	0.046	0.000	-16.925
SULFUR	LB/HR	0.000	67.646	23.727	4.862	0.133	0.000	-5.604
ASH	LB/HR	0.000	43.288	122.518	66.261	1.917	0.000	28.297
HEAT CONTENT								
	KBTU/HR	0.000	26597.717	7879.433	869.193	49.193	425.000	8.814

TABLE 3-5

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

STREAM NO.		1	2	3	4	5	6	7
STREAM DESCRIPTION		STEAM TO GRID	STEAM TO AIR TUBE	BOOSTER STEAM	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL	LB/HR	0.00	403.00	0.00	0.00	154.00	545.39	1022.85
TEMPERATURE	F	0.0	449.0	0.0	0.0	120.0	143.0	583.0
GAS	LB/HR	0.00	403.00	0.00	0.00	164.00	545.39	1022.85
SOLID	LB/HR	0.00	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	0.00
MOLECULAR WEIGHT		0.000	18.016	0.000	0.000	44.011	26.369	26.369
CO	VOLUME %	0.00	0.00	0.00	0.00	0.00	53.03	53.03
CO2	VOLUME %	0.00	0.00	0.00	0.00	100.00	23.18	23.18
H2	VOLUME %	0.00	0.00	0.00	0.00	0.00	19.91	19.91
CH4	VOLUME %	0.00	0.00	0.00	0.00	0.00	2.06	2.06
N2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.97	0.97
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	100.00	0.00	0.00	0.00	0.18	0.18
GAS CHARACTERIZATION								
	H2S PPM	0.000	0.000	0.000	0.000	0.000	6967.190	6967.190
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	0.000	0.000	0.000	0.000	44.757	194.416	364.617
HYDROGEN	LB/HR	0.000	45.096	0.000	0.000	0.000	10.384	19.474
OXYGEN	LB/HR	0.000	357.904	0.000	0.000	119.243	329.486	617.933
NITROGEN	LB/HR	0.000	0.000	0.000	0.000	0.000	5.639	10.575
SULFUR	LB/HR	0.000	0.000	0.000	0.000	0.000	4.620	8.665
ASH	LB/HR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT								
	KBTU/HR	0.000	68.258	0.000	0.000	1.477	2049.988	3979.513

TABLE 3-5, Continued

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

STREAM NO.		8	9	10	11	12	13	14
STREAM DESCRIPTION		BOOSTER GAS	TRANSPORT GAS (FV-33)	TRANSPORT GAS (FV-29)	COAL FEED & TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G.	C119 FEED & TRANS. G.
TOTAL	LB/HR	349.36	895.72	0.00	2197.26	978.00	374.00	348.39
TEMPERATURE	F	143.0	143.0	0.0	144.0	562.0	120.0	291.0
GAS	LB/HR	349.36	895.72	0.00	812.26	978.00	374.00	348.39
SOLID	LB/HR	0.00	0.00	0.00	1385.00	0.00	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		26.369	26.369	0.000	26.369	31.862	44.011	26.369
CO	VOLUME %	53.03	53.03	0.00	53.03	0.00	0.00	53.03
CO2	VOLUME %	23.18	23.18	0.00	23.18	0.00	100.00	23.18
H2	VOLUME %	19.91	19.91	0.00	19.91	0.00	0.00	19.91
CH4	VOLUME %	2.06	2.06	0.00	2.06	0.00	0.00	2.06
N2	VOLUME %	0.97	0.97	0.00	0.97	0.00	0.00	0.97
O2	VOLUME %	0.00	0.00	0.00	0.00	99.57	0.00	0.00
H2O	VOLUME %	0.18	0.18	0.00	0.18	0.00	0.00	0.18
GAS CHARACTERIZATION								
	H2S PPM	6967.190	6967.190	0.000	6967.190	0.000	0.000	6967.190
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	124.537	319.299	0.000	1268.882	0.000	102.068	124.191
HYDROGEN	LB/HR	6.651	17.054	0.000	68.510	0.000	0.000	6.633
OXYGEN	LB/HR	211.059	541.131	0.000	600.680	978.000	271.932	210.472
NITROGEN	LB/HR	3.612	9.261	0.000	30.004	0.000	0.000	3.602
SULFUR	LB/HR	2.960	7.588	0.000	44.969	0.000	0.000	2.951
ASH	LB/HR	0.000	0.000	0.000	182.958	0.000	0.000	0.000
HEAT CONTENT								
	KBTU/HR	1313.160	3366.795	0.000	19872.400	108.029	3.368	1324.510

TABLE 3-5, Continued

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

STREAM NO.		15	16	17	18	19		
STREAM DESCRIPTION		LIQUID WATER INJECTION	PRODUCT GAS	C119 COLLEC. & TRANS.G.	ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	0.00	7006.90	562.86	127.00	6.00	0.00	-5.84
TEMPERATURE	F	0.0	1212.0	109.0	301.0	1765.0	0.0	0.0
GAS	LB/HR	0.00	6662.90	562.86	0.00	0.00	0.00	0.00
SOLID	LB/HR	0.00	344.00	0.00	127.00	6.00	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	25.871	26.369	0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	49.56	53.03	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	21.77	23.18	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	18.52	19.91	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	1.95	2.06	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.91	0.97	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	6.61	0.18	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION								
	H2S PPM	0.000	6892.330	6967.190	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	0.000	2512.126	200.643	20.790	3.178	0.000	-7.628
HYDROGEN	LB/HR	0.000	155.319	10.716	0.102	0.007	0.000	4.406
OXYGEN	LB/HR	0.000	4108.729	340.039	0.000	0.000	0.000	-4.977
NITROGEN	LB/HR	0.000	68.205	5.819	0.165	0.026	0.000	-18.379
SULFUR	LB/HR	0.000	66.444	4.768	8.179	0.183	0.000	-10.899
ASH	LB/HR	0.000	84.314	0.000	97.765	2.606	0.000	-0.944
HEAT CONTENT								
	KBTU/HR	0.000	29878.963	2110.194	349.244	49.160	425.000	-2.260

TABLE 3-6

GASIFIER HEAT AND MATERIAL BALANCES, TEST TP-033-1, STEADY STATE 3A

STREAM NO.	1	2	3	4	5	6	7
STREAM DESCRIPTION	STEAM TO GRID	STEAM TO AIR TUBE	BOOSTER STEAM	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL LB/HR	0.00	501.00	0.00	0.00	213.00	391.42	801.11
TEMPERATURE F	0.0	498.0	0.0	0.0	126.0	139.0	646.0
GAS LB/HR	0.00	501.00	0.00	0.00	213.00	391.42	801.11
SOLID LB/HR	0.00	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	0.00
MOLECULAR WEIGHT	0.000	18.016	0.000	0.000	44.011	25.897	25.897
CO VOLUME %	0.00	0.00	0.00	0.00	0.00	40.84	40.84
CO2 VOLUME %	0.00	0.00	0.00	0.00	100.00	29.65	29.65
H2 VOLUME %	0.00	0.00	0.00	0.00	0.00	24.34	24.34
CH4 VOLUME %	0.00	0.00	0.00	0.00	0.00	4.46	4.46
N2 VOLUME %	0.00	0.00	0.00	0.00	0.00	0.36	0.36
O2 VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O VOLUME %	0.00	100.00	0.00	0.00	0.00	0.16	0.16
GAS CHARACTERIZATION							
H2S PPM	0.000	0.000	0.000	0.000	0.000	1727.237	1727.237
COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON LB/HR	0.000	0.000	0.000	0.000	58.130	136.071	278.494
HYDROGEN LB/HR	0.000	56.062	0.000	0.000	0.000	10.234	20.945
OXYGEN LB/HR	0.000	444.538	0.000	0.000	154.870	242.579	496.482
NITROGEN LB/HR	0.000	0.000	0.000	0.000	0.000	1.543	3.158
SULFUR LB/HR	0.000	0.000	0.000	0.000	0.000	0.837	1.713
ASH LB/HR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT							
KBTU/HR	0.000	96.005	0.000	0.000	2.189	1476.026	3150.121

TABLE 3-6, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST TP-033-1, STEADY STATE 3A

STREAM NO.		8	9	10	11	12	13	14
STREAM DESCRIPTION		BOOSTER GAS	TRANSPORT GAS (FV-33)	TRANSPORT GAS (FV-29)	COAL FEED & TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G.	C119 FEED & TRANS. G.
TOTAL	LB/HR	372.18	979.99	0.00	3392.32	1137.00	367.00	919.18
TEMPERATURE	F	139.0	139.0	0.0	124.0	563.0	126.0	222.0
GAS	LB/HR	372.18	979.99	0.00	921.32	1137.00	367.00	347.18
SOLID	LB/HR	0.00	0.00	0.00	2471.00	0.00	0.00	572.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		25.897	25.897	0.000	25.897	31.862	44.011	25.897
CO	VOLUME %	40.84	40.84	0.00	40.84	0.00	0.00	40.84
CO2	VOLUME %	29.65	29.65	0.00	29.65	0.00	100.00	29.65
H2	VOLUME %	24.34	24.34	0.00	24.34	0.00	0.00	24.34
CH4	VOLUME %	4.46	4.46	0.00	4.46	0.00	0.00	4.46
N2	VOLUME %	0.36	0.36	0.00	0.36	0.00	0.00	0.36
O2	VOLUME %	0.00	0.00	0.00	0.00	99.57	0.00	0.00
H2O	VOLUME %	0.16	0.16	0.00	0.16	0.00	0.00	0.16
GAS CHARACTERIZATION								
	H2S PPM	1727.237	1727.237	0.000	1727.237	0.000	0.000	1727.237
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	129.385	340.679	0.000	1607.182	0.000	100.158	463.320
HYDROGEN	LB/HR	9.731	25.622	0.000	102.172	0.000	0.000	11.537
OXYGEN	LB/HR	230.659	607.342	0.000	1321.427	1137.000	266.842	215.162
NITROGEN	LB/HR	1.467	3.863	0.000	37.238	0.000	0.000	3.256
SULFUR	LB/HR	0.796	2.096	0.000	20.750	0.000	0.000	11.725
ASH	LB/HR	0.000	0.000	0.000	303.192	0.000	0.000	214.042
HEAT CONTENT								
	KBTU/HR	1403.494	3695.506	0.000	22117.469	125.862	3.771	6398.747

TABLE 3-6, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST TP-033-1, STEADY STATE 3A

