



Advanced Coal Gasification System for Electric Power Generation

WESTINGHOUSE ELECTRIC CORPORATION
GENERATION SYSTEMS DIVISION
LESTER, PENNSYLVANIA 19113

QUARTERLY PROGRESS REPORT

SECOND QUARTER - FISCAL YEAR 1977

FOR THE PERIOD JANUARY 1 TO MARCH 31, 1977

DATE PUBLISHED: APRIL 20, 1977

PREPARED FOR:

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
FOSSIL ENERGY - GASEOUS FUELS
WASHINGTON, D.C. 20545

UNDER CONTRACT EF-77-C-01-1514

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BIBLIOGRAPHIC DATA SHEET	1. Report No. FE-1514-65	2.	3. Recipient's Accession No.																					
4. Title and Subtitle ADVANCED COAL GASIFICATION SYSTEM FOR ELECTRIC POWER GENERATION RESEARCH AND DEVELOPMENT			5. Report Date APRIL 20, 1977																					
7. Author(s) L.A. SALVADOR AND D. KEAIRNS			6. 8. Performing Organization Rept. No.																					
9. Performing Organization Name and Address WESTINGHOUSE ELECTRIC CORPORATION GENERATION SYSTEMS DIVISION P.O. BOX 9175 - LESTER BRANCH PHILADELPHIA, PA. 19113			10. Project/Task/Work Unit No. WG-45930-T9																					
12. Sponsoring Organization Name and Address U.S. ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION CCU - FOSSIL ENERGY WASHINGTON, D.C. 20545			11. Contract/Grant No. ERDA EF-77-C-01-1514																					
15. Supplementary Notes			13. Type of Report & Period Covered QUARTERLY - 1/1-3/31 1977																					
16. Abstracts A UNIQUE COAL GASIFICATION SYSTEM EMPLOYING MULTIPLE FLUIDIZED BEDS HAS BEEN EMBODIED INTO A PROCESS DEVELOPMENT UNIT LOCATED AT WALTZ MILL, PA. THE TWO MAIN PROCESS LOOPS ARE AT PRESENT ARRANGED FOR INDEPENDENT OPERATION. THE DEVOLATILIZER/DESULFURIZER SUBSYSTEM TESTING ON COAL WAS PREVIOUSLY COMPLETED, AFTER A 168-HOUR CONTINUOUS RUN PROCESSING TWO HIGHLY-CAKING PITTSBURGH SEAM COALS. THE GASIFIER/AGGLOMERATOR SUBSYSTEM IS NOW UNDERGOING TEST OPERATION. THREE RUNS WERE COMPLETED DURING THIS QUARTER.			14.																					
17. Key Words and Document Analysis. 17a. Descriptors																								
<table border="0"> <tr> <td>FLUIDIZING</td> <td>SYNTHESIS GAS GENERATORS*</td> <td>EROSION CORROSION</td> </tr> <tr> <td>FLUIDIZED BED PROCESSING</td> <td>GAS PURIFICATION</td> <td>AGGLOMERATION</td> </tr> <tr> <td>FLUIDIZED BED PROCESSORS</td> <td>DOLOMITE</td> <td>GASIFIER AGGLOMERATORS*</td> </tr> <tr> <td>COAL GAS</td> <td>DESULFURIZER</td> <td>DEVOLATILIZER/DESULFURIZERS*</td> </tr> <tr> <td>MANUFACTURED GAS</td> <td>EXHAUST EMISSIONS</td> <td>GAS TURBINE POWER GENERATION</td> </tr> <tr> <td>GASIFICATION</td> <td></td> <td></td> </tr> <tr> <td>GAS GENERATORS</td> <td></td> <td></td> </tr> </table> <p style="text-align: center;">* NEW TERM (NOT IN THESAURUS)</p>				FLUIDIZING	SYNTHESIS GAS GENERATORS*	EROSION CORROSION	FLUIDIZED BED PROCESSING	GAS PURIFICATION	AGGLOMERATION	FLUIDIZED BED PROCESSORS	DOLOMITE	GASIFIER AGGLOMERATORS*	COAL GAS	DESULFURIZER	DEVOLATILIZER/DESULFURIZERS*	MANUFACTURED GAS	EXHAUST EMISSIONS	GAS TURBINE POWER GENERATION	GASIFICATION			GAS GENERATORS		
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GASIFICATION																								
GAS GENERATORS																								
17b. Identifiers/Open-Ended Terms																								
ADVANCED COAL GASIFICATION PROCESS DEVELOPMENT UNITS																								
17c. COSATI Field/Group 0701, 0704, 0807, 1001, 1113, 1307, 1308, 1309, 1407, 2102, 2104																								
18. Availability Statement		19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 52																					
		20. Security Class (This Page) UNCLASSIFIED	22. Price \$4.50																					

PREPARED FOR THE UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

Under Contract No. EF-77-A-01-1514

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1.0 OBJECTIVE AND SCOPE OF WORK

The overall objective of the Westinghouse coal gasification program is to produce a clean low-Btu gas from caking, high-sulfur coal that will meet environmental standards yet have enough heating value to drive a turbine that will produce electrical energy. In order to achieve this goal, the program is divided into several areas of development, each with individual goals but all working toward the same end result.

1.1 PHASE I, TASK 2 - OPERATION OF THE PDU

Before adequate and reliable designs can be achieved for a large-scale generating plant, a combination of analytical studies, bench-scale experiments and semi-works or pilot scale evaluations are essential, especially for areas of new technology. The Westinghouse PDU program provides this bridge in knowledge and experience between small scale operations and a scaled-up plant.

The Task 2 objective is operation of the PDU to evaluate the process feasibility and operability of the Westinghouse coal gasification process as it is now conceived with devolatilization and in situ desulfurization of coal in one fluidized bed and with complete combustion and gasification of the char along with agglomeration of the ash in a second fluidized bed reactor. Initial work in this task involved evaluation of the devolatilizer system. Shakedown and operating tests, reactor design tests and feasibility demonstrations were conducted with a variety of coal feedstocks. Present work involves evaluation of the gasifier-agglomerator subsystem through a series of gasifier tests similar to those conducted with the devolatilizer. Eventually, the two reactors will be integrated and operated together.

1.2 PHASE I, TASK 2A - MODIFICATIONS TO THE PDU

This task deals with modifications to reactor piping and controls to achieve integrated operation. The objectives are to design, procure and install piping and controls for series operation of the gasifier and the devolatilizer.

1.3 PHASE I, TASK 3 - LABORATORY SUPPORT STUDIES

Support studies are being conducted to provide background information on process technology, to provide PDU design data, to project operating conditions for the PDU, to provide troubleshooting capability during PDU operation and to develop commercial plant design data. Primary areas of investigation include: fluidization and fluid-particle systems, coal behavior, ash agglomeration, sorbent behavior and reactor analysis.

Fluidization studies are directed toward development of the devolatilizer and the combustor-gasifier units. Test facilities include a flexible one-foot diameter semi-circular unit which operates at atmospheric pressure and ambient temperature, a four-inch scale pressurized unit and atmospheric pressure units. The semi-circular unit has been used for investigation of important devolatilizer design parameters (area ratio of downcomer/draft-tube, draft tube height, distributor plate design, methods of solid feeding); operating parameters (flow ratio of downcomer/draft-tube, amount of downcomer aeration); and startup and shutdown procedures in relation to solid circulation rate, jet penetration length, solids mixing and gas bypassing. A pneumatic transport line of 2.54 cm I.D. is an integral part of this experimental system so that concentric solid feeding into the reactor similar to that of the PDU can be simulated.

The semi-circular model is being operated to simulate the PDU combustor-gasifier unit. Tests were performed during this quarter to investigate design parameters, e.g., air tube location, and operating parameters, e.g. air tube gas velocity.

The coal behavior program complements the fluidization model studies and includes coal behavior in the devolatilizer, char behavior in the gasifier and ash behavior in the agglomerating combustor. Data are obtained on kinetic rates, product gas composition, tar formation and char characteristics. A fluidized bed test unit, operating at design temperature and pressure, is being used for supporting investigations. Initial tests on the ash agglomeration test unit were completed for investigation of ash agglomeration.

The calcium-based sorbent studies provide data to support PDU, to recommend process options for first generation plants, to project operating conditions for investigation in the PDU, to develop design and operating criteria and to evaluate the potential for advanced systems. Work was previously conducted to develop sorbent selection criteria, a once-through process, regenerative process options, spent sorbent disposition options, and to provide technical and economic assessment of the alternatives. A pressurized thermogravimetric analysis system, differential thermal analysis and a pressurized, high-temperature fluidized bed test unit have been used to conduct these investigations. No work was scheduled this quarter.

Mathematical analyses are performed on the gasification process using the collected data and reactor performance at different reactor configurations and at different operating conditions. Solids fluidization and transport investigations are conducted as needed to provide data to complement information from the PDU. Objectives are to provide a basis to develop models and scaling relationships to design and predict performance of the PDU and larger scale fluidized bed gasification plants.

2.0 SUMMARY OF PROGRESS TO DATE

2.1 PHASE I, TASK 2 - OPERATION OF THE PDU

Severe winter weather during January and February resulted in record low temperatures, high winds, ice and snow. These weather conditions caused plant operations to be difficult and hazardous with personnel operating out of doors in temperatures, including the wind chill factor, of -50°F . Water lines, instrumentation lines, pumps and valve actuators were continually freezing, and metal temperatures were near the point at which embrittlement is a primary consideration. In addition, propane and carbon-dioxide supplies were sparse to non-existent during January and February due to fuel shortages in the East and Midwest. In spite of weather difficulties, three gasifier runs were completed during this quarter.

1. Gasifier Test TP-011-2

TP-011-2 testing was only partially successful in that no agglomerates were produced. The reactor was successfully filled, fluidized, ignited and operated at 1800°F for several hours before a broken cooling water line resulted in termination of the test.

2. Gasifier Test TP-011-3

Successful operation of the combustor-agglomerator with coke breeze was achieved in TP-011-3 for over 52 hours. During this time, the reactor was operated at agglomerating temperatures 1900°F to 1950°F for 28 hours and ash agglomerates were discharged for 20 hours. TP-011-3 proved that ash agglomerates could be formed in the combustor-agglomerator at elevated pressures and that carbon losses, based on incoming coal, could be readily kept less than 10%. Because of the rather low ash density ($45\text{-}50\text{ lb/ft}^3$), control of an ash-char interface due to density alone was not achieved. However, results indicated that interface control can be based on particle size differences between char and ash.

During the latter portion of the test, ash concentrations in the ash withdrawal stream increased to 95% and in the bed to 48% because the maximum starwheel feeder speed was too low to maintain an adequate withdrawal rate. Following a sprocket change which provided a 4:1 speed increase, the ash concentration in the bed was reduced; however, shortly after this time, the ash withdrawal port plugged with large agglomerates. With no withdrawal, the ash agglomerates began to fill the bed above the air tube, and the bed defluidized. The run was terminated after unsuccessful attempts to withdraw ash from the bottom of the reactor.