STREAM NO.		15	16	17	18	19		
STREAM DESCRIPTION		LIQUID WATER INJECTION	PRODUCT GAS	C119 COLLEC. & TRANS.G.	ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	0.00	7273.87	1338.69	164.00	3.64	0.00	3.24
TEMPERATURE	F	0.0	1139.0	469.0	334.0	1427.0	0.0	0.0
GAS	LB/HR	0.00	7000.87	836.69	0.00	0.00	0.00	0.00
SOLID	LB/HR	0.00	273.00	502.00	164.00	3.64	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	25.313	25.897	0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	38.01	40.84	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	27.49	29.65	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	22.77	24.34	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	4.28	4.46	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.33	0.36	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	6.95	0.16	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION								
	H2S PPM	0.000	1972.766	1727.237	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	0.000	2460.840	591.562	26.158	2.216	0.000	1.048
HYDROGEN	LB/HR	0.000	215.699	24.034	0.033	0.015	0.000	-1.472
OXYGEN	LB/HR	0.000	4422.059	518.535	0.000	0.000	0.000	3.453
NITROGEN	LB/HR	0.000	26.730	4.955	0.213	0.016	0.000	36.835
SULFUR	LB/HR	0.000	22.382	11.428	3.756	0.026	0.000	0.860
ASH	LB/HR	0.000	125.607	187.848	133.840	1.367	0.000	13.257
HEAT CONTENT								
	KBTU/HR	0.000	29937.781	7726.079	400.341	33.709	425.000	-0.138

TABLE 3-7

GASIFIER HEAT AND MATERIAL BALANCES, TEST TP-033-1, STEADY STATE 3A-1

STREAM NO.		1	2	3	4	5	6	7
STREAM DESCRIPTION		STEAM TO GRID	STEAM TO AIR TUBE	BOOSTER STEAM	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL	LB/HR	0.00	484.00	0.00	0.00	119.00	404.67	856.28
TEMPERATURE	F	0.0	477.0	0.0	0.0	118.0	144.0	634.0
GAS	LB/HR	0.00	484.00	0.00	0.00	119.00	404.67	856.28
SOLID	LB/HR	0.00	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	0.00
MOLECULAR WEIGHT		0.000	18.016	0.000	0.000	44.011	24.683	24.683
CO	VOLUME %	0.00	0.00	0.00	0.00	0.00	41.05	41.05
CO2	VOLUME %	0.00	0.00	0.00	0.00	100.00	26.61	26.61
H2	VOLUME %	0.00	0.00	0.00	0.00	0.00	27.19	27.19
CH4	VOLUME %	0.00	0.00	0.00	0.00	0.00	4.19	4.19
N2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.56	0.56
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	100.00	0.00	0.00	0.00	0.24	0.24
GAS CHARACTERIZATION								
	H2S PPM	0.000	0.000	0.000	0.000	0.000	1346.723	1346.723
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	0.000	0.000	0.000	0.000	32.476	141.474	299.360
HYDROGEN	LB/HR	0.000	54.160	0.000	0.000	0.000	11.882	25.143
OXYGEN	LB/HR	0.000	429.340	0.000	0.000	86.524	247.894	524.546
NITROGEN	LB/HR	0.000	0.000	0.000	0.000	0.000	2.579	5.458
SULFUR	LB/HR	0.000	0.000	0.000	0.000	0.000	0.708	1.498
ASH	LB/HR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT								
	KBTU/HR	0.000	88.395	0.000	0.000	1.021	1645.001	3618.780

TABLE 3-7, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST TP-033-1, STEADY STATE 3A-1

STREAM NO.	8	9	10	11	12	13	14
STREAM DESCRIPTION	BOOSTER GAS	TRANSPORT GAS (FV-33)	TRANSPORT GAS (FV-29)	COAL FEED & TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G.	C119 FEED & TRANS. G.
TOTAL LB/HR	302.33	795.25	0.00	3304.41	1053.00	374.00	87.32
TEMPERATURE F	144.0	144.0	0.0	116.0	559.0	118.0	70.0
GAS LB/HR	302.33	795.25	0.00	946.41	1053.00	374.00	87.32
SOLID LB/HR	0.00	0.00	0.00	2358.00	0.00	0.00	0.00
LIQUID LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT	24.683	24.683	0.000	24.683	31.862	44.011	24.683
CO VOLUME %	41.05	41.05	0.00	41.05	0.00	0.00	41.05
CO2 VOLUME %	26.61	26.61	0.00	26.61	0.00	100.00	26.61
H2 VOLUME %	27.19	27.19	0.00	27.19	0.00	0.00	27.19
CH4 VOLUME %	4.19	4.19	0.00	4.19	0.00	0.00	4.19
N2 VOLUME %	0.56	0.56	0.00	0.56	0.00	0.00	0.56
O2 VOLUME %	0.00	0.00	0.00	0.00	99.57	0.00	0.00
H2O VOLUME %	0.24	0.24	0.00	0.24	0.00	0.00	0.24
GAS CHARACTERIZATION							
H2S PPM	1346.723	1346.723	0.000	1346.723	0.000	0.000	1346.723
COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON LB/HR	105.695	278.024	0.000	1556.560	0.000	102.068	30.527
HYDROGEN LB/HR	8.877	23.351	0.000	122.110	0.000	0.000	2.564
OXYGEN LB/HR	185.202	487.161	0.000	1337.387	1053.000	271.932	53.490
NITROGEN LB/HR	1.927	5.069	0.000	24.897	0.000	0.000	0.557
SULFUR LB/HR	0.529	1.391	0.000	18.397	0.000	0.000	0.153
ASH LB/HR	0.000	0.000	0.000	244.760	0.000	0.000	0.000
HEAT CONTENT							
KBTU/HR	1228.980	3232.751	0.000	22474.744	115.561	3.210	352.961

TABLE 3-7, Continued

GASIFIER HEAT AND MATERIAL BALANCES, TEST TP-033-1, STEADY STATE 3A-1

STREAM NO.		15	16	17	18	19		
STREAM DESCRIPTION		LIQUID WATER INJECTION	PRODUCT GAS	C119 COLLEC. & TRANS.G.	ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	0.00	7176.88	207.50	176.00	5.00	0.00	2.76
TEMPERATURE	F	0.0	1043.0	82.0	352.0	1435.0	0.0	0.0
GAS	LB/HR	0.00	6890.88	207.50	0.00	0.00	0.00	0.00
SOLID	LB/HR	0.00	286.00	0.00	176.00	5.00	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	24.236	24.683	0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	36.30	41.05	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	24.57	26.61	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	23.78	27.19	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	3.69	4.19	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.50	0.56	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	10.99	0.24	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION								
	H2S PPM	0.000	1637.784	1346.723	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	0.000	2347.469	72.542	36.203	3.388	0.000	3.400
HYDROGEN	LB/HR	0.000	243.682	6.093	0.246	0.019	0.000	-0.787
OXYGEN	LB/HR	0.000	4386.496	127.110	0.000	0.000	0.000	3.493
NITROGEN	LB/HR	0.000	40.603	1.323	0.229	0.016	0.000	-4.158
SULFUR	LB/HR	0.000	19.936	0.363	1.866	0.062	0.000	1.982
ASH	LB/HR	0.000	139.196	0.000	137.456	1.516	0.000	-13.649
HEAT CONTENT								
	KBTU/HR	0.000	29524.322	839.518	547.403	51.182	425.000	4.194

TABLE 3-8

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

STREAM NO.	1	2	3	4	5	6	7
STREAM DESCRIPTION	STEAM TO GRID	STEAM TO AIR TUBE	BOOSTER STEAM	AIR	CO2 PURGE	GRID GAS	SPARGER RING
TOTAL LB/HR	0.00	0.00	0.00	0.00	1253.00	474.28	1055.42
TEMPERATURE F	0.0	0.0	0.0	0.0	143.0	136.0	622.0
GAS LB/HR	0.00	0.00	0.00	0.00	1253.00	474.28	1055.42
SOLID LB/HR	0.00	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	0.00
MOLECULAR WEIGHT	0.000	0.000	0.000	0.000	44.011	33.286	33.286
CO VOLUME %	0.00	0.00	0.00	0.00	0.00	32.55	32.55
CO2 VOLUME %	0.00	0.00	0.00	0.00	100.00	53.26	53.26
H2 VOLUME %	0.00	0.00	0.00	0.00	0.00	11.51	11.51
CH4 VOLUME %	0.00	0.00	0.00	0.00	0.00	2.05	2.05
N2 VOLUME %	0.00	0.00	0.00	0.00	0.00	0.37	0.37
O2 VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O VOLUME %	0.00	0.00	0.00	0.00	0.00	0.19	0.19
GAS CHARACTERIZATION							
H2S PPM	0.000	0.000	0.000	0.000	0.000	788.484	788.484
COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS							
CARBON LB/HR	0.000	0.000	0.000	0.000	341.955	150.352	334.576
HYDROGEN LB/HR	0.000	0.000	0.000	0.000	0.000	4.559	10.145
OXYGEN LB/HR	0.000	0.000	0.000	0.000	911.045	317.477	706.477
NITROGEN LB/HR	0.000	0.000	0.000	0.000	0.000	1.470	3.271
SULFUR LB/HR	0.000	0.000	0.000	0.000	0.000	0.360	0.802
ASH LB/HR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HEAT CONTENT KBTU/HR	0.000	0.000	0.000	0.000	17.408	887.701	2112.462

TABLE 3-8, Continued

GASIFICATION HEAT AND MATERIAL BALANCES, TEST TP-033-1, STEADY STATE 3B-1

STREAM NO.		8	9	10	11	12	13	14
STREAM DESCRIPTION		BOOSTER GAS	TRANSPORT GAS (FV-33)	TRANSPORT GAS (FV-29)	COAL FEED & TRANS. G.	OXYGEN TO TUBE	C120 CYCLONE TRANS. G.	C119 FEED & TRANS. G.
TOTAL	LB/HR	361.98	1167.72	0.00	3383.02	1060.00	377.00	245.32
TEMPERATURE	F	136.0	136.0	0.0	116.0	558.0	143.0	327.0
GAS	LB/HR	361.98	1167.72	0.00	1111.02	1060.00	377.00	245.32
SOLID	LB/HR	0.00	0.00	0.00	2272.00	0.00	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		33.286	33.286	0.000	33.286	31.862	44.011	33.286
CO	VOLUME %	32.55	32.55	0.00	32.55	0.00	0.00	32.55
CO2	VOLUME %	53.26	53.26	0.00	53.26	0.00	100.00	53.26
H2	VOLUME %	11.51	11.51	0.00	11.51	0.00	0.00	11.51
CH4	VOLUME %	2.05	2.05	0.00	2.05	0.00	0.00	2.05
N2	VOLUME %	0.37	0.37	0.00	0.37	0.00	0.00	0.37
O2	VOLUME %	0.00	0.00	0.00	0.00	99.57	0.00	0.00
H2O	VOLUME %	0.19	0.19	0.00	0.19	0.00	0.00	0.19
GAS CHARACTERIZATION								
	H2S PPM	788.484	788.484	0.000	788.484	0.000	0.000	788.484
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	114.751	370.176	0.000	1577.493	0.000	102.887	77.768
HYDROGEN	LB/HR	3.480	11.225	0.000	105.195	0.000	0.000	2.358
OXYGEN	LB/HR	242.304	781.549	0.000	1445.292	1060.000	274.113	164.212
NITROGEN	LB/HR	1.122	3.620	0.000	21.847	0.000	0.000	0.760
SULFUR	LB/HR	0.275	0.887	0.000	15.385	0.000	0.000	0.186
ASH	LB/HR	0.000	0.000	0.000	217.658	0.000	0.000	0.000
HEAT CONTENT								
	KBTU/HR	677.510	2185.581	0.000	21054.795	116.077	5.238	471.156

TABLE 3-8, Continued

GASIFICATION HEAT AND MATERIAL BALANCES, TEST TP-033-1, STEADY STATE 3B-1

STREAM NO.		15	16	17	18	19		
STREAM DESCRIPTION		LIQUID WATER INJECTION	PRODUCT GAS	C119 COLLEC. & TRANS.G.	ASH WITH-DRAWAL	BED SAMPLE (SC-22)	HEAT LOSS	TOTAL CLOSURE
TOTAL	LB/HR	0.00	8405.91	237.69	140.00	6.00	0.00	6.27
TEMPERATURE	F	0.0	1061.0	74.0	332.0	1430.0	0.0	0.0
GAS	LB/HR	0.00	8040.91	237.69	0.00	0.00	0.00	0.00
SOLID	LB/HR	0.00	365.00	0.00	140.00	6.00	0.00	0.00
LIQUID	LB/HR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MOLECULAR WEIGHT		0.000	29.889	33.286	0.000	0.000	0.000	0.000
CO	VOLUME %	0.00	37.78	32.55	0.00	0.00	0.00	0.00
CO2	VOLUME %	0.00	38.82	53.26	0.00	0.00	0.00	0.00
H2	VOLUME %	0.00	12.57	11.51	0.00	0.00	0.00	0.00
CH4	VOLUME %	0.00	2.19	2.05	0.00	0.00	0.00	0.00
N2	VOLUME %	0.00	0.39	0.37	0.00	0.00	0.00	0.00
O2	VOLUME %	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	VOLUME %	0.00	8.09	0.19	0.00	0.00	0.00	0.00
GAS CHARACTERIZATION								
	H2S PPM	0.000	1176.448	788.484	0.000	0.000	0.000	0.000
	COS PPM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ELEMENTS								
CARBON	LB/HR	0.000	2728.718	75.349	14.000	3.748	0.000	8.083
HYDROGEN	LB/HR	0.000	137.964	2.285	0.154	0.024	0.000	-2.530
OXYGEN	LB/HR	0.000	5316.744	159.103	0.000	0.157	0.000	7.227
NITROGEN	LB/HR	0.000	30.566	0.737	0.098	0.026	0.000	2.068
SULFUR	LB/HR	0.000	16.535	0.181	1.428	0.042	0.000	-1.628
ASH	LB/HR	0.000	177.645	0.000	124.320	2.003	0.000	-39.655
HEAT CONTENT								
	KBTU/HR	0.000	24024.158	441.249	222.359	56.010	425.000	8.570

SECTION 4.0

PROCESS ANALYSIS

4.1 ENVIRONMENTAL CHARACTERIZATION RESULTS

With the overall objective of minimizing scaleup risks, the environmental, health and safety program was designed to build a relevant data base through raw gas and wastewater characterization.

Data were collected during three separate PDU test periods, TP-032-1, TP-032-2, and TP-033-1. Upper Freeport and Brookville A seam coal feedstocks were used at a freeboard temperature of 1800°F and a system pressure of 230 psig, and North Dakota lignite feedstock was used at a freeboard temperature of 1600°F and a system pressure of 230 psig as shown in Table 4-1. PDU streams sampled were raw gas from the C-115 gasifier (with the mini scrubber shown in Figure 4-1), separator pit and make-up water. Parameters, analytical methods and detection limits for the raw gas analyses are detailed in Table 4-2.

Summary results of these raw gas and wastewater characterization studies are presented in Tables 4-3 through 4-6. Data ranges were developed by reviewing all raw data and no attempt was made to exclude questionable data. Results from TP-032-1 and TP-032-2, Table 4-3, indicate that the raw product gas does not contain very high levels of toxic organic compounds. Results from TP-033-1 show that benzene, the only process -attributable organic compound in the raw product gas, was detected only during the gasification of North Dakota lignite though it was present in all separator pit samples taken. This indicates the benzene production and fate within the PDU are complex phenomena which will need further data and analyses to be clearly understood.

Figure 4-1. Miniscrubber Sampler

TABLE 4-1

GENERAL PROCESS CONDITIONS DURING PDU CHARACTERIZATION STUDIES

<u>PDU Test No.</u>	<u>Set Points</u>	<u>Coal</u>	<u>Temperature (°F)</u>	<u>Pressure (psig)</u>
TP-032-1	1B	Upper Freeport (Pennsylvania)	1800	230
TP-032-2	1 and 2	Upper Freeport (Pennsylvania)	1800	230
TP-033-1	1, 1A and 2	Brookville (Pennsylvania)	1800	230
	3	North Dakota Lignite	1600	230

TABLE 4-2

PARAMETERS, ANALYTICAL METHODS AND DETECTION LIMITS
FOR RAW GAS ANALYSIS

<u>Parameter</u>	<u>Method of Analysis*</u>	<u>Detection Limit</u>	
<u>Deionized Water Scrub</u>			
<u>Unpreserved</u>			
pH	Standard Method 423	+0.1	unit
TDS	Standard Method 209	1.0	mg/l
Alkalinity	Standard Method 403	1.0 mg/l as	CaCO ₃
BOD	Standard Method 507	1.0	mg/l
Chloride	Standard Method 407	1.0	mg/l
<u>Nitric Acid Addition</u>			
Boron	Standard Method 404A	0.02 mg/l	
Antimony	EPA Method 94	0.1	mg/l
Arsenic	EPA Method 95	0.001	mg/l
Beryllium	EPA Method 99	0.002	mg/l
Cadmium	EPA Method 101	0.01	mg/l
Chromium	EPA Method 105	0.01	mg/l
Copper	EPA Method 108	0.01	mg/l
Lead	EPA Method 112	0.03	mg/l
Mercury	Standard Method 303F	0.0005	mg/l
Nickel	EPA Method 141	0.03	mg/l
Selenium	EPA Method 145	0.02	mg/l
Silver	EPA Method 146	0.01	mg/l
Thallium	EPA Method 149	0.1	mg/l
Zinc	EPA Method 155	0.01	mg/l
<u>Acid Scrub</u>			
COD	Standard Method 508	1.0	mg/l
TOC	Standard Method 505	1.0	mg/l
Total Phenols	EPA Method 241	0.05	mg/l
Thiocyanate	Standard Method 412K	0.1	mg/l
Ammonia - nitrogen	Standard Method 417B	0.02	mg/l
Organic - nitrogen	Standard Method 420A	0.02	mg/l
Sodium	EPA Method 147	0.002	mg/l
Calcium	EPA Method 114	0.002	mg/l
Potassium	EPA Method 143	0.01	mg/l
Magnesium	EPA Method 114	0.001	mg/l
Iron, Total	EPA Method 110	0.01	mg/l

TABLE 4-2 (continued)

PARAMETERS, ANALYTICAL METHODS AND DETECTION LIMITS
FOR RAW GAS ANALYSIS

<u>Parameter</u>	<u>Method of Analysis*</u>	<u>Detection Limit</u>	
<u>Base Scrub</u>			
<u>Unpreserved</u>			
Sulfides	Standard Method 376.2	0.02	mg/l
Thiosulfate	EPA Method 376.2	0.1	mg/l
Sulfites	EPA Method 377.1	2.0	mg/l
Sulfates	Standard Method 427	1.0	mg/l
<u>Zinc Acetate Addition</u>			
Total Cyanides	Standard Method 412B	0.005	mg/l
<u>Methylene Chloride Scrub</u>			
<u>Purgeable Organics</u>	EPA Method 1624		
Acrolein		0.01	mg/l
Acrylonitrile		0.01	mg/l
Benzene		0.01	mg/l
Bis (chloromethyl) ether		0.01	mg/l
Bromoform		0.01	mg/l
Carbon tetrachloride		0.01	mg/l
Chlorobenzene		0.01	mg/l
Chlorodibromomethane		0.01	mg/l
Chloroethane		0.01	mg/l
2-Chloroethylvinyl ether		0.01	mg/l
Chloroform		0.01	mg/l
Dichlorobromomethane		0.01	mg/l
Dichlorodifluoromethane		0.01	mg/l
1, 1-Dichloroethane		0.01	mg/l
1, 2-Dichloroethane		0.01	mg/l
1, 1-Dichloroethylene		0.01	mg/l
1, 2-Dichloropropane		0.01	mg/l
1, 3-Dichloroprophylene		0.01	mg/l
Ethylbenzene		0.01	mg/l
Methyl bromide		0.01	mg/l
Methyl chloride		0.01	mg/l
Methylene chloride		0.01	mg/l
1, 1, 2, 2-Tetrachloroethane		0.01	mg/l
Tetrachloroethylene		0.01	mg/l
Toluene		0.01	mg/l
1, 2-Trans-dichloroethylene		0.01	mg/l