3. Gasifier Test TP-011-4

After 40 hours of coke breeze gasification and combustion during which ash was successfully agglomerated for 13 hours at 1900°F and for five hours at 1950°F, TP-011-4 was concluded on March 19. Ash content in the bed and the ash withdrawal annulus were carefully monitored and controlled during this test. The ash level was controlled in the bed at 20% to 35% and in the annulus from 50-80%. A clinker developed at the top of the air tube and ash withdrawal from the annulus was restricted. A second clinker developed at the grid plate. These problems are being analyzed and preliminary observations support the conclusions that more agitation is needed in the bed at the grid plate and at the top of the air tube. Subsequent test plans will provide increased agitation by increasing the steam flow to the grid plate and increasing fluidizing gas flow to the annulus.

The shakedown tests were successful in establishing operating techniques for the gasifier and in demonstrating that ash agglomerates can be continuously produced and withdrawn from the reactor. Greater effort will be directed toward establishing controlled operation for sustained periods and defining the effects of the various operating parameters. Efforts will be exerted in the next shakedown tests, TP-011-5 and TP-011-6, and a subsequent reactor design test, TP-012, which are all to be conducted in the next quarter operations.

2.2 PHASE I, TASK 2A - MODIFICATIONS TO THE PDU

Engineering efforts were intensified on the design and procurement of the hardware required to integrate the gasifier and to upgrade existing PDU subsystems and components. Designs were completed for:

- Basic piping and instrumentation changes to integrate the two reactors.
- Conical grid plate for the devolatilizer.
- Expanded sections for the devolatilizer and gasifier reactors.

Designs were in progress on two additional revisions as follows:

- Use of two series cyclones for product gas cleaning during integrated operation.
- Upgrading product gas cooling and waste handling systems.

Procurement packages were compiled for completed designs and bids were obtained from prospective suppliers and subcontractors. All procurement actions will be initiated in the next quarter.

2.3 PHASE I, TASK 3 - LABORATORY SUPPORT STUDIES

Support work on fuel processing was conducted to investigate operating conditions for the PDU test program, provide troubleshooting capability for PDU operation, obtain data for PDU modifications, analyze and interpret results from the PDU operation and develop information for future process development. Primary effort was expended to provide support for PDU in areas of fluidization and fluid-particle systems, coal behavior, ash behavior and reactor analysis.

2.3.1 Fluidization and Fluid Particle Studies

In the past quarter, the cold model simulation experiments to study the effect of air tube location and size on the solid circulation rate between the gasifier and the combustor were concluded. Four air tube locations (0 in., 6 in., 12 in., and 18 in. from the conical transition between the gasifier and the combustor) and two sizes of air tubes (1.5 in. and 2.12 in. I.D.) were used. Different combinations of air tube flow, annular flow and flow through the conical distributor plate were employed. The penetration depths of the air tube jet at different velocities and at different operating conditions were recorded. The jet penetration depths and solid circulation rates for the smaller air tube at 30.5 cm (12 in.) from the transition section are reported here.

Cold flow simulation of continuous char-ash separation in the annular section was temporarily postponed. The semi-circular unit is being modified to the devolatilizer configuration to study the new distributor plate design for integrated operation.

2.3.2 Coal Behavior

A rate equation for the coke breeze-CO₂ reaction showing the effect of temperature and the partial pressure of CO₂ was obtained over a temperature range of 1600°F to 1900°F and a partial pressure range of one to four atmospheres. Results of carbon conversion on the reaction rate for both Minnehaha char and coke breeze show that the reaction rate can be correlated as an exponential function of the square of carbon conversion. Results were presented for the reaction rate of coke breeze with steam at a partial pressure of steam of 1 atm. over a temperature range of 1600°F to 1900°F.

2.3.3 Ash Behavior

Four ash agglomeration tests were run with a Western Kentucky coal char. The objectives were to demonstrate operability of the combustor and its ability to agglomerate ash. Agglomeration was achieved in tests 3 and 4 at a bed temperature of 1950°F to 2000°F; however, only part of the product was in the form of rounded pellets. To convert more of the ash

to pellet form, a higher bed temperature and more vigorous fluidization may be needed. Modification of the internal configurations of the combustor is planned to improve bed fluidization and permit higher air flows.

2.3.4 Reactor Analysis

Material and energy balances were performed on the combustor-gasifier unit for specified operating conditions to help generate an operating map for the PDU at Waltz Mill.

2.4 SUMMARY SCHEDULES

2.4.1 Phase I, Task 2/2A - Operation & Modification of the PDU

Task Description	1977			1977		
	Jan	Feb	Mar	Apr	May	Jun
Devolatilizer Test Analyses						*
Gasifier Tests:						
TP-011-2, Shakedown	—*					
TP-011-3, Shakedown		—*				
TP-011-4, Shakedown			—*			
TP-011-5, Shakedown			—*			
TP-011-6, Shakedown				—*		
TP-012-1, Reactor Design					—*	
TP-012-2, Reactor Design					—*	
TP-012-3, Reactor Design						—*
TP-013, Reactor Design						—*
Integrated Operation:						
Bid Solicitation			*			
Design					*	
Procurement						
Test Planning						
PDU Upgrading:						
Gas Cooling System Design					*	
Gas Characterization Design					*	

2.4 SUMMARY SCHEDULES

2.4.2 Phase I, Task 3 - Laboratory Support Studies

Task Description	1977			1977		
	Jan	Feb	Mar	Apr	May	Jun
Fluidization & Fluid-Particle:						
Combustor-Gasifier Hydrodynamics			---	---		
Devolatilizer Grid Design			---			
PDU Operation Interface						
Instrumentation						
Coal Behavior:						
Devolatilization					*	
PDU Char Gasif. Kinetics						
Ash Behavior:						
Ash Agglomeration Behavior						
Sorbent Behavior: ⁽¹⁾						
PDU Support						
Reactor Analysis:						
Devolatilizer Modeling	---	---	---	---	---	---
Combustor-Gasifier Material/Energy Balances				---	---	---
Combustor-Gasifier Modeling						
NOTE:						
(1) No work scheduled this period.						

3.0 DETAILED DESCRIPTION OF TECHNICAL PROGRESS

3.1 PHASE I, TASK 2 - OPERATION OF THE PDU

3.1.1 Devolatilizer Tests - Work Accomplished

Feasibility of the devolatilizer reactor was demonstrated in calendar year 1976 with highly-caking and mildly-caking coals. These tests were completed in August 1976, and operations were concentrated on the gasifier reactor. No extensive in-bed desulfurization demonstration tests were conducted; these will be accomplished later in the program. In the intervening months, work on the devolatilizer has been ongoing at a modest level of effort in two areas.

1. Analytical and modelling work directed toward understanding the data produced during the entire test series.
2. Design of hardware for the expanded section and the conical grid plate required for integration of the two reactors.

As the analytical work effort produces meaningful results, reports will be issued on this data; the hardware design effort is discussed below in Section 3.1.3.

3.1.2 Gasifier Tests - Work Accomplished

3.1.2.1 TP-011-2 Test

Debriefings were held with all test personnel on TP-011-1 results, and problems encountered during this test were solved by engineering design of hardware and procedural changes. A revised test plan was prepared and issued for TP-011-2 which had the same purpose and scope as TP-011-1 but included several heat conservation techniques to reduce the heat load on the gasifier.

TP-011-2 system pressurization and leak tests were accomplished on 1/13/77. During pressurization, a hot spot was observed on the four-inch line at the bottom of C102B lockhopper. Apparently, some residual char in the line had ignited and was burning slowly. The combustion zone was cooled with CO₂; however, it was estimated that the temperature of the line may have reached 1600°F based on the color of the Incoloy line. This line was dye penetrant inspected and requalified by a pneumatic pressure test at 290 psi.

Hot air dryout of the system was begun on January 14, and the utility and reactor systems were commissioned in preparation for the test run with the exception of the plant water and cooling water systems. Several lines

were frozen as a result of extremely cold weather, and the hot air dryout phase was placed on "Hold" as procedures were implemented to thaw the water header and other frozen lines. Repeated attempts to start the gasifier system were met with difficulties and frustration. With outdoor temperatures ranging between 5°F and -15°F and wind chill factors resulting in temperatures of -50°F, it was extremely difficult to keep process lines from freezing even with electrical heat tracing and insulation. Much of the Test Operations group activities involved heating and thawing process and instrumentation lines to remove ice blockages. (During January, the Pittsburgh area experienced the coldest weather recorded in about 100 years.)

By January 21, temperatures moderated to 20°F, and all process lines were thawed and heated, the gas cooling system was filled with water and final preparations were made to conduct the test. Char and char fines were loaded into the lockhoppers, the refractory cure cycle was completed using F123 startup burner, and the system was pressurized to begin the test run. By 2300 hours on January 22, a 22-foot bed of coke breeze was established in the gasifier reactor and the air preheater was set at 1000°F in preparation for ignition of the bed. Ignition took place at 0200 hours on January 23, and a smooth temperature ramp, to 1800°F, was achieved.

During startup, outdoor temperatures dropped steadily from 10°F at midnight to -15°F at 0500 hours. At this point, all outlet lines from C113 cooling tower froze or became inoperative as a result of control valves and actuators freezing. Several unions on the steam and circulating water lines began to leak severely as a result of stresses imposed on the lines by contraction of the piping system; and the cooling water flow to C111 quench scrubber was lost, causing temperatures in that vessel to rise sharply. The plant was immediately shut down to prevent damage to the cooling system.

Attempts to restart the gasifier were again frustrated by freezing of process lines and lack of fuel supplies. One truck load of propane was obtained from the supplier on January 28. With 5000 gallons of propane in the tank, this shipment brought the inventory to 13,000 gallons which was sufficient propane to run one gasifier test. Efforts to obtain carbon-dioxide for purge gas and use in the gasifier ash collection annulus met with little success. Since most carbon-dioxide is manufactured from the combustion of natural gas, all carbon-dioxide manufacturing plants were ordered to shut down as a result of the national fuel emergency. These difficulties resulted in a four to six-week delay in the program.

Data from TP-011-2 is summarized in Table 3.1-1 for the period of operation at 1800°F.