TABLE 4-2 (continued)
PARAMETERS, ANALYTICAL METHODS AND DETECTION LIMITS
FOR RAW GAS ANALYSIS

<u>Parameter</u>	<u>Method of Analysis*</u>	<u>Detection Limit</u>	
1, 1, 1-Trichloroethane		0.01	mg/l
1, 1, 2-Trichloroethane		0.01	mg/l
Trichloroethylene		0.01	mg/l
Trichlorofluoromethane		0.01	mg/l
Vinyl chloride		0.01	mg/l
<u>Base/Neutrals</u>			
Acenaphthene		0.01	mg/l
Acenaphthylene		0.01	mg/l
Anthracene		0.01	mg/l
Benzo (a) anthracene		0.01	mg/l
Benzo (a) pyrene		0.01	mg/l
3, 4-Benzofluoranthene		0.01	mg/l
Benzo (ghi) perylene		0.025	mg/l
Benzo (k) fluoranthene		0.01	mg/l
Bis (2-chloroethoxy) methane		0.01	mg/l
Bis (2-chloroethyl) ether		0.01	mg/l
Bis (2-chloroisopropyl) ether		0.01	mg/l
Bis (2-ethylhexyl) phthalate		0.01	mg/l
4-Bromophenyl phenyl ether		0.01	mg/l
Butyl benzyl phthalate		0.01	mg/l
2-Chloronaphthalene		0.01	mg/l
4-Chlorophenyl phenyl ether		0.01	mg/l
Chrysene		0.01	mg/l
Dibenzo (a, h) anthracene		0.025	mg/l
1, 2-Dichlorobenzene		0.01	mg/l
1, 3-Dichlorobenzene		0.01	mg/l
1, 4-Dichlorobenzene		0.01	mg/l
3, 3-Dichlorobenzidine		0.01	mg/l
Diethyl phthalate		0.01	mg/l
Dimethyl phthalate		0.01	mg/l
Di-n-butyl phthalate		0.01	mg/l
2, 4-Dinitrotoluene		0.01	mg/l
2, 6-Dinitrotoluene		0.01	mg/l
Di-n-octyl phthalate		0.01	mg/l
1, 2-Diphenylhydrazine		0.01	mg/l
Fluoranthene		0.01	mg/l
Fluorene		0.01	mg/l
Hexachlorobenzene		0.01	mg/l
Hexachlorobutadiene		0.01	mg/l
Hexachlorocyclopentadiene		0.01	mg/l
Hexachloroethane		0.01	mg/l

TABLE 4-2 (continued)

PARAMETERS, ANALYTICAL METHODS AND DETECTION LIMITS
FOR RAW GAS ANALYSIS

<u>Parameter</u>	<u>Method of Analysis*</u>	<u>Detection Limit</u>	
Indeno (1, 2, 3-cd) pyrene		0.025	mg/l
Isophorone		0.01	mg/l
Naphthalene		0.01	mg/l
Nitrobenzene		0.01	mg/l
N-Nitrosodimethylamine		0.01	mg/l
N-Nitrosodi-n-propylamine		0.01	mg/l
N-Nitrosodiphenylamine		0.01	mg/l
Phenanthrene		0.01	mg/l
Pyrene		0.01	mg/l
1, 2, 4-Trichlorobenzene		0.01	mg/l
<u>Acids</u>	EPA Method 1625		
2-Chlorophenol		0.025	mg/l
2, 4-Dichlorophenol		0.025	mg/l
2, 4-Dimethylphenol		0.025	mg/l
4, 6-Dinitro-o-cresol		0.025	mg/l
2, 4-Dinitrophenol		0.025	mg/l
2-Nitrophenol		0.025	mg/l
4-Nitrophenol		0.025	mg/l
p-Chloro-m-cresol		0.025	mg/l
Pentachlorophenol		0.025	mg/l
Phenol		0.025	mg/l
2, 4 6-Trichlorophenol		0.025	mg/l

* Standard Methods - American Public Health Association, American Water Works Association and Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater, 15th Edition, Washington, D. C., American Public Health Association, 1980.

EPA Methods = Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, U.S. EPA Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, March 1979.

TABLE 4-3

SUMMARY RESULTS OF TEST POINTS TP-032-1 AND TP-032-2
CHARACTERIZATION STUDY: UPPER FREEPORT COAL

<u>Parameter*</u>	<u>Miniscrubber**(ppm)</u>
pH (units)	-†
Alkalinity	20-200
Ammonia-N	100-1000
BOD	130-300
COD	<20-1400
TOC	1350-3500
CN	50-75
SCN	<20
Organic-N	3-11
Sulfide	300-500
Sulfite	100-200
Thiosulfate	400-500
Sulfate	500-2000
Chloride	<19-<31
Total Dissolved Solids	20-53
Calcium	<1-20
Iron	50-200
Magnesium	<1-10
Mercury	<0.001-0.015†
Nickel	<0.6 ^Δ
Zinc	<.01-0.3
Priority Organics	
Volatiles	<3.12-<31.15 ^{ΔΔ}
Acids	<0.19-<5.97 ^{ΔΔ}
Base/Neutrals	<0.19-<0.24 ^{ΔΔ}
Cyclohexane	Present
Alkyl Alcohols	Present
Cyclo Tetrasiloxane	Present
Alkanes	Present

-
- * Trace elements not reported if below detection limits
 ** Ppm, wt/wt raw gas. Sample size = 3
 † Not analyzed
 †† Includes a detectable value of 0.015 ppm
 Δ Includes a detectable value of 0.26 ppm
 ΔΔ Instrument detection limit

TABLE 4-4

SUMMARY RESULTS OF TEST POINT TP-033-1 CHARACTERIZATION STUDY:
SET POINTS 1, 1A AND 2 - BROOKVILLE A SEAM COAL*

Parameter	Miniscrubber	Separator Pit
	(ppm) <u>3</u>	mg/l <u>2</u>
pH (units)	4.9-5.8**	7.1-7.6
Alkalinity	<25	-†
Ammonia-N	100-120	-
BOD	<10-30	2-19
COD	<20-300	-
TOC	1970-2420	170-174
CN	<60	2.18-6
SCN	<20	8-51
Organic-N	4	-
Kjeldahl-N	3-25	-
Sulfide	300-700	<0.03
Sulfate	20-400	-
Thiosulfate	<20-60	<1
Total Dissolved Solids	<25	-
Antimony	<3.2	<0.2-0.4
Beryllium	<0.12	<0.005-0.016
Boron	25	1.6-2.4
Cadmium	<0.12	<0.005-0.2
Calcium	2-4	-
Chromium	<0.32	<0.002-0.68
Copper	<0.25	<0.002-0.44
Iron	10-60	-
Lead	<1.25	<0.05-0.39
Magnesium	1-3	<0.008
Mercury	<0.02	<0.002-0.49
Nickel	<0.48	-
Potassium	<0.2-0.7	-
Sodium	2-60	<0.002-0.46
Zinc	<0.5-1.0	<0.002-0.46

* Trace organics are reported in Table 4-6. Trace elements are reported if below detection limit in all samples.

† Not analyzed.

** As measured in deionized water scrubber.

TABLE 4-5

SUMMARY RESULTS OF TEST POINT TP-033-1 CHARACTERIZATION STUDY:
SET POINT 3 - NORTH DAKOTA LIGNITE*

<u>Parameter</u>	<u>Miniscrubber (ppm)</u>	<u>Pit (mg/l)</u>
pH (units)	4.8**	8.6
Alkalinity	<20	- ⁺
Ammonia-N	185	-
BOD	<20	6
COD	100	6
TOC	1100	380
CN	40	<1
SCN	<10	60
Organic-N	18.5	-
Kjeldahl-N	<22.3	-
Sulfide	1100	<0.03
Sulfite	<40	-
Thiosulfate	20	3
Sulfate	260	-
Total Dissolved Solids	<20	-
Arsenic	<0.16	<0.05
Calcium	1	-
Iron	0.5	-
Magnesium	0.5	-
Selenium	0.5	-
Sodium	5	-

-
- * Sample size = 1. Trace organic values reported on Table 4-6. Trace elements not reported if below the detection limit in both samples.
 ** As measured in the deionized scrub.
 + Not analyzed.

TABLE 4-6

SUMMARY RESULTS OF TEST POINT TP-033-1 CHARACTERIZATION STUDY:
TRACE ORGANICS

Parameter [†]	Brookville Coal*		North Dakota Lignite**	
	Miniscrubber Separator (ppm)	Pit (mg/l)	Miniscrubber Separator (ppm)	Pit (mg/l)
<u>Priority Pollutants</u>				
Benzene	0.48-0.59	0.08-0.68	630	0.3
Acenaphthene	<0.03-<0.043	0.02-0.04	<0.34	0.03
Acenaphthylene	<0.03-<0.043	0.02-0.04	<0.034	0.02
Fluoranthene	<0.03-<0.043	<0.01-0.01	<0.01	<0.01
Fluorene	<0.03-<0.043	<0.01	0.02	0.02
Naphthalene	<0.03-<0.043	0.3-0.6	0.5	0.5
Phenanthrene	<0.03-<0.043	0.02-0.03	0.04	0.04
Pyrene	<0.03-<0.043	0.06-0.13	0.02	0.02
<u>Others</u>				
Methanethiol		Present		
Thiophene		Present		
Dimethyl Disulfide		Present		
Chlorinated Propane		Present		
Benzenes (Ethynyl, Methyl)		Present		Present
Acetic Acid Esters		Present		
Tetrahydro Thiorandones		Present		Present
Trithiolanes		Present		
Cyclopropanes		Present		
Hexathiophene				Present
Pyridenes				Present
Cyclohexane				Present
Alkyl Alcohol				Present
Tetrahydronaphthalene				Present
Aliphatic Alcohol				Present
Alkylated PAH				Present

* Includes samples from Set Points 1, 1A and 2

** Not reported if below the detection limit

† Not reported if below the detection limit.

Conclusions

- The concentration range for parameters of environmental, health and safety concern in the raw gas have been identified for dissolvable gases, sulfur compounds, cyanides, volatile organics, PAH compounds, and trace elements.
- Observed concentration ranges are typical of a high-temperature fluidized-bed gasifier system (e.g., low concentrations of toxic organics and trace elements).
- Data do not suggest that any unique treatability problems will be encountered for the gasifier (e.g., benzene levels can be handled by steam stripping and PAH compounds can be treated by carbon absorption).
- A lower detection level will be required to quantify more nitrogen/sulfur species in the raw gas.
- Concentration of non-priority pollutant organics must be quantified.
- Analysis of some routine parameters could be improved.

4.2 COAL GAS COMBUSTION RESULTS

Results of the concurrent combustion tests TP-033-1 and DOE-1-GF2 performed on coal gas obtained from PDU operation using North Dakota lignite are presented herein.

The purpose of test plan DOE-1-GF2 was to evaluate the combustor emissions data generated from combustion of both low- and medium-Btu preheated gas against emissions data obtained from previous tests using ambient temperature fuel. Work completed was successful in that ignition and high temperature operation was achieved for medium-Btu gas, 250 Btu/scf; however, ignition could not be achieved for low-Btu gas in the range of 75 Btu/scf. Preheated fuel temperatures were 500, 750 and 950°F.

This test obtained combustor emissions data on burning fuel preheated to various temperatures for both low and medium Btu gas and compared this to data generated in previous combustion tests using fuel at ambient temperatures. The "B-4" combustor, on test passage 1, had been characterized using liquid fuels, No. 2 fuel oil and coal-derived oil, and using coal gas from the PDU under test plan TP-031-1.

Prior to this test, the piping system for the Trane Thermal Model 1500 heat exchanger was connected to link the PDU gas supply line to the test passages. A return line was installed as a bypass to divert all or part of the gas flow, depending on test passage requirements, from the preheater back to the thermal oxidizer at the PDU. This preheater can be fired on either No. 2 fuel oil or natural gas and has the following operating parameters:

Temperature	200°F - 1000°F
Pressure, max.	325 psig
Mass flow	250 lb/hr - 3000 lb/hr
Duty	1.0 MM Btu/hr

The heat exchanger in the gas return line can handle a maximum gas flow of 600 lb/hr with a 600°F gas inlet temperature limitation. Instrumentation will automatically close off the PDU gas supply to the preheater at any temperature exceeding 600°F at the heat exchanger.

A flow loop consisting of a flow control valve, an orifice, a thermocouple and pressure and differential pressure transmitters is located in the gas line and controls the mass gas flow to the preheater. Adjustment of flow can be handled either in an automatic or manual mode by the control room operator under the direction of the test engineer.

Line size for the preheater is 3-inch 304SS SCH 40. The orifice size chosen, based on anticipated operating conditions, was 1 inch. Test conditions as outlined in the test plan called for preheated fuel combustion at both low and medium Btu gas values; however, ignition could not be achieved using coal gas generated from Brookville A seam coal having a heating value in the range of 75 Btu/scf. Several attempts were made for ignition without success; therefore, combustion testing on low Btu gas was postponed to a later date.

On August 12, coal gas derived from North Dakota lignite with a heating value of approximately 250 Btu/scf was supplied from the PDU facility and ignition was achieved. The 3-inch preheater line size caused problems while trying for ignition such that when the flow control valve was open sufficiently to pass any flow, the amount passed would be too much and the passage temperature following ignition would rapidly rise to a temperature that would burn out the passage thermocouples.

A total of three different fuel preheat temperatures were tested at the same passage pressure, 140 psig. Those temperatures were 500°F, 750°F and 1000°F. At the lower two temperatures, two different reference velocities were tested, 60 and 80 ft/sec. Tables 4-7 and 4-8 show the data obtained at these conditions. A total of 27 set points were taken over the entire range. At each set of conditions (i.e., maintaining constant fuel temperature, passage pressure and reference velocity) the fuel/air ratio was adjusted to give a range of combustor outlet temperatures from 1175°F to 1975°F

Also shown in Table 4-7 is data on NO_x and CO emissions at ambient temperatures. As can be seen in comparing the preheated fuel to the ambient temperature fuel, NO_x emissions. The preheated fuel were approximately 30 ppmv higher than the ambient fuel; whereas, CO emissions were about the same or slightly less for the preheated fuel data points at a reference velocity of 80 ft/sec. No data exist for ambient temperature fuel combustion for reference velocities of 60 ft/sec to make any comparisons.

TABLE 4-7

OPERATING CONDITIONS AND EMISSION DATA FOR MEDIUM BTU GAS

<u>T_{FUEL}</u> <u>°F</u>	<u>V_{REF}</u> <u>Ft/sec</u>	<u>T_{OUT}</u> <u>°F</u>	<u>Pressure</u> <u>Psig</u>	<u>NO_x</u> <u>ppmv</u>	<u>CO</u> <u>ppmv</u>
950	80	1900	140	125	15.5
950	80	1750	140	73	17.0
950	80	1550	140	59	20.0
950	80	1300	140	38	22.4
750	80	1900	140	88	17.3
750	80	1800	140	80	18.0
750	80	1650	140	61	19.0
750	80	1550	140	66	21.5
750	80	1350	140	37	23.3
500	80	1900	140	108	16.3
500	80	1750	140	90	16.5
500	80	1600	140	81	20.0
500	80	1600	140	75	21.8
500	80	1500	140	59	22.4
500	80	1400	140	40	22.8
500	80	1250	140	32	21.2
32	80	2125	140	91	24.0
32	80	2000	140	93	24.5
32	80	1900	140	90	24.5
32	80	1825	140	82	25.5
32	80	1775	140	65	27.0
32	80	1700	140	66	27.5

TABLE 4-8
OPERATING CONDITIONS AND EMISSION DATA FOR MEDIUM BTU GAS

<u>T_{FUEL}</u> <u>°F</u>	<u>V_{REF}</u> <u>Ft/sec</u>	<u>T_{OUT}</u> <u>°F</u>	<u>Pressure</u> <u>Psig</u>	<u>NO_x</u> <u>ppmv</u>	<u>CO</u> <u>ppmv</u>
750	60	1975	140	110	17.2
750	60	1975	140	125	18.0
750	60	1775	140	105	15.5
750	60	1500	140	76	16.5
750	60	1350	140	61	17.0
500	60	1925	140	99	17.2
500	60	1775	140	92	15.4
500	60	1650	140	73	16.0
500	60	1600	140	60	15.5
500	60	1425	140	43	15.1
500	60	1175	140	26	12.6

Figures 4-2 and 4-3 plot NO_x emissions at various average combustor outlet temperatures. Figure 4-2 shows the increase in NO_x emissions between the maximum preheat temperature of 950°F and ambient temperature of 32°F at a reference velocity of 80 ft/sec. It also shows all three preheat temperatures and their inter-relationship to NO_x emissions. As expected, the data points for 750°F fall between the points for 950°F and 32°F; however, the data points for 500°F do not conform as NO_x emissions are higher for 500°F than for 750°F and are even higher than for 950°F except at combustor outlet temperatures exceeding 1800°F.

Following completion of the combustion test, the combustor can and the fuel nozzle were removed from the passage and inspected. No local overheating of the combustor can or fuel nozzle had occurred and there was no iron oxide deposits observed on the combustor walls, as had been the case for all previous gaseous tests.

The Trane preheater operated efficiently over its entire temperature range and had quick response to changes in temperature settings.

4.3 FINES ELUTRIATION AND CONSUMPTION RESULTS

PDU tests TP-032-1 and TP-032-2, run in April and May of 1982, were designed to gather fines elutriation and consumption data. Coal feedstock for TP-033-1 and part of TP-032-2 was Upper Freeport E-seam coal. Western Kentucky #9 coal was the feedstock for the latter part of TP-032-2. Analysis of data from these tests show that:

- The fines elutriation rate appears to be proportional to the freeboard velocity to the 2.2 power for Upper Freeport E-seam coal.
- The gross per pass fines consumption rate for Western Kentucky primary fines recycled axially was 62%. The consumption rates for other modes of recycle (radial, annulus or combination) ranged from 13 to 65%.
- The average particle size of the bed was smaller for steady states with fines recycle than steady states without fines recycle.

Based on the data collected, it is recommended that further investigation be made to determine the effect of fines recycle on bed density, and that an accurate and reliable fines flow measurement device be found to determine fines elutriation and consumption rates.

TP-032-1 and TP-032-2

The test conducted during April and early May, 1982, TP-032-1, was run with Upper Freeport E-seam coal with no fines recycle. Three steady states were achieved at similar freeboard temperatures but various freeboard velocities. Since no fines were recycled, these steady states provided data on the elutriation rate of the coal as a function of the freeboard velocity. Results

Figure 4-2. Medium BTU Gas Results 8/12/82 Test NO_X Vs. T_{AVG}

Figure 4-3. Medium BTU Gas Results 8/12/82 NO_x Vs. T_{AVG}

are tabulated in Table 4-9. The fines loss rate was determined by ash balance. Data in Table 4-9 are plotted in Figure 4-4 and show that the elutriation rate is proportional to the velocity raised to the 2.2 power, or:

$$K \propto \mu^{2.2}$$

This information was used in analyzing data obtained during TP-033-2. A series of steady states were conducted during TP-033-2 with Western Kentucky #9 coal to study fines consumption rates. The following modes of fines recycle were employed: no recycle of fines, axial injection of primary fines, axial injection of primary fines with annulus injection of secondary fines, radial injection of all fines, and annulus injection of all fines.

A simple model of the gasifier and cyclone system was used in the analysis of fines consumption rates:

$$C = KF + (1-x)R$$

where

- C = fines elutriation rate lb/hr
- F = coal feedrate, lb/hr
- R = fines recycle rate lb/hr
- K = net fraction of fines generated from the coal
- x = fraction of fines consumed per pass through gasifier

The initial value of K was estimated using Western Kentucky coal, steady state with no recycle of fines. The value of K for steady states with fines recycle was adjusted for freeboard velocity using the correlation derived from Upper Freeport data. Results from this study are presented in Table 4-10. A per pass fines consumption rate of 61.5% was achieved for the axial recycle of primary fines. Fines consumption rate varied from 21% to 65% during steady states with primary and secondary recycle of fines. During steady states using the secondary fines system for the collection and recycle of all fines, the per pass consumption rate ranged from 13% to 38%. This decrease was probably due to the poor collection efficiency of the secondary cyclone during these steady states (40-60% collection efficiency) rather than the various injection points.