TABLE 3.1-1 SUMMARY OF OPERATING DATA FOR GASIFIER TEST RUNS

TEST RUN, TIME, DATE		TP-011-2	TP-011-3	TP-011-4	
		0440 Hr 1-23-77	1200 Hr 2-28-77	1500 Hr 3-18-77	
<u>GASIFIER TEMPERATURES</u>					
TE-504-5	Exit Gas Temperature	°F	1700	1899	1878
TE-504-6	24' Bed Temperature	°F	1760	1890	1852
TE-504-7	19' Bed Temperature	°F	1799	1898	1882
TE-504-8	17' Bed Temperature	°F	1756	1946	1907
TE-504-9	12' Bed Temperature	°F	351	327	276
TE-504-11	11' Bed Temperature	°F	280	399	348
TE-504-10	5' Bed Temperature	°F	414	399	289
TE-504-7	2' Bed Temperature	°F	200	251	120
<u>FLUIDIZED BED PARAMETERS</u>					
Average Bed Height	Ft		17.3	24.9	24.7
System Pressure	Psig		207	200	204
PDT-22 Bed Density - 28'-37'	Psi		0	0	0
PDT-23 Bed Density - 24'-28'	Psi		0	6.6	4.4
PDT-24 Bed Density - 19'-24'	Psi		0	21.7	18.6
PDT-25 Bed Density - 17'-19'	Psi		0.8	22.9	27.4
PDT-26 Bed Density - 12'-17'	Psi		22.8	19.7	23.1
PDT-121 Bed Density - 10'-12'	Psi		30.0	5.1	13.5
PDT-120 Bed Density - 5'-10'	Psi		31.2	0	7.3
PDT-119 Bed Density - 4'- 5'	Psi		24.0	12.3	14.2
Annulus Gas Velocity	Fps		0.33	0.45	0.30
Freeboard Gas Velocity	Fps		2.40	3.15	2.55
<u>GAS INLET CONDITIONS</u>					
Steam to Grid, FE-34	Flow	Lb/Hr	361	0	82
TE-506-10	Temp	°F	412	412	412
Steam to Air Tube FE-35	Flow	Lb/Hr	446	84	166
Steam to Annulus FE-36	Flow	Lb/Hr	0	0	0
CO ₂ to Annulus FE-48	Flow	Lb/Hr	1016	0	0
TE-503-2	Temp	Lb/Hr	613	0	0
Air Tube Air FE-37	Flow	Lb/Hr	2225	2465	2126
TE-503-9	Temp	°F	1004	1073	1049
Recyc.Gas-Annulus FE-48	Flow	Lb/Hr	0	875	515
TE-503-2	Temp	°F	0	571	496
Combustor Fines Transport,					
FE-21	Flow	Lb/Hr	488	546	362
TE-505-2	Temp	°F	320	105	291
Char Transport FE-60	Flow	Lb/Hr	0	870	423
TE-505-1	Temp	°F	240	106	390
Recyc.Char Trans. FE-62	Flow	Lb/Hr	411	156	217
TE-503-11	Temp	°F	296	477	449
<u>SOLIDS INPUTS AND OUTPUTS</u>					
Char Feed, WR-27		Lb/Hr	0	309	450
Fines Feed, WR-14		Lb/Hr	396	276	290
Recycle Char WR-32		Lb/Hr	0	0	0
Overhead(Cyclone)Char WR-19		Lb/Hr	153	170	255
Ash Withdrawal		Lb/Hr	40	84	134
<u>PRODUCT GAS ANALYSIS</u>					
Percent CH ₄			0	0	0.1
Percent CO			0	11.9	13.6
Percent CO ₂			0	18.8	24.8
Percent H ₂			0	1.4	2.9
Percent H ₂ S			0	0	0.2
Percent O ₂			0	0.9	0.8
Percent N ₂			0	67.0	57.6

Not all test objectives were achieved in TP-011-2; but the following conclusions were drawn from the data that was obtained.

1. Using an air preheater temperature of 1000°F, autogenous ignition of char was achieved at a fluidized bed temperature of 600°F to 700°F.
2. A smooth temperature ramp to an operating temperature of 1800°F was achieved by addition of steam to the air inlet as shown in Figure 3.1-1.
3. Steam addition of 680 lb/hr was excessive and resulted in condensation in the cyclone fines drawoff system and in the recycle gas lines that were used for solid transport.
4. Recycle gas system problems were solved by adjustments to the control system to minimize carbon-dioxide makeup.
5. No agglomerates were formed in the reactor because of the low operating temperature. However, a great deal of useful data on bed pressure drops, bed height control, and ash annulus control was obtained.

3.1.2.2 TP-011-3 Test

Moderation of the weather in mid-February alleviated PDU operations freezing problems, and final preparations were completed for test run TP-011-3. Suppliers of carbon-dioxide and propane were able to deliver sufficient quantities of fuel to WESO to run this test. Changes were made in the test plan and in plant equipment to conserve propane and carbon-dioxide as noted below.

1. A line was added to the recycle gas system to permit use of recycle gas instead of carbon-dioxide to cool and fluidize the ash collection annulus in the reactor. This resulted in a savings of about 1000 lb/hr of CO₂.
2. Heatup with propane burner F123 was eliminated in favor of a longer duration hot-air dryout at 1000°F. This conserved propane without substantially affecting refractory heatup.
3. Recycle of elutriated fines to the gasifier was eliminated to conserve heat in the system and prevent rapid ash concentration increases in the gasifier which might sinter the bed.

The two combustion-zone thermocouples were inspected following TP-011-2 and were found in good repair; they extended six and eight inches, respectively, above the air tube. Both thermocouples measured an incoming air temperature of 1000°F throughout the test. In order to monitor combustion

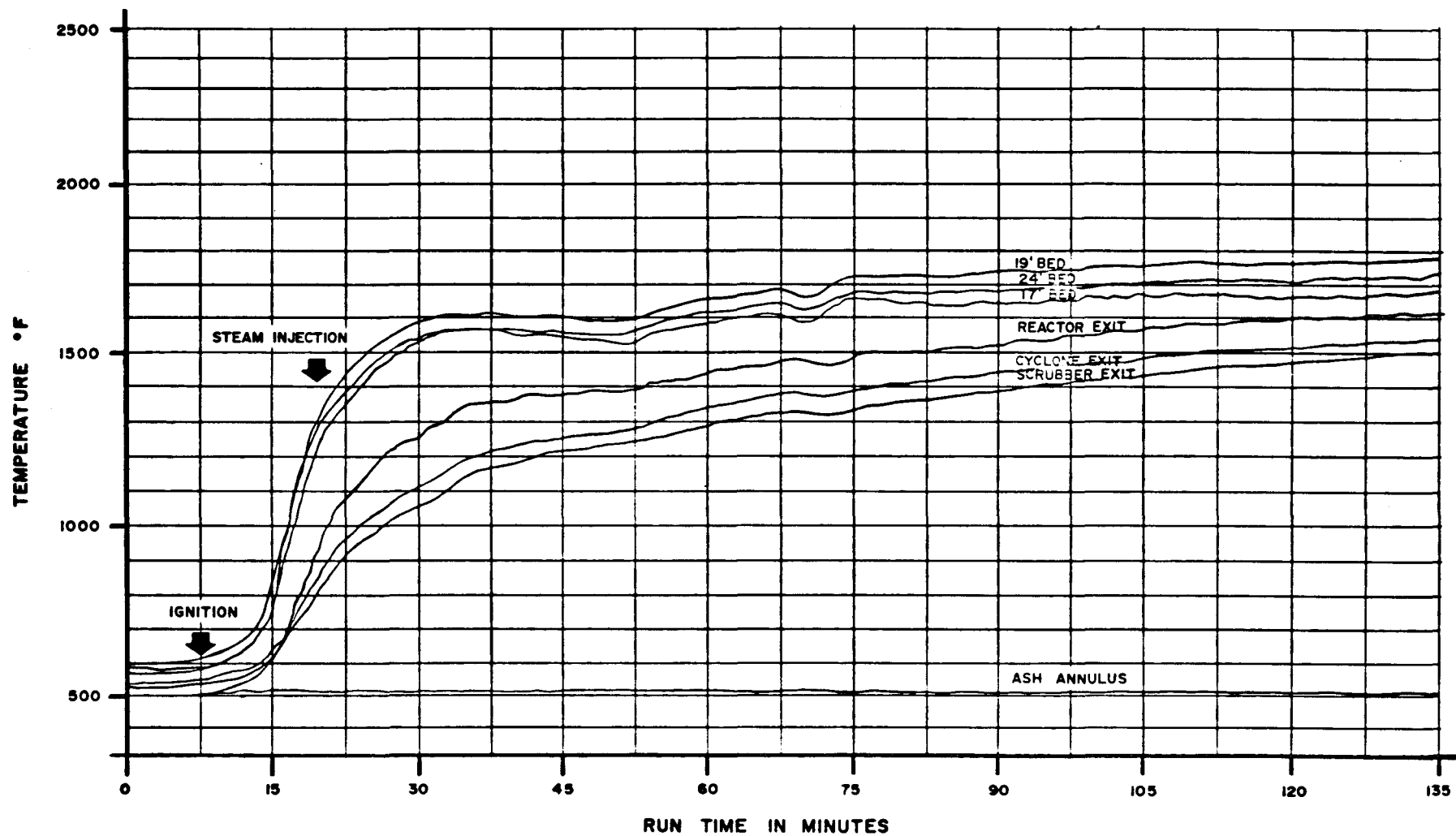


Figure 3.1-1 Temperature Profiles for Startup of TP-011-2

temperature, it was necessary to insert these thermocouples farther into the air jet; therefore, they were inserted an additional 10 inches above the air tube for TP-011-3 testing.

TP-011-3 test run began on February 22 with pressurization, leak checks and heatup of the system. Minor problems were encountered and solved, and the system was prepared for char feed on February 24. Transport gas heaters F114 and F122 (for char and devolatilizer fines) were found to be partially burned out at this point, and the system was depressurized so new heater elements could be installed. The system was repressurized on February 25 and was heated to 500°F. Coke breeze feed began at 1015 hours and a 22-foot char bed was achieved within three hours. The inlet air temperature was ramped to 1000°F and ignition of the bed was achieved within four hours. Feeding of fines to the combustion zone was started at 1854 hours and the temperature in the bed was lining out at nominally 1800°F. At this time, a pipe failure occurred in the fines transport line as a result of a crack in the heat-affected zone of a weld downstream of heater F114. The system was immediately shut down to repair this pipe. The cracked pipe was removed, and a new section of Incoloy 800 was welded into the system on February 26.

Hot air flow was resumed, the bed was reestablished at 24 feet, and re-ignition took place on February 27 at 0212 hours. About an hour later, the glycol cooling line on the process air compressor failed as a result of vibration on a fitting. The system was maintained on stream but was depressurized to 50 psi to permit operation with only the first stage of the compressor while the line was repaired.

The system was repressurized on February 28 and was heated from 1830°F to 1940°F by reducing the amount of recycle gas on the gasifier fines transport gas from 445 to 260 lb/hr and reducing the sparger ring recycle gas flow from 880 to 730 lb/hr. Samples taken from the ash collection boot began to show the first evidence of ash agglomerates in the 1/16-inch and 1/8-inch particle size range. Run conditions during this steady-state period are shown in Table 3.1-1 and on Figure 3.1-2. Samples of agglomerated ash taken during the first 12 to 16 hours of agglomeration increased in ash content and size. The concentration of ash in the ash withdrawal phase also increased because withdrawal rates were very low during this portion of the test. These results are presented in Table 3.1-2.