Figure 4-4. TP-032-1 Upper Freeport (No Recycle)

TABLE 4-9

T0-032-1 UPPER FREEPORT ELUTRIATION DATA

	<u>Fines Carryover Rate (lb/hr)</u>	<u>Coal Feed Rate (lb/hr)</u>	<u>Fines Elutriation (lb/lb Coal Feed)</u>	<u>Freeboard Velocity (fps)</u>	<u>Freeboard Temperature (°F)</u>
TP-032-1 SS 1A1	245	1174	0.2087	1.01	1827
TP-032-1 SS 1B1	337	1152	0.2925	1.22	1820
TP-032-1 SS 1B2	511	1333	0.3833	1.34	1822

TABLE 4-10

TP-032-2 WESTERN KENTUCKY FINES RECYCLE STUDY DATA

<u>Steady State No.</u>	<u>Primary Recycle Mode</u>	<u>Secondary Recycle Mode</u>	<u>Freeboard Velocity (fps)</u>	<u>Predicted Coal Attrition Rate (% of Coal Feed)</u>	<u>Freeboard Temperature (°F)</u>	<u>Fines Consumption Per Pass (%)</u>
MOD 3B1	N.R.	N.R.	1.266	21.87	1880	--
MOD 3B2	Axial	N.R.	1.48	30.84	1872	61.5
MOD 3A1	Axial	Annulus	1.185	18.91	1860	53.8
MOD 3B3	N.R.	Radial	1.197	19.33	1843	13.0
MOD 3B4	N.R.	Annulus	1.209	19.76	1851	37.7
MOD 3C1	Axial	Radial	1.311	23.62	1824	64.9
3A	Axial	Annulus	0.988	12.68	1807	20.6

N.R. - No recycle of fines, cyclone in idle mode.

SECTION 5.0

COLD FLOW SCALEUP FACILITY (CFSF)

5.1 MODIFICATIONS AND MAINTENANCE

The month of July was spent in preparing the CFSF for operation. During this time period the following modifications and maintenance to the facility were completed:

- Installation of 10-inch diameter single air tube.
- Starwheel feeders 001, 003 and 004 were refurbished and installed.
- Eight recorders and CO₂ GOW Mac gas analyzers were installed.
- Piping and instrumentation for the separate grid flow measurement/control was installed.
- Recalibration of the CFSF instrumentation and controls was completed.
- Approximately 25,000 lbs of acrylic particles were loaded into the storage bins.
- The top cover was installed on the model and the 24-inch carryover pipe was reinstalled.
- The computer logic was updated to include new instrumentation.

Additional modifications and repairs completed during the fourth week of August are as follows:

- The non-mechanical fines recycle components were installed;
- The CM006 cyclone was inspected and repaired;
- The drawoff line was modified to use 20 psi air as opposed to 15 psi;
- Data acquisition system repairs were completed;
- Oil inlet strainers were cleaned;
- The 2-inch air supply (20 psig) header was installed;
- The purge and backwash system on the baghouse was repaired; and,
- Modifications to the recycle material conveyor were made to reduce the airborne dust during material transfer.

5.2 OPERATIONS

TP-M005-1, a 10-inch diameter single air tube shakedown test was completed on August 2. Results of shakedown test were used to establish set point conditions for CO₂ testing. TP-M005-3, a 10-inch diameter single air tube

operation with motion pictures, was completed on August 5. Normal CFSF motion pictures were taken at 16 set point conditions and in addition, motion pictures of flow through the transparent feedline were taken.

TP-M007-1, a 10-inch single air tube operation - CO₂ tracer gas test, was started on August 6. Set points 1 through 12 were completed with CO₂ injected into the feedline. Set points 11 and 12 were completed with CO₂ injected into the air tube. CO₂ concentrations were measured at all six elevations with the traversing probes.

Testing for TP-M007-1 was terminated the fourth week of August and resumed September 7, 1982. Concurrent with TP-M007-1, the shakedown tests of the non-mechanical valve fines recycle installation (with fines being recycled to the solids feedline) were conducted.

TP-M007-1, set points 3 through 11 were completed with CO₂ injected into the annulus section. Set points 1, 2, 10, 11 and 12 were completed with CO₂ injected into the grid. CO₂ concentrations were measured at all six elevations with the traversing probes.

5.3 DATA ANALYSIS

A frame-by-frame analysis of the films taken during test TP-M005-3 has been completed. The data extracted from these films are jet penetration depth, bubble size, frequency, and velocity. These data will be compared with the predicted values from known correlations in the literature.

Analysis of the pressure drop data obtained using the pitot tubes (TP-M003-1) was continued. The pitot tube measured the momentum of the gas and also that of the solids. To convert the pitot tube pressure drop measurements to a gas velocity profile, assumptions were developed to estimate the voidage in the jet nozzle and solids velocity. This approach and the equations used were outlined in the Quarterly Report for April-June 1982.

The approximation of the gas velocity profiles in a jet by the Tollmien similarity method was not found to be successful. This is because the two concentric jets operating at different conditions exchange momentum with each other and with the fluidized bed to a different degree both radially and axially. However, the dissipation of the maximum velocity was analyzed 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:

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

$(U_J)_c$, the compound jet velocity at the two concentric jet nozzles, was calculated using the following equation:

$$\rho_f (U_J)_c^2 = \frac{(M_g)_i (U_g)_i + (M_s)_i (U_s)_i + (M_g)_o (U_g)_o}{A_t}$$

Where:

U_m = maximum gas velocity at the jet axis

h = a distance from the jet nozzle

d_o = jet nozzle diameter

a, b = parameters

$(M_g)_i$ = mass flow rate of gas in the inner jet

$(M_g)_o$ = mass flow rate of gas in the outer jet

$(M_s)_i$ = mass flow rate of solids in the inner jet

$(U_s)_i$ = jet velocity in the inner jet

$(U_g)_o$ = jet velocity in the outer jet

$(U_g)_i$ = solid particle velocity in the inner jet

A_t = total cross-sectional area of the concentric jets

ρ_f = fluid density

The parameters a and b for all data are summarized in Table 5-1.

Data obtained from TP-M004, CO₂ test (16-inch diameter air tube) have been plotted in the form of gas concentration profiles. A typical gas concentration profile is shown in Figure 5-1.

This task objective is to provide technical support to the operation of the CFSF and to its data analysis. Data from Tests TP-M003-1 and TP-M003-2 were analyzed and a topical report is being prepared. The results are summarized here. The difference between the impact pressure and the local static pressure measured by the pitot tube was substantially larger than that expected from the gas alone, as shown in Figures 5-2 through 5-4. The pitot tube apparently sensed not only the momentum of the gas, but also the momentum of the solids. If the pitot tube had measured only the momentum of the gas, as originally hoped, the local gas velocity could readily be calculated from:

$$U_g = \sqrt{\frac{2g\Delta P}{\rho_f}} \quad (1)$$

Where: U_g = local gas velocity
 ΔP = the differential pressure measured by the pitot tube
 ρ_f = gas density evaluated at local static pressure.

TABLE 5-1

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

Figure 5-1. Gas Concentration Profiles

Figure 5-2. Pressure Data Obtained by Pitot-Tube – Set Point 1

Figure 5-3. Pressure Data Obtained by Pitot Tube – Set Point 2

Figure 5-4. Pressure Data Obtained by Pitot Tube – Set Point 3

Where: ϵ_0 = voidage at the jet nozzle
 $\epsilon_0 = 1$ when the jet is a pure gas jet
 ϵ_L = voidage at jet penetration
 $\epsilon_L = \epsilon_{mf}$, voidage at minimum fluidization
 L = jet penetration depth

Also assumed is that the slip velocity between the gas and the solid particles was equal to the terminal velocity of a single particle, or

$$U_s = U_g - U_t \quad (2)$$

Solving equations (2) through (4) gives the gas velocity profiles as shown in Figures 5-5 through 5-7. Equations (2) through (4) are applicable only in the jet region. Pressure profiles obtained through pitot tubes located at locations 5 and 6 were not analyzed because they are beyond the jet penetration depth.

Since the differential pressure measured by the pitot tube includes the momentum of the solids, the correct equation becomes:

$$\Delta P = \frac{\rho_f \epsilon U_g^2}{2g} + \frac{\rho_s (1-\epsilon) U_s^2}{2g} \quad (3)$$

This introduces two more unknowns, U_s , the solid particle velocity, and ϵ , the local voidage. In order to calculate the gas velocity profiles from the measured profiles using equation (2), two more equations are needed. Voidage distribution in the jet was assumed to depend exponentially on the distance from the jet nozzle. This enables the voidage at any height, ϵ_h , to be calculated from:

$$\epsilon_h = \epsilon_0 \exp \left[\frac{1_n \epsilon_L}{L} \cdot h \right] \quad (4)$$

Figure 5-5. Reduced Velocity Profiles – Set Point 1

Figure 5-6. Reduced Velocity Profile – Set Point 2

Figure 5-7. Reduced Velocity Profiles — Set Point 3

SECTION 6.0

PROCESS AND COMPONENT ENGINEERING AND DESIGN

During this report period, design procurement and installation activities for the PDU non-mechanical valve modification continued.

The significant accomplishments achieved during this report period related to PDU modification are as follows:

- Completed the non-mechanical valve system description, FMEA arrangement and P&ID drawings.
- Completed relocation of primary cyclone, C-110, for the non-mechanical valve PDU test and installed 95% of the large diameter piping (12- and 18-inch diameter).

6.1 HOT FINES RECYCLE MODIFICATIONS

During this report period, work was concentrated on the modifications required for non-mechanical valve test scheduled for October. The primary cyclone, C-110, Figure 6-1, was relocated on the 9th floor of the PDU to an area over the gasifier. Piping arrangement drawings were completed and installation of the large diameter piping (12- and 18-inch diameter) including the installation of the spring support system was initiated.

A progress summary of the construction activity follows:

- Relocated C-110, the primary cyclone.
- Completed 95% of the large diameter piping installation.
- Relocated pressure safety valve vent system for the C-115 gasifier.
- Installed thru-trap in the gasifier outlet nozzle.
- Relocated the vent system for lockhoppers C-109B, C-103B and C-108B.

Purchase orders placed for hardware to implement testing of the non-mechanical valve on the PDU included:

- K-Ray system for level control
- Spring support system for the 12- and 18-inch diameter piping
- Structural steel for Spring Support System
- CO₂ aeration flow system, piping and control hardware for dipleg

6.2 HOT RECYCLED FINES

The hot rotary feeder was received and work was continued on completing the fabrication of the modified seal pot. The lateral for providing rotary feeder sampling capability, spool piece and K-Ray support for solids level control upstream of the rotary feeder were also delivered. The PDU test to evaluate the system performance of the rotary feeder arrangement has been deferred in favor of the non-mechanical valve test series.