As the average particle size grew from 1/4-inch to 3/8-inch in size, the lower portion of the ash annulus became defluidized and the interface between a coke-breeze fluidized region and the defluidized ash was readily observed. The ash particles were spherical and rather dense although some internal voids were noted as shown in Figure 3.1-3. In order to decrease the ash residence time and avoid potential sintering of the bed should ash content rise excessively, the ash withdrawal rate was increased to the maximum. A sprocket change was made on T129 starwheel feeder to permit up to 3.8 times the previous feed rate. Over the next few hours,

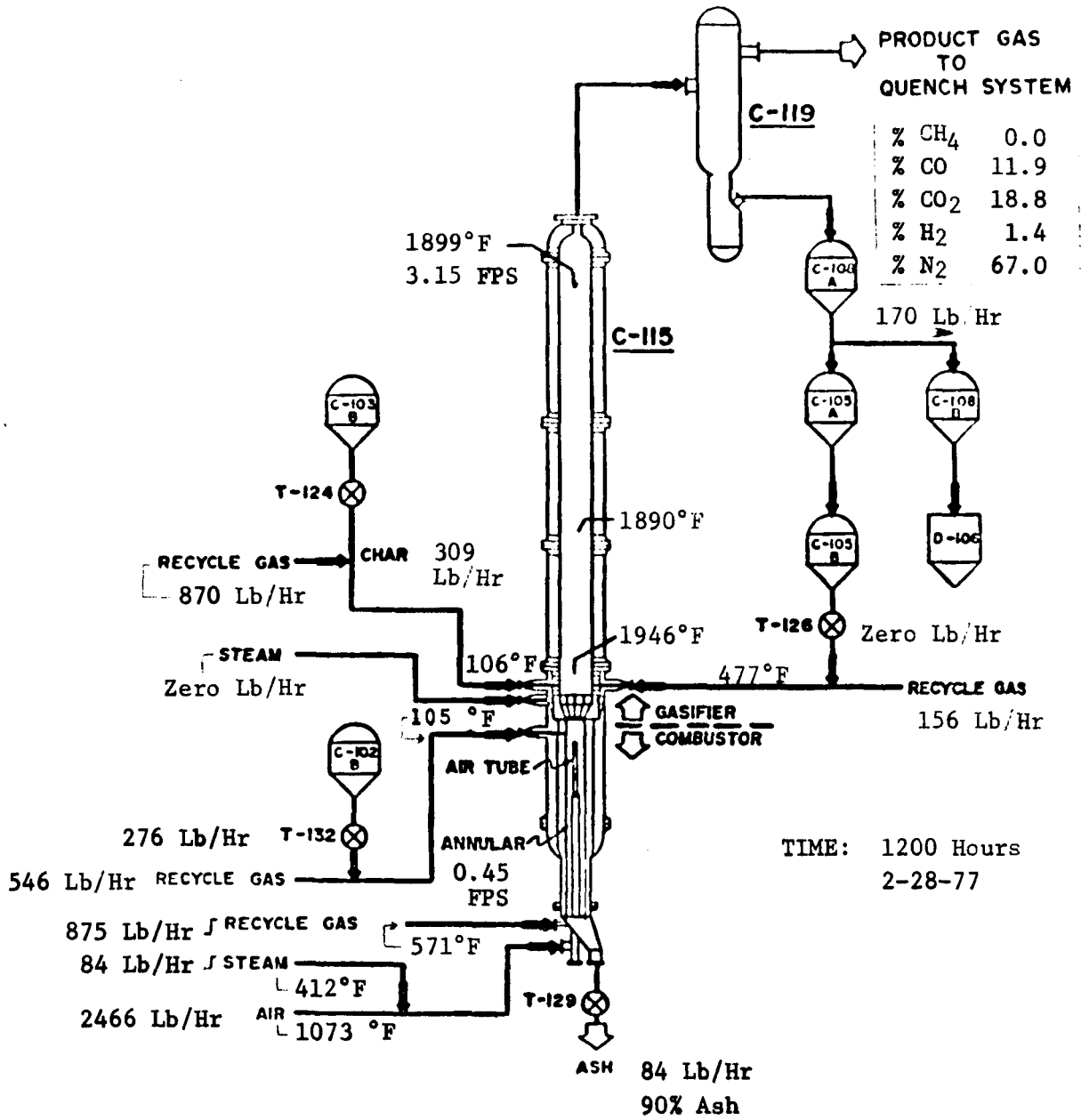


Figure 3.1-2 Gasifier Operating Parameters, Test TP-011-3

TABLE 3.1-2 ASH ANALYSES AND WITHDRAWAL RATES,
GASIFIER TEST TP-011-3

<u>Time</u>	<u>Percent Ash</u>	<u>Withdrawal Rate, Lb/Hr</u>
0230 (2/28)	25.0	17
0830	44.1	17
1045	37.3	84
1230	92.7	84
1459	95.8	84
1630	95.6	84
1830	87.8	51
0630 (3/1)	86.6*	0

*Taken during shutdown phase.

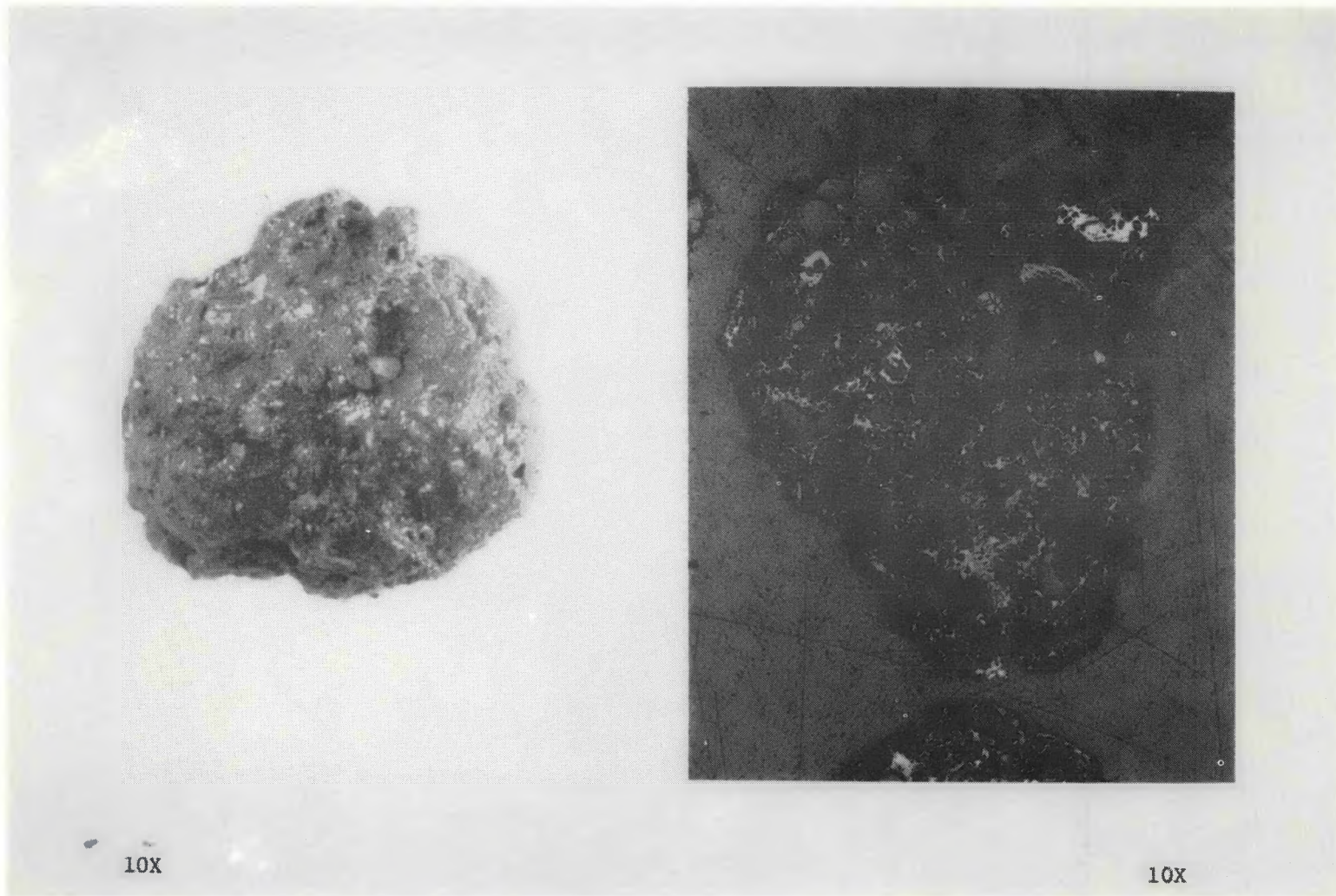


Figure 3.1-3 Ash Agglomerates Produced in the PDU Gasifier During TP-011-3 at 1900°F

the ash withdrawal rate was varied to reduce ash content in the bed, and success was achieved in that the ash annulus was partially refluidized as the heavier ash was withdrawn.

The ash withdrawal port became partially blocked with a large ash agglomerate on March 1 and very little ash drawoff was possible. During this period, ash agglomerates began to fill the bed above the air tube and the bed slumped. The run was terminated after unsuccessful attempts to refluidize and withdraw ash from the bottom of the reactor. Upon inspection, T129 was found to be blocked by a 6"x3" mass of agglomerates. The source of this clinkered mass is not clear, but the inspection of the annular region around the air tube suggested that the mass may have been formed during low-ash withdrawal rates when annular gas flow was low enough to cause a partial or total bridge between the air tube and the combustor walls. This partial bridge was probably broken by either high annular recycle gas flows or by an increased bed height.

Attempts to locate and monitor the combustion zone were partially successful using the two thermocouples extending above the air tube. The thermocouple located 13 inches above the air tube continued to read the air inlet temperature from 800°F to 1000°F. The 18-inch thermocouple indicated a temperature of 1200°F to 1400°F throughout the test after ignition. Apparently, the latter thermocouple was reading a mixed temperature of air and hot solids but was still not far enough into the jet to measure combustion-zone temperature.

Steam input to the gasifier was extremely low (80 lb/hr) during this test run due to the high volume of recycle gas used for transport flows. Gasification was performed via high carbon-dioxide partial pressures rather than steam partial pressures. Efforts were made in test TP-011-4 to reduce recycle gas usage for transport flows by increasing preheater capacity to more closely simulate the original design preheat temperatures of 1000°F.

Results of test TP-011-3 indicated that recycle gas flow rates into the annular region around the air tube should be increased to provide a more violent fluidized region near the top of the air tube to prevent any stagnation of ash or coke breeze particles in this region. Stagnation of fluidization in this region was likely the cause of a bridge across the air tube found after TP-011-3 shutdown.

The existence of relatively large ash agglomerates in the bed was probably a function of the large size distribution (-4+34 mesh) of the coarse coke breeze feed and the relatively high ash content and residence time in the bed. The latter effect was a result of problems encountered in withdrawing ash from the bed at sufficiently high rates. The results suggested that future tests be run with a close control on ash contents in the bed and ash collection annulus rather than strictly on ash-to-char interface control. In addition, experience indicated that should ash withdrawal be interrupted during subsequent testing, efforts should be made to quench

combustion to 1700°F within one to three hours from the initial time that the withdrawal is interrupted. This will prevent ash buildup in the bed that can cause agglomeration of large ash particles to create a particle size too large for fluidization and removal from the reactor.

The gasifier reactor head was removed following completion of TP-011-3. A five- to seven-foot layer of partially sintered ash filled the 20-inch diameter section of the gasifier above the air tube. This layer formed during the final hours of operation when ash removal was not being accomplished. A large agglomerate found at the exit of the ash annulus was responsible for this drawoff system blockage. The ash layer was mechanically removed through the ash drawoff port, and the reactor was cleaned and prepared for resumption of the scheduled test program.

3.1.2.3 TP-011-4 Test

A test plan for TP-011-4 was written, reviewed and issued to PDU Test Engineering and Operating personnel. The goal of this shakedown test was to explore the following operating performance parameters:

1. Effect of combustion temperature on ash agglomerate particle size and composition.
2. Effect of steam-to-air ratio and steam-inlet location on char gasification and temperature distribution in the reactor.
3. Effect of freeboard velocity on fines elutriation.
4. Effect of annulus fluidization velocity on char-ash separation.
5. Effect of fines recycle on combustion and agglomeration.

The coke breeze used in this test was a finer size cut to reduce the potential for line plugging at a given transport gas flow rate. The line plugging and the heat load on the gasifier was reduced substantially by the addition of greater transport gas heater capacity for char, char fines and recycle fines streams.

The reactor system was pressurized to 200 psig and was leak tested on March 14. Preheating the refractory with hot air at 1000°F was completed prior to initial feeding of -6+60 mesh coke breeze on March 16, and a 25-foot bed of coke breeze was established. The initial temperature ramp on the air heater was begun at 2035 hours on March 16, and auto-ignition of the char took place at 0120 hours on March 17.

Steam was added to the air tube to moderate the combustion temperature, which leveled out at 1650°F. During this heatup period, a high shell temperature of 850°F was observed on the reactor ash withdrawal cone.

Steam added through the ash annulus sparger did not appreciably lower the shell temperature; so the combustion was quenched by lowering the air flow to the reactor. Flow and pressure drop data from the previous few hours of the run were reviewed to determine the cause of excessive temperatures in the ash annulus, and it was decided that the fluidizing gas flow to the annulus was too high. This resulted in an annulus gas velocity of 1.1 to 2.4 fps and in slugging of the bed in the ash annulus. This slugging caused hot solids from the combustion zone to be carried to the ash collection zone. Based on these results, a 1300 lb/hr limit was placed on the fluidizing gas flow to the annulus, particularly on startup. The reactor cone was both visually and dye-penetrant inspected, and the pressure was tested at 250 psig prior to restarting the unit. Combustion was resumed at 1717 hours on March 17. Again, slugging-induced high temperatures were observed in the ash annulus, but immediate reduction of fluidizing gas to 400 lb/hr brought these temperatures under control.

Several changes were made at this time. The casing on the cooling water pump for the quench scrubber failed, and the pump had to be quickly valved out of the system. Cooling was continued on the basis of makeup water from C113 cooling tower. Also, the ash annulus fluidizing gas was changed from carbon-dioxide to recycle gas, and flows were set to nominally 500 lb/hr. The initial test point of 1900°F in the fluidized bed was achieved at 0520 hours on March 18.

A program to increase ash concentration in the bed was begun about 0300 hours and resulted in the first formation of agglomerates at 0815 hours. At this time, the ash concentration in the bed was 20-30% and it was 50-80% in the ash withdrawal annulus. These nominal values were held for the next 12 hours by matching ash withdrawal rates with ash input rates. Ash withdrawal rates of 80 to 140 lb/hr were required based on the feed and fines carryover rates. The differential pressure in the ash annulus decayed to 0.06 psi per foot as the ash replaced the coke breeze originally present in the annulus. Operating values for this portion of the test run are shown in Table 3.1-1 and on Figure 3.1-4.

Following completion of the 1900°F set point, the bed temperature was increased to 1950°F. A steady-state temperature was achieved in the bed at 2120 hours on March 18 at which time a plug developed in the char fines feed line. Temperatures in the reactor were reduced to 1840°F while the plug was removed. By 0140 hours on March 19, the temperature was again established at nominally 1950°F, but another plug developed in the feed line. During the period between plugs, the apparent bed densities in the annulus gradually fell and material withdrawal from the ash annulus was at zero by 0530 hours. An attempt to refluidize the annulus and dislodge apparent blockages to the ash withdrawal port was unsuccessful, and the reactor was shut down.

Post-test examination of the reactor revealed that the ash annulus contained no material, thus accounting for the "low" density and the zero ash withdrawal. An ash clinker blocked the ash annulus near the top of

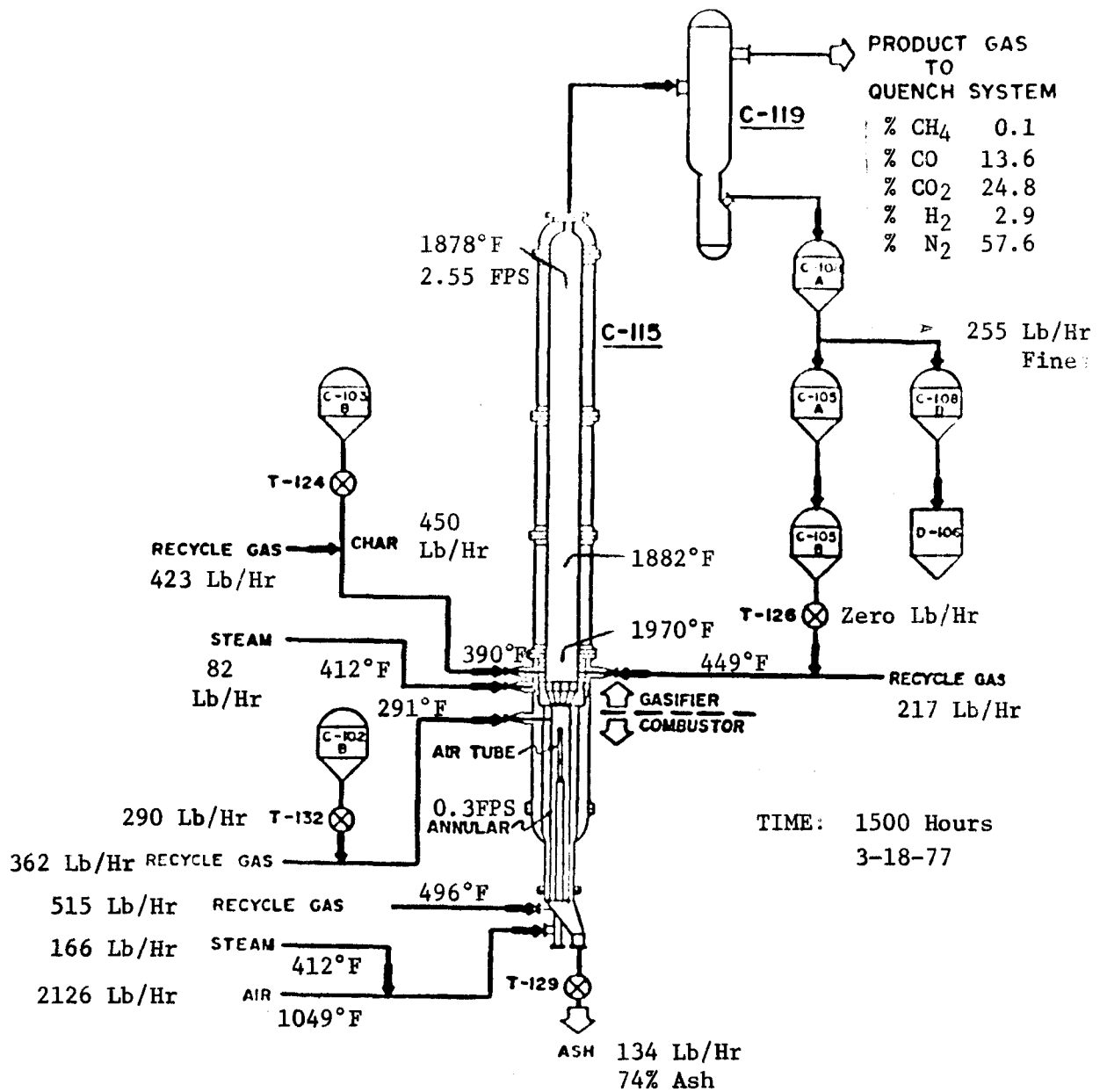


Figure 3.1-4 Gasifier Operating Parameters, Test TP-011-4

the air tube and prevented ash agglomerate withdrawal from the bed. The grid plate region was restricted to an 8-inch diameter by a buildup of sintered ash. This sintered mass was composed of 1/8-inch to 3/8-inch agglomerates fused together and not noticeably oxidized.

During run TP-011-4, a number of important operational techniques were established and additional data were obtained on fluidized bed operation and on heat and material balances. Due to the premature termination of the test, not all the goals were accomplished; however, important conclusions drawn from the data obtained were:

1. Ash agglomeration occurred at 1900°F when bed ash concentration was between 20% and 35%.
2. Ash particle size for a -6 mesh feedstock at 1900°F bed temperature was 1500 μ and bed particle size was 600 μ when ash content in the agglomerates was held in the range of 50-80%. These data are shown in Figure 3.1-4.
3. Bulk density of the agglomerates was 44 to 54 lb/ft³ while the bulk density of the bed was from 29 to 40 lb/ft³ as shown on Figure 3.1-5.
4. Efficient mixing of the ash annulus near the top of the air tube appears to be important in preventing sintering the agglomerates. It is also important that ash withdrawal and continuous char feed be maintained in order to control ash concentrations locally in the combustion zone.
5. Slugging in the annulus due to high gas velocities caused excessive solids mixing which resulted in a skin temperature excursion. This can be controlled on the basis of temperature indications on thermocouples in the annulus by decreasing ash annulus fluidizing flow.
6. Reactor startup and steady-state bed temperatures are readily controlled by adjusting inlet air temperature and both air and steam flow rates.