Figure 6-1. C-110 Cyclone Relocation and Piping Assembly

6.3 WORK FORECAST FOR NEXT QUARTER

- Complete PDU modification work for non-mechanical valve test system.
- Complete non-mechanical valve test program.
- Complete operational evaluation of thru-trap.

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. Jet interaction of the main jet in the gasifier and the jet feeding char into the gasifier located in the char/ash separator annulus was simulated in the 30-cm (1 foot) diameter laboratory semicircular mode. The main jet nozzle had an inside diameter of 5.4 cm (2-1/8 in.) with a semicircular cross section, while the secondary jet in the annulus was circular and had an inside diameter of 1.1 cm (7/16 in.). Main jet velocities ranged from 9.2 m/s to 24 m/s (30 to 80 fps) to minimize the pressure fluctuation in the bed. Secondary jet velocities were from 24 to 110 m/s (80 to 360 fps). The two jets were located 5.7 cm (2-1/4 in.) apart, center to center, with the main jet against the front plate at a fixed vertical position, and the secondary jet at either 15.2 cm (6 in.) or 30.5 cm (1 foot) below the main jet in two separate series of experiments.

Only visual observation was conducted during these experiments. The following conclusions were obtained on the basis of those exploratory observations:

- The total momentum in the jet rather than the momentum flux is responsible for jet interaction. If the secondary jet was located at 30.5 cm (1 foot) below the primary jet, the total momentum in the secondary jet required to deflect the main jet could be correlated with the following equation:

$$\frac{M_s}{M_m} = 4.9 M_m^{-0.78}$$

where M_s = total momentum in the secondary jet
 M_m = total momentum in the main jet

When the secondary jet was located at 15.2 cm (6 in.) below the main jet, no correlation similar to equation (1) could be obtained, though the trend expressed in equation (1) was still apparent for main jets with velocity higher than about 15 m/s (50 fps). A secondary jet with momentum half of that of the main jet, i.e., $M_s/M_m = 0.5$, was sufficient to cause deflection of the main jet. For comparison, M_s/M_m would have to be longer than 1.2 for deflection of the main jet to occur if the secondary jet were located 30.5 cm (1 foot) below the main jet. Before the main jet was deflected, the secondary jet deflected toward the main jet and merged into the main jet at very close to the top of the jet nozzle. After the main jet was deflected, both the main and the secondary jets deflected in the same direction, rather than toward each other, and merged.

- In the PDU operation the char feeding jet in the char ash separator annulus should be located far enough from the main jet in the gasifier and possess low enough momentum to prevent deflection of the main jet.

Shakedown tests for the high-temperature unit were completed. Experiments will be carried out initially to measure the minimum fluidization velocity at different bed temperatures to investigate the temperature effect on a few bed materials of different characteristics.

7.1.2 FINE PARTICLE HISTORY

To design the fines recapturing and recirculation systems that accompany an operating fluidized-bed reactor and to be able to predict fines consumption and reactor performance, the mixing and residence times of the fines in the reactor must be known.

Residence time of fines in a fluidized bed is intimately related to the motion of bed solids and is expected to be a function of the loading of fines in the reactor: the flow conditions within the reactor, such as the mode of operation of the reactor (slugging vs nonslugging); superficial gas velocity; fines feed point; size of fines; shape of fines (increase of adhesion of irregularly shaped particles relative to that of spherical particles); density of fines; modulus of elasticity; agglomerating, adhesive, cohesive, and hydrophilic properties of fines; and temperature and relative humidity of the fluidizing gas.

The objective of this subtask is to study the fate of fines that are injected either concentrically or radially into the gasifier as a function of flow field characteristics to develop a meaningful process model and to understand reactor performance. This study will try to evaluate the deviation of fines mixing from ideal flow conditions, which is essential to determine the proper factors needed in scaling the reactor design up from bench-scale models.

A series of experiments was designed to study the fate of injected fine particles as a function of jet injection velocity, variation in the gross flow-field characteristics (slugging versus nonslugging fluidized bed) for different fines feed points, and different fine particle sizes and shapes.

Experiments consist of the injection of fine tracer particles of narrow size distribution ($d_{\text{tracer}} < 100 \mu\text{m}$) into the test apparatus. A pulse of tracers is introduced into a steady operating fluidized bed and the rate at which the injected fines are recovered is monitored. During these experiments the stimulus is the tracer particle put into the fluidized bed, and the response is the time record of the tracer leaving the vessel. From the experimentally obtained exit age distribution function for the injected fines, the mean residence time of the injected fines in the fluidized-bed reactor is calculated as the time by which 50 percent of the injected fine particles are recovered.

To perform the fine-particle history experiments, the existing 30-cm semicircular cold-flow unit was modified. A schematic diagram of the apparatus is shown in Figure 7-1. The modified apparatus includes a mechanism by which the rate at which the injected particles are carried away from the

Figure 7-1. Schematic Diagram of Fluidized-Bed Cold-Flow Gasifier Unit

fluidized bed is recorded. This mechanism consists of a size 1-1/2 to 4-inch high-performance cyclone located above the transport disengaging height corresponding to our design flow conditions. The tracer particles captured by the cyclone are discharged into a specially constructed dipleg. The lower portion of this dipleg consists of a sealed, transparent, Plexiglas tube graduated to permit recording of the rate at which the fines are captured by the cyclone. This apparatus also includes a tracer particle injection mechanism for injecting fine tracer particles radially into the test unit. This mechanism consists of a vertically mounted metallic tube that will contain up to 50 g (1.75 oz) of the fines to be injected. The top of this tube is connected to a compressed air line. The solids are discharged into the fluidized bed through a ball valve connected to the bottom of the tracer particle injection tube.

Accordingly, 250 pounds of antistatic polyethylene resin pellets (RCAS-2200 HD RESIN) were to be ground cryogenically into two 125-pound batches of $\sim 100 \mu\text{m}$ and $\sim 50 \mu\text{m}$ particles.

Also connected was a cyclone efficiency enhancement air line to the inlet of the cyclone. This line is capable of providing airflow to the cyclone in addition to the supply of air provided through the jet, grid, and annulus. Thus, the cyclone inlet velocity can be increased to improve the cyclone collection efficiency whenever necessary.

A vibrator motor was added to shake the transparent portion of the cyclone dipleg while the injected fine tracer particles are being collected. This ensures that the advancing interface of the collected fines in the transparent dipleg is flat and that the weight of the fines collected through the cyclone at any time is proportional to the observed dipleg height by a constant factor.

A few preliminary tests run to evaluate the proposed experimental concept showed that, for the injected tracer fines (-120 +140 mesh acrylic fines) at the given flow rates, the cyclone efficiency was satisfactory and that practically all the material injected was collected at the cyclone dipleg at a measureable rate of collection.

To make a preliminary determination of fines mixing and to evaluate the proposed experimental concept, a few tests were run during which tracer fines (-120 + 140 mesh acrylic fines) were injected radially into a single location in a slugging fluidized bed of acrylic particles with a mean diameter of $750 \mu\text{m}$ and narrow particle size distribution. Tests were performed for one set of flow conditions (annular and grid flow rates at minimum fluidization conditions for the main bed material, i.e., $u = u_{mf} = 25.5 \text{ cm/s}$ (10 i.p.s.) and jet at a velocity of 37 m/s (120 fps)). These tests were satisfactorily duplicated and showed that the data obtained were adequately repeatable.

The initial results of fine tracer particle injection experiments were partially analyzed. To characterize the extent of non-ideal flow the cumulative weight of tracers collected at the cyclone dipleg was plotted as a function of time on a log-normal probability diagram. Figure 7-2 shows an example of such an experiment for a 50-g (1.75 oz) pulse injection of tracer fines into the fluidized bed. This figure shows clearly that the residence

Figure 7-2. Cumulative Percentage of Tracer Weight Vs. Time on Log-Normal Probability Diagram for a 50-g Pulse; $V_{\text{Jet}} = 37 \text{ m/s}$

time distribution of fines in the cold flow gasifier unit is expressed well by the log-normal probability law. The experimental results presented in Figure 7-2 show that for the given flow conditions the mean residence time of fines in the cold flow reactor was approximately 100 seconds and that although there was significant dispersion of the fines, their exit age distribution suggested that they were not thoroughly mixed.

7.1.3 CHAR/ASH SEPARATION

This task objective is to determine the effect of different particle characteristics on the rate and effectiveness of particle separation. No work was conducted in this area this report period.

A solid circulation probe based on piezoelectric principles was constructed and tested in the 30-cm (1 foot) semicircular cold model unit with promising results. Peak voltage produced by particle impaction on the probe was electronically counted with a variable voltage threshold. Within a small span of threshold voltage, the number of peaks responded correctly to the changes in the bed operating conditions. When the probe was in the emulsion phase of the jetting fluidized bed, the counts dropped off dramatically. Thus, the probe will be very useful for detecting the jet boundaries in a three-dimensional bed. The probe can also be developed into a tool for measuring gas bubbles in the fluidized bed. A new piezoelectric probe with high damping is being fabricated on the basis of the experimental findings obtained with the first probe. The probe with high-damping characteristics will cut down the resonance produced during particle impaction and thus will provide a better quantitative measurement of the number of particle impactions on the probe.

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 the coals for reactivity and sintering characteristics in support of the PDU operation.

7.2.1 COAL GASIFICATION

North Dakota lignite was characterized at 982°C (1800°F) by preparing char in a mixture of nitrogen and hydrogen. An average relative reactivity of 122 was obtained on the basis of the results of three tests. Data on reaction rates and proximate analyses of three samples are shown in Table 7-1. Reactivity profiles are shown in Figure 7-3. This reactivity compares well with an average relative reactivity of 169 for the Texas lignite studied earlier.