3.1.3 Gasifier Tests - Work Forecast For Next Quarter

The TP-011 shakedown series of tests will be concluded and will produce data, procedures and hardware to permit consistent and understandable operation of the PDU. Following this test series, TP-012 reactor evaluation tests will be conducted with coke breeze to explore and define the effects of important variables on reactor performance. Geometry, flow rates, solid particle sizes, ash concentration, gasification rates, agglomeration rates, temperatures and related variables will be examined.

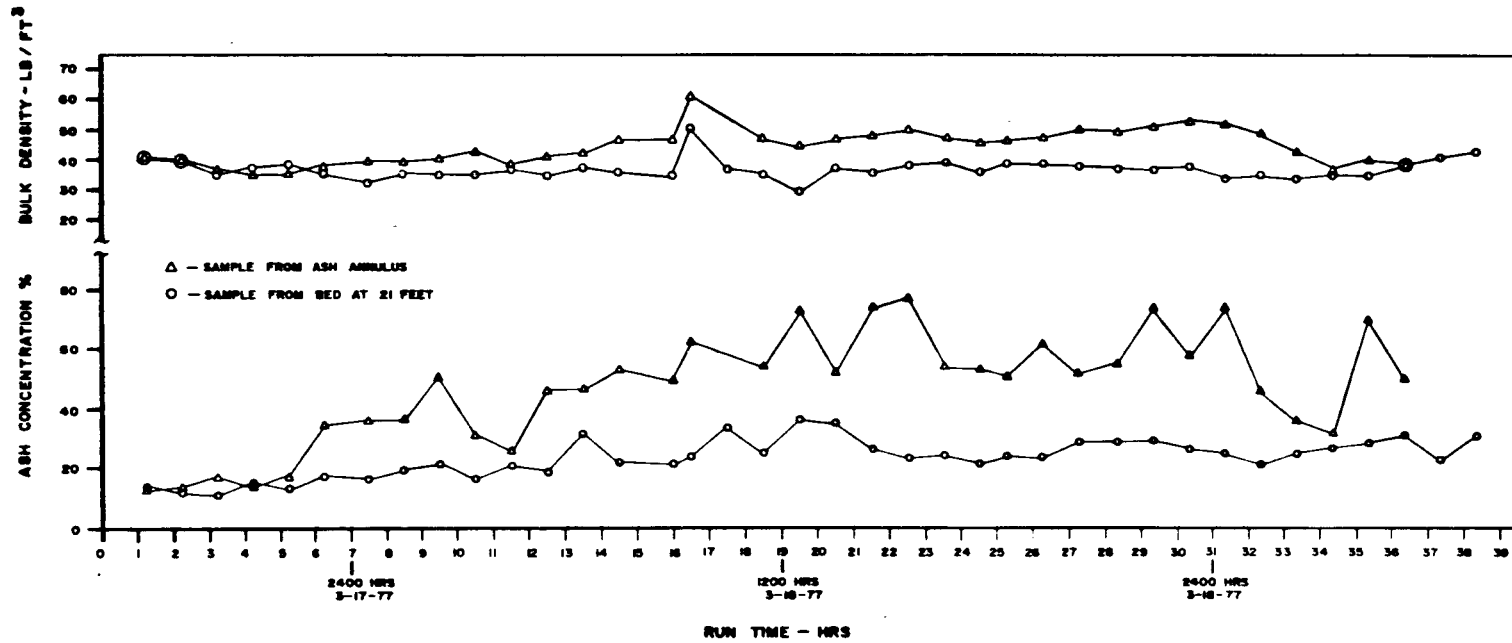


Figure 3.1-5 Ash Concentrations and Bulk Densities for Gasifier Test TP-011-4

3.1.4 PDU Engineering and Design

3.1.4.1 Work Accomplished

Two programs were designed and coded for the computerized data acquisition and management system. One routine is a generalized experimental filter for processing online raw data from lockhopper load cells and converting it to a derivative or rate. This program attempts to interface the load cells to the real-time data system since, at present, these variables are only recorded on analog charts requiring manual data reduction. A second program interfaces the analog recorder to the computer to permit outputting digital data from the process in analog form for test data review and process control.

An experimental program was initiated to evaluate various elbow configurations used in the pneumatic transport of solids and to examine the failure of two 45° ells in the Incoloy char feed line during TP-011-2. Results of this study, to be reported later, will help set design criteria for future scaled-up plant transport lines. The two 45° Incoloy elbows which failed were removed for inspection along with one 90° elbow which did not fail, and the entire line was measured for erosion using an ultrasonic probe. No significant erosion was measured or observed for the 90° bends; however, an analysis of the erosion pattern on 45° bends suggested that erosion occurred as a result of the reflection of particles from the surface of particle buildup in the dead leg of the elbow. This mechanism was confirmed by calculations of erosion rates at various impingement angles which indicated that impingement at 30° to 40° results in maximum erosion. Hardness tests were also conducted on Incoloy and carbon steel, and a decision was made to continue to use Incoloy 800 as the piping material for high-temperature lines but to eliminate all 45° bends.

Plans for characterization of PDU product streams were formulated in January and involve characterization of product gas streams for gaseous composition, particulates, alkali metals, ammonia and trace elements. Solids streams will be analyzed for proximate and ultimate analyses as well as for ash composition and particle size distribution. Liquid samples from the cooling water system will be analyzed for: solids content and particle size, hydrocarbon content and composition, and dissolved components (H₂S, ammonia, chlorine and related species). With respect to product gas measurement, a meeting was held with representatives from Aerotherm Corporation to discuss the product gas sampling and analysis probe that they are developing under an EPA contract. Aerotherm proposed to do work with this probe for Westinghouse on the coal gasification PDU.

An investigation of gas chromatograph data for the devolatilizer test series indicated that the oxygen content in the product gas was between 0.5% and 0.8% for all tests. From a thermodynamics point of view, it is unlikely that free oxygen can co-exist with carbon-monoxide and hydrogen at these temperatures. Further investigations revealed that, with the type of molecular sieve used in the chromatographic columns, the peaks for argon and oxygen overlap. Calibrations confirmed this peak to be an argon peak.

A study was made to determine whether the thermal oxidizer could be converted to use #2 fuel oil rather than propane fuel in the event propane supplies became scarce. This conversion is possible and would cost \$5000 for hardware and \$8500 for labor; the proposal is being studied for future implementation. Another study was made to determine whether nitrogen or argon could be used in the event carbon-dioxide became unavailable, and preliminary findings indicated that this change would be too costly to implement, at this time.

An analysis of the recycle gas compressor system was made based on problems encountered during the last two tests with high carbon-dioxide makeup flow to the system. Experiments were conducted in January with this system following a complete cleaning of the recycle gas headers and cooling towers, and the problems were traced to an improperly adjusted set point on the controller which delivers recycle gas to the cooling tower from the product gas stream. When this set point was reset to give a 10 psi drop, carbon-dioxide makeup to the system was reduced to zero and the material balance for the recycle gas system was closed to 5%.

During post-test inspection for gasifier test TP-011-1, substantial erosion and corrosion was observed on the outlet dump flange for C111 quench scrubber. A slip-on flange was used for this installation; however, this flange has since been replaced and only weld-neck flanges will be used in the future for such corrosive, erosive service.

During TP-011-1 testing, it was determined that high transport flows were required on char feed lines to the gasifier to maintain velocities on the order of 45-55 fps. At these flow rates, the transport gas preheaters were not able to maintain required temperatures at the inlet to the reactor and they were redesigned (in cooperation with Hynes Electric) to achieve greater capacity. The char heater was increased from 23-34 kW and the two fines heaters were increased from 15-28 kW each. These units were procured and installed in March.

The main shutoff valves to the recycle gas filter system leaked during TP-011-1 testing, making it impossible to safely change filters with the plant in operation. Conversations with the valve manufacturer determined that these valves must have plugs and seats that are matched pairs and machine-lapped at the factory as well as be a split-wedge design for proper sealing against gaseous service. New valves were procured for this purpose.

An analysis of heater failures on the CO₂ vaporizer system and discussions with Hex Industries (heater manufacturer) resulted in redesign of the heater supports and spacing to prevent vibration which could cause insulation cracking and ultimate shorting of the heaters. A new entry flange was designed to properly space the heaters at their entry into the water bath, and support spacers were designed for the U-bend near the base of the heaters. A low-temperature alarm and a cutout switch were designed to shut down the heaters and the CO₂ flow system when outlet temperatures fall to the point at which liquid can condense in the line.

Problems encountered during TP-011-3 testing were investigated and solutions implemented: (1) F114 and F122 heaters failed due to burned-out elements and a failed rectifier. Element failures at the hottest portion of the heaters may have resulted from material imperfections or carbon deposition in a localized area. Both heaters were repaired and placed into service. (2) One of the Hills-McCanna dump valves on C113 cooling tower failed; this appeared to result from an improper fit between the body and the Waukesha-88 metallic seats. This valve was replaced while the system was on line at 200 psig, marking the first time that the new bypass system for these dump valves was used.

3.1.4.2 Work Forecast For Next Quarter

Major tasks include completion of the design for the modified product gas cooling system and waste handling system, procurement of equipment for product characterization, and Test Engineering work in support of gasifier operations.

3.1.5 PDU Maintenance, Construction and Operation

3.1.5.1 Work Accomplished

Equipment and piping damaged by freezing weather during January and February were repaired and reinstalled including: cooling water lines on the quench scrubber, circulating water pumps, strainers and lockhopper shutoff valves. All water lines throughout the plant were inspected for faulty heat tracing, and several areas of inoperative or inadequate heat tracing were defined. Corrections were made to the trycock drain lines from C122 and C113; dump valves on C113, C112 and C122; and seal water lines on all pumps.

Parts for the char feed line block and bleed valve system were received and installed to permit clearing of plugs from the char feed line without depressurizing the reactor. New heater elements were installed in transport gas heaters F114, F117 and F122 to increase their power ratings by 50%. This modification also reduced the heat load on the gasifier, lowered the freeboard velocities required to run at 1950°F, and reduced the carry-over of fines.

A sample conical grid plate for the devolatilizer was cast using a special form constructed for this purpose, and a local facility was solicited to fire the shape to cure the refractory. In related work for integrated operation, the C110 cyclone dip leg was removed from the structure and was prepared for removal of its refractory lining. New castable ES refractory will be installed to better protect the metal shell.

The new K-Ray nuclear densitometer was installed on the reactor to monitor ash-char interface in the ash collection annulus. A radiation survey conducted by safety personnel indicated too high a level of gamma radiation when the sources are open. To prevent exposure of personnel, lead shielding was designed and installed around the unit, and acceptable levels of radiation were achieved.

Based on the poor results obtained in TP-011-1 with the pyrometer which measures combustion temperature in the gasifier, the pyrometer was removed from the bottom of the gasifier. Parts were procured for fabricating a dual thermocouple installation to measure combustor temperature. Two chromel-alumel thermocouples were installed in the air tube of the gasifier and were extended 13 and 18 inches, respectively, above the air tube. One thermocouple well was fabricated from silicon carbide and one with calcia-stabilized zirconia. These ceramic tips were secured to the 310 stainless steel thermocouple well with Sauereisen #78 cement. Both performed adequately during the gasifier tests conducted this quarter.

3.1.5.2 Work Forecast For Next Quarter

Maintain and operate the plant in support of gasifier tests TP-011-5, TP-011-6 and TP-012.

3.2 PHASE I, TASK 2A - MODIFICATIONS TO THE PDU

3.2.1 Work Accomplished

Several additions to the PDU are required in order to integrate present independent gasifier and devolatilizer configurations into a series operation. A char transfer line between the two reactors and a refractory-lined product gas line connecting the top of the gasifier with the devolatilizer are the primary components required. Numerous instrumentation changes are also required. These changes were submitted in January to prospective component suppliers and subcontractors for bid. Bids were received, compiled and reviewed. Subcontractors and component suppliers were selected, and purchase packages were prepared to initiate procurements. A summary of the bids was submitted to ERDA.

Design packages for integrated operating hardware were reviewed from the standpoint of "Make or Buy" decisions which had to be made. If time and personnel are available, WESO personnel may be used to install electrical and instrumentation hardware, wiring and refractory lining of major vessels. Mechanical installations, structural modifications and major vessel placement will be subcontracted. Procurement actions will be initiated in the next quarter.

In addition to the basic hardware required to integrate the two reactors, three additional design changes are being processed: (1) addition of expanded freeboard sections to the reactors, (2) a conical grid plate for the devolatilizer, and (3) series operation of the two existing cyclones.

3.2.1.1 Expanded Sections

The operation of the devolatilizer during 1976 was limited by its size. Heat losses from the unit made it difficult to maintain an exit temperature of 1600°F with the gas throughputs used in the tests. Increasing the gas flow rates to increase heat input into the reactor was limited by increased elutriation and corresponding increased loadings on the cyclone and quench system. These operational problems were largely a result of the low char densities in the unit as compared with those values specified in the original design. To some extent, increased inlet temperatures on fluidizing gas and on coal transport gas would alleviate this problem. Some sintering and slagging of the ash was encountered at the higher inlet temperatures, above 1950°F. An alternative method of solving the problem would be to enlarge the upper section of the devolatilizer to permit increased gas throughputs at the same freeboard velocity.

The expanded freeboard design includes a 48-inch diameter section above the draft tube. The existing 36-inch diameter section will be retained below the draft tube. Effectively, with refractory installed, the expanded section will increase the cross-sectional area of the reactor from 2.18 ft² to 4.23 ft². The addition of the 18-foot long section will increase the present unit's length by about five feet.

Design of the expanded freeboard section for the devolatilizer was reviewed by both WESO and R&D Center personnel. It was agreed that the design would be a benefit in allowing the throughput of the reactor to be increased without increasing fines carryover. Heat conservation will still be required to achieve 1600°F exit gas temperatures, and this will be accomplished by the use of a more efficient refractory insulator and minimization of sensible heat duty on the refractory by heating the inlet streams and reducing coolant flows and purges. An analysis of the expanded reactor design showed that additional freeboard height would alleviate carryover, would provide more consistent char drawoff and would accommodate the increased jet penetration expected at the higher proposed draft tube velocities. This section would also provide better separation (classification) of the char and dolomite should in-bed desulfurization be used.

An expanded freeboard section for the gasifier was designed which is nearly identical to the one for the devolatilizer with the exception of nozzle locations. Bid packages were prepared and submitted to prospective suppliers, and procurements are expected to take place in the next quarter.

3.2.1.2 Conical Grid Plate

The existing flat grid plate design for the devolatilizer performed adequately but exhibited two problems which can be overcome by proper redesign. The flat grid allowed solids to collect in stagnant areas near the wall since these areas were not swept with recirculating char. If sufficient gasification of carbon takes place, the remaining ash particles in these stagnant areas can sinter or slag. The use of a single gas inlet grid plate would be desirable when the gasifier is integrated with the devolatilizer since it would be difficult to meter the flow of fluidizing gases to the downcomer and draft tube as is presently done externally through control valves.

A conical grid redesign would solve both problems. Mockup of the redesign in the semi-circular plastic cold-flow model at the R&D Center indicated that good solids circulation can be maintained with a single gas inlet to the draft tube, providing the spacing of the gas inlet with respect to the draft tube inlet is adequate. This allowed a portion of the jet to bypass the draft tube and enter the downcomer. The conical surfaces also provided a clean swept surface, free of stagnant areas.

Two designs were completed for the conical grid plate. The prime design is for a conical section that can be inserted between the present grid plate and the bottom of the draft tube in the devolatilizer. Gas distributor holes would provide for fluidizing gas in the downcomer and would introduce the gas through a "bubble cap" configuration near the base of the draft tube. The alternate design includes flow distributor holes in the conical section that directs the fluidizing gas in a downward direction to enhance solid circulation. The more simple design was submitted to several refractory manufacturers for bid, and the complex design, to increase char circulation in the devolatilizer, was fabricated by the WESO Maintenance Group, using Castolast G refractory. An excellent result was achieved on the latter. A decision on the final design to be used will be made on the basis of model tests conducted by the R&D Center Fluidization Research Group.

3.2.1.3 Series Cyclones

When the gasifier and devolatilizer are integrated, the gasifier cyclone will not be used. If this cyclone could be connected to the outlet of the existing product gas cyclone, a better gas cleaning could be achieved. Studies are being performed to determine the feasibility of using the second cyclone. Two alternate configurations are being evaluated from the standpoint of cost, performance and required downtime: (1) move the gasifier cyclone to the outlet of the devolatilizer and close-couple it with the existing cyclone for the devolatilizer, and (2) leave both cyclones in place and install refractory-lined piping between them.

This work is being performed along with design of the devolatilizer expanded freeboard section to insure that proper interfaces are achieved. Decisions will be made in the next quarter as to the advisability of proceeding with this change. Procurements will be initiated at this time.

The original design layouts for the devolatilizer conical grid plate, the expanded sections for the two reactors and for repair of the dip legs in both cyclones were modified, based on communications with Rockaway Tank Company (devolatilizer manufacturer) and with Harbison-Walker Corp. (supplier of refractory linings). Original design modifications were recommended as follows:

1. Use a shell thickness of one inch instead of 3/4-inch for the expanded sections to eliminate the need for reinforcing pads around entry nozzles. According to the manufacturer, this construction will provide a more reliable, less costly unit.
2. Use a medium density refractory (ES Castable) for relining the dip legs in both cyclones to prevent the high skin temperatures noted during recent gasifier and devolatilizer tests. This lining was chosen instead of the traditional two-layer lining

of Castolast G and HW-4064 or of the single four-inch lining of HW-4064 because it provides adequate abrasion resistance and skin temperatures with the simplicity of a single-layer refractory.

3. Use a high-temperature prefired refractory, Korundal XD, for manufacture of the conical grid plate. Harbison-Walker advised that a lead time of three months is required for grid plate manufacture. Casting the conical grid plate at WESO Waltz Mill is an acceptable backup.
4. Attempt to use a single layer of insulating refractory in the expanded sections in view of the fact that the hydrogen content in the product gas is less than 20% and the temperature is less than 2000°F. Under these conditions, silica migration would not be a problem.

3.2.2 Work Forecast For Next Quarter

Complete all hardware designs and initiate all procurements. Begin test planning for the integrated test series.

3.3 PHASE I, TASK 3 - LABORATORY SUPPORT STUDIES

Laboratory support studies were carried out in four areas: fluidization and fluid particle systems, coal behavior, ash agglomeration and reactor analysis. No work was conducted on sorbent behavior this quarter.

3.3.1 Fluidization and Fluid Particle Systems

3.3.1.1 Work Accomplished

The series of cold model simulation experiments studying the performance of the combustor-gasifier under different design and operating conditions was concluded. The design parameters studied were air tube location and the air tube diameter. Experiments were performed with the air tube flow alone; with a combination of air tube flow and flow in the char-ash separation zone; with a combination of air tube flow and flow through the conical section between the gasifier and the combustor; and with a combination of air tube flow (jet flow), flow in the char-ash separation zone (annular flow) and flow through the conical section between the gasifier and the combustor (conical flow).

The air tube velocity was varied from 3 m/sec to 67 m/sec, and the annular flow in the char-ash separation zone was maintained at slightly higher than the minimum fluidization condition. Both jet penetration data and solid circulation rates were recorded. The jet penetration depth was observed visually and the solid circulation rate was measured by following tracer particles with a stop-watch for a distance of 15.2-20.3 cm (6-8 in.). The air tube positions studied were 0 cm, 15.2 cm (6 in.), 30.5 cm (12 in.), and 45.7 cm (18 in.) from the bottom of the conical transition between the gasifier and the combustor. Two air tubes of inside diameters 3.8 cm (1.5 in.) and 5.4 cm (2.12 in.) and semi-circular in cross-section were used.

Preliminary data on solid circulation rate and jet penetration depth for the 3.8 cm I.D. air tube at 15.2 cm from the transition section are presented in Figures 3.3-1 through 3.3-4. Figures 3.3-1 and 3.3-2 show the effect of air tube velocity and flow combination on the solid circulation rate (measured through the particle velocity). Several important points can be noted. The solid circulation rate is linearly proportional to the air tube velocity. At low air tube velocities (less than 80 ft/sec), flow through the conical section or annular section, in addition to the jet flow, does not increase the particle velocity; however, up to 25% increase of solid circulation rate is possible at higher air tube velocities with a combination of jet flow and annular flow. At an air tube velocity above ~47 m/sec (155 ft/sec), the particle velocity increases at a faster rate with respect to the air tube velocity. At about this air tube velocity, the jet was visually observed to penetrate through the bed, and the gasifier was operated as a spouted bed.