Brookville "A" seam coal from the eastern region of the country was characterized by preparing char in a mixture of nitrogen and hydrogen. An average relative reactivity of 2.2 was determined from the tests done. PDU char from the same feedstock was also characterized at 982°C (1800°F). An average relative reactivity of 2.7 obtained for this char compares very well with a value of 2.2 obtained for the parent coal. Brookville "A" seam coal is

TABLE 7-1

REACTIVITY AND ANALYSIS OF NORTH DAKOTA LIGNITE

Coal/Char: North Dakota Lignite; -1.00 +.250 mm (-0.04 + 0.01 in.); sample heated to 982°C (1800°F) in N₂ 125 ml/min (4.2 oz/min.); H₂ 125 ml/min (4.2 oz/min); reacted at 982°C (1800°F) with steam 100 ml/min (3.4 oz/min), H₂ -50 ml/min (-1.7 oz/min); N₂ -150 ml/min (-5 oz/min)

<u>Test No.</u>	<u>G348</u>	<u>G349</u>	<u>G350</u>	<u>Average</u>
<u>Reactivity Data</u>				
Average reaction rate x 10 ² , min ⁻¹	38.04	32.78	39.01	36.6
Average relative reactivity	126.8	109.3	130.0	122.0
<u>Proximate Analysis, wt %</u>				
Moisture	17.04	18.74	22.86	19.55
Volatile Matter	36.36	34.09	30.38	33.61
Ash	5.68	2.71	5.48	4.62
Fixed Carbon	40.9	44.47	41.29	42.22
<u>Analysis of Char, wt %</u>				
Carbon	87.8	94.26	88.29	90.12
Ash	12.2	5.74	11.71	9.88

Figure 7-3. Reactivity Profiles of North Dakota Lignite

very similar in reactivity to Pittsburgh Seam coal. Proximate analyses and reaction rates of different samples used for the study are given in Table 7-2. Reactivity profiles and carbon conversion curves are shown in Figures 7-4 and 7-5.

Texas lignite was characterized for reactivity at 815°C (1500°F) to correspond to the PDU operating temperature. The results of these tests yielded an average relative reactivity of 60. This is the most reactive of the chars processed in the PDU to date. The reaction rates and the proximate analyses of the samples are given in Table 7-3. Reactivity profiles and carbon conversion curves for Texas lignite are shown in Figures 7-6 and 7-7.

Illinois No. 6 coal was characterized at 982°C (1800°F). An average relative reactivity of 16.3 was obtained, based on the results of three tests. This figure compares reasonably with a value of 24.4 obtained for Illinois No. 6 char from the PDU as reported earlier. Information on the reaction rates and proximate analyses is given in Table 7-4. The reactivity profiles and carbon conversion curves are shown in Figures 7-8 and 7-9.

West Virginia char from the PDU (Test TP-030-3) was characterized at 982°C (1800°F). Results of three tests yielded an average relative reactivity of 1.9, which is close to that of Brookville "A" seam char from the PDU.

The characterization of midwestern coals has been completed.

7.2.2 ASH BEHAVIOR

The objective of this task is to study the behavior of coal ashes. In an effort to study the effect of particle size on ash sintering behavior, ash was prepared from Pittsburgh Seam and Wyoming Sub C coal using a size distribution of -30 +35 mesh by the high-temperature ashing method. Ash particles from both coals were examined on the hot-stage microscope in an oxidizing atmosphere. In each case, about 6 to 8 particles were examined at the same time. Sintering of the particles was observed by placing a transparent sheet over the television screen and tracing the original contours of the particles on this sheet. The temperature at which the size of the particle is significantly reduced is taken as the sintering temperature. The following results were obtained:

	Sintering Temp., °F	Initial Melting Temp., °F
Wyoming Sub C coal ash	1940	2000
Pittsburgh Seam coal ash	1650	1950

During the next test a smaller particle size distribution will be used.

7.2.3 DEPOSIT CONTROL

A probe was installed in the PDU gasifier for Test TP-033-1 to determine the metal wall temperature at which deposit formation starts. It consists of two concentric, stainless steel tubes: an inner tube for the in-flow of cooling

TABLE 7-2

REACTIVITY AND ANALYSIS OF BROOKVILLE "A" SEAM COAL

Coal/Char: Brookville "A" Seam, -1.00 +.250 mm (-0.04 + 0.01 in.), sample heated to 982°C (1800°F) in N₂ -125 ml/min (4.2 oz/min), H₂ -125 ml/min (4.2 oz (mm)) reacted at 982°C (1800°F) with steam 100 ml/min (3.4 oz/min), H₂ -50 ml/min (-1.7 oz/min), N₂ -150 ml/min (-5 oz/min)

<u>Test No.</u>	<u>G351</u>	<u>G352</u>	<u>G353</u>	<u>Average</u>
<u>Reactivity Data</u>				
Average reaction rate x 10 ² , min ⁻¹	0.57	0.47	0.91	0.65
Average relative reactivity	1.9	1.6	3.04	2.2
<u>Proximate Analysis, wt %</u>				
Moisture	0.48	0.49	0.45	0.47
Volatile Matter	35.42	34.15	32.73	34.10
Ash	4.82	9.27	6.82	6.97
Fixed Carbon	59.28	56.10	60.0	58.46
<u>Analysis of Char, wt %</u>				
Carbon	92.48	85.82	89.86	89.39
Ash	7.52	14.18	10.13	10.61

Figure 7-4. Reactivity Profiles of Brookville "A" Seam Coal

Figure 7-5. Carbon Conversion Curves for Brookville "A" Seam Coal

TABLE 7-3

REACTIVITY AND ANALYSIS OF TEXAS LIGNITE

Coal/Char: Texas Lignite; CO-81-0116; -1.00 +.250 mm (-0.04 + 0.01 in.), sample heated to 215°C (420°F) in N₂, 250 ml/min (8.5 oz/min), reacted at 815°C (1500°F) with steam, 100 ml/min (3.4 oz/min), H₂ -50 ml/min (-1.7 oz/min), N₂ -150 ml/min (-5 oz/min)

<u>Test No.</u>	<u>G265</u>	<u>G266</u>	<u>G267</u>	<u>G268</u>	<u>Average</u>
<u>Reactivity Data</u>					
Average reaction rate x 10 ² , min ⁻¹	26.34	23.19	8.29	13.94	17.94
Average relative reactivity	87.78	77.29	27.62	46.46	59.79
<u>Proximate Analysis, wt %</u>					
Moisture	28.72	8.71	10.12	9.09	14.16
Volatile Matter	30.26	37.82	37.18	37.45	35.68
Ash	7.69	11.39	9.41	5.05	8.38
Fixed Carbon	33.33	42.08	43.29	48.40	41.78
<u>Analysis of Char, wt %</u>					
Carbon	81.26	78.70	82.14	90.55	83.16
Ash	18.74	21.30	17.86	9.45	16.84

Figure 7-6. Reactivity Profiles of Texas Lignite

Figure 7-7. Carbon Conversion Curves for Texas Lignite

TABLE 7-4

REACTIVITY AND ANALYSIS OF ILLINOIS NO. 6 COAL

Coal/Char: Illinois No. 6 Coal

<u>Test No.</u>	<u>G351</u>	<u>G352</u>	<u>G353</u>	<u>Average</u>
<u>Reactivity Data</u>				
Average reaction rate x 10 ² , min ⁻¹	4.71	5.48	4.45	4.88
Average relative reactivity	15.7	18.3	14.9	16.3
<u>Proximate Analysis, wt %</u>				
Moisture	7.68	7.53	5.87	7.03
Volatile Matter	37.78	37.42	36.80	37.33
Ash	10.71	10.32	13.07	11.37
Fixed Carbon	43.84	44.73	44.27	44.28
<u>Analysis of Char, wt %</u>				
Carbon	80.37	81.25	77.21	79.61
Ash	19.63	18.75	22.79	20.39

Figure 7-8. Reactivity Profiles of Illinois No. 6 Coal

Figure 7-9. Carbon Conversion Curves for Illinois No. 6 Coal

gas (CO₂) and an outer tube for the outflow of gas and for the collection of deposits. Thermocouples are located in grooves along the inner wall of the outer tube to record the probe wall temperature. As deposits form on the probe this temperature will decrease because the deposits insulate the probe. The probe was located in the gasifier freeboard in front of the inlet to the spool piece, where there would be a large number of particles striking its surface at high velocity.

The CO₂ cooling gas flow was kept at 200 lb/hr for 40 hours during the Brookville coal feed, then decreased to 165 lb/hr for 8 hours and to 100 lb/hr for 7 hours, at which point the coal feed was changed from Brookville coal to North Dakota lignite. The cooling gas flow was maintained at 100 lb/hr during the lignite tests. Figure 7-10 shows the temperature profiles obtained with the probe during TP-033-1.

At 200 lb/hr cooling gas flow, with Brookville coal feed, the temperature readings along the length of the probe were between 200 and 1100°F, and at 100 lb/hr the readings were between 330 and 1320°F. The gasifier freeboard temperature (from TE-510-5) was around 1850°F. Brookville coal is high in pyritic sulfur (2.95 percent) and moderately high in alkali-aluminum-silicates. It would, therefore, rank as a highly fouling coal.

A small temperature decrease was noted for two thermocouple readings, from around 1050°F and 1100°F to 900°F during the Brookville coal feed which may indicate an accumulation of deposit. Another thermocouple reading (TE-48) showed cyclic increase and decrease, which may indicate periodic accumulation and spalling off of ash material. The gasifier was not opened, however, and signs of deposit for formation on the probe could not be observed after the test with Brookville coal.

The probe was left in the gasifier through shutdown, restart, and test run with North Dakota lignite. At the end of the test, the gasifier was opened and the deposit probe examined. The probe appeared clean, free of any ash deposit.

Of the many possible reasons for the absence of ash deposit on the probe surface the most obvious are:

- Ash deposit would not adhere to stainless steel metal at surface temperatures below 1300°F.
- Ash deposit was formed on the probe at surface temperatures around 1050 and 1100°F but spalled off when the gasifier was shut down and when it restarted.
- Ash deposit was formed but was eroded away by nonsticky carry-over material in the effluent stream during the test with lignite.

The probe will be removed from the gasifier and examined microscopically for signs of remaining deposits or signs of spalling. Probe thermocouple readings obtained during the tests will be analyzed for consistent trends and correlations between these temperature measurements and deposit formation.

Figure 7-10. Temperature Profiles Obtained with Deposit Probe

7.2.4 WORK FORECAST

- Provide support to the CFSF operation and data analysis - complete TPM003 and TPM004 analysis.
- Fabricate solid circulation probe for CFSF testing.
- Initiate new series of fine tracer particle injection experiments to study the effect of variation in the flow conditions and the injection location on the fines residence times.
- Complete the reactivity characterization of recycle fines and high reactive coals on the TGA.
- Determine the temperature dependence of the reactivity of western coals and lignites.
- Study the effect of particle size on ash sintering behavior and characterize various coal ashes on the hot-stage microscope facility.
- Complete analysis and issue report on fine recycle particle combustion.
- Analyze data from the PDU deposit probe and issue report.
- Continue experimental program to verify the proposed mechanism of deposit formation.