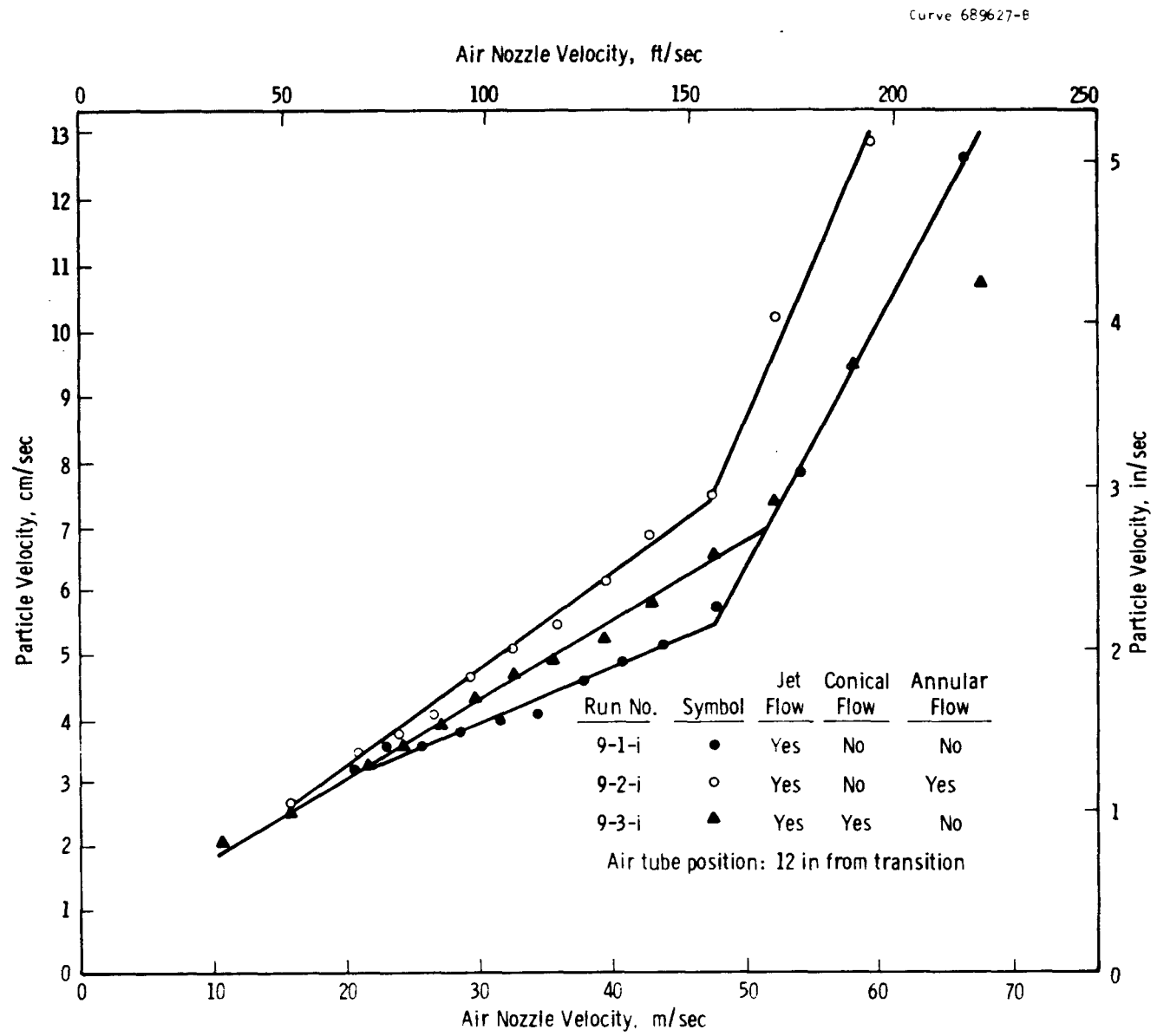


Figure 3.3-1 Dependence of Solid Circulation Rate on Air Tube Velocity - Test Runs 1, 2 and 3

Curve 689626-8

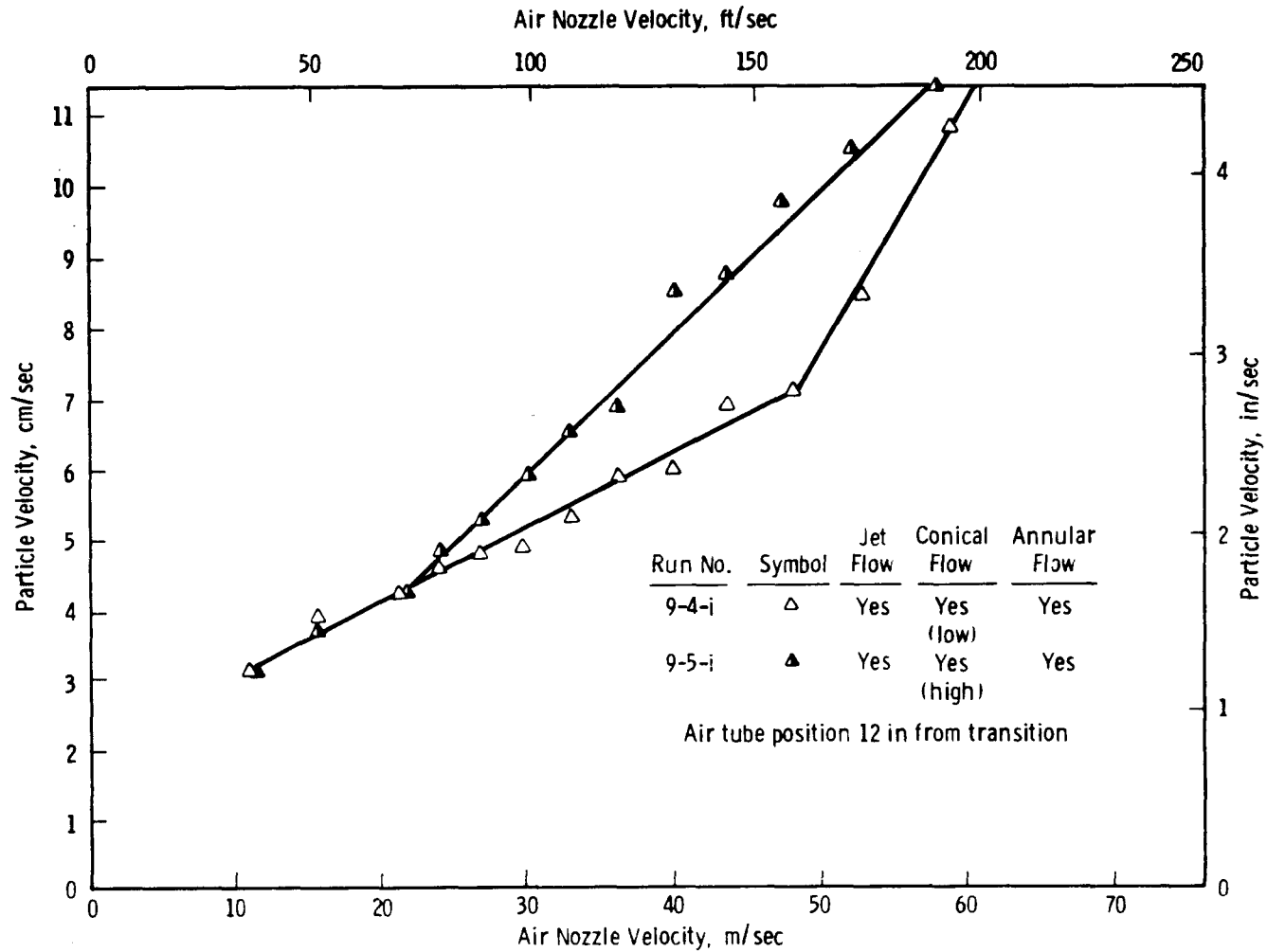


Figure 3.3-2 Dependence of Solid Circulation Rate on Air Tube Velocity - Test Runs 4 and 5

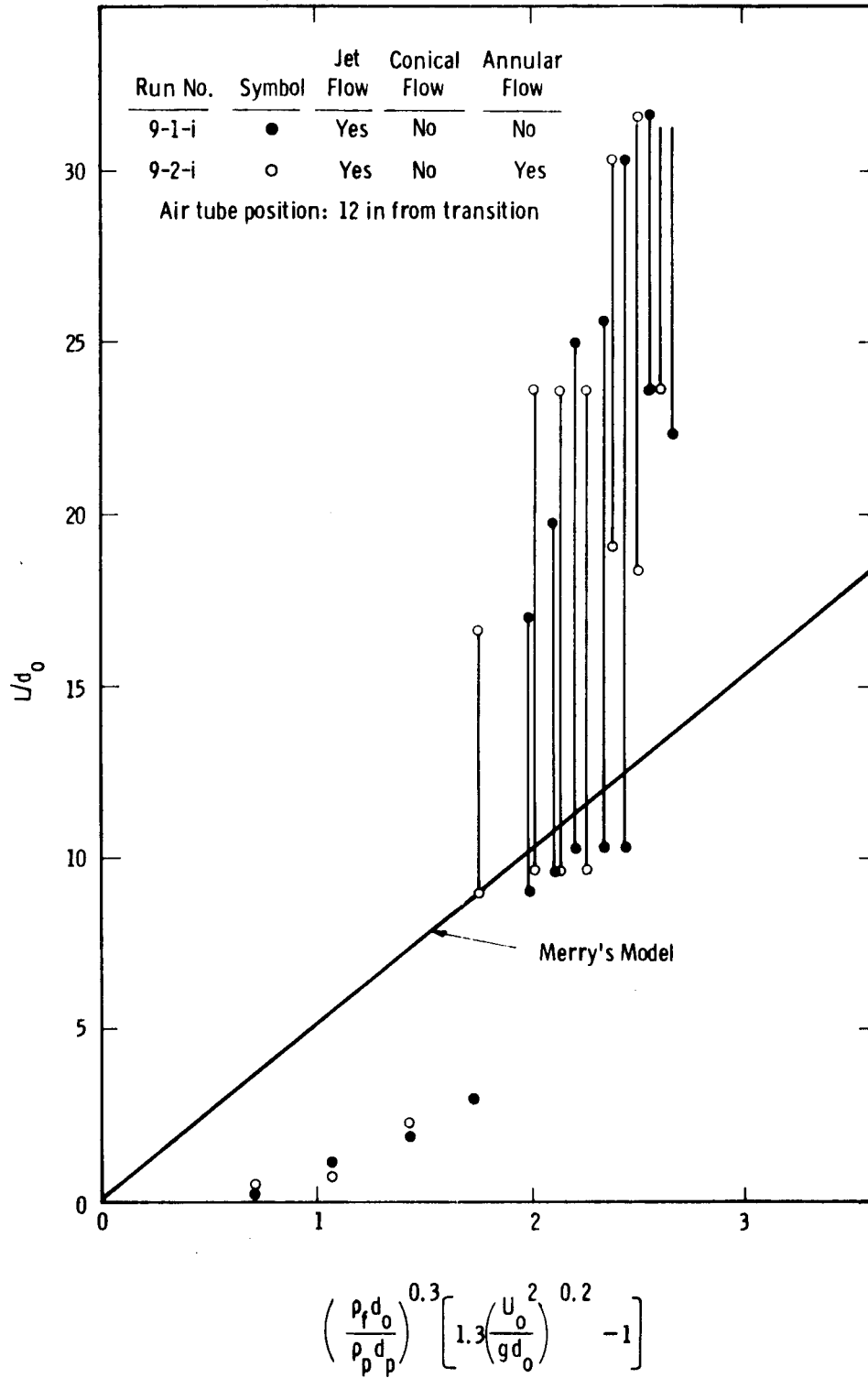


Figure 3.3-3 Observed Jet Penetration Depths at Different Operating Conditions - Test Runs 1 and 2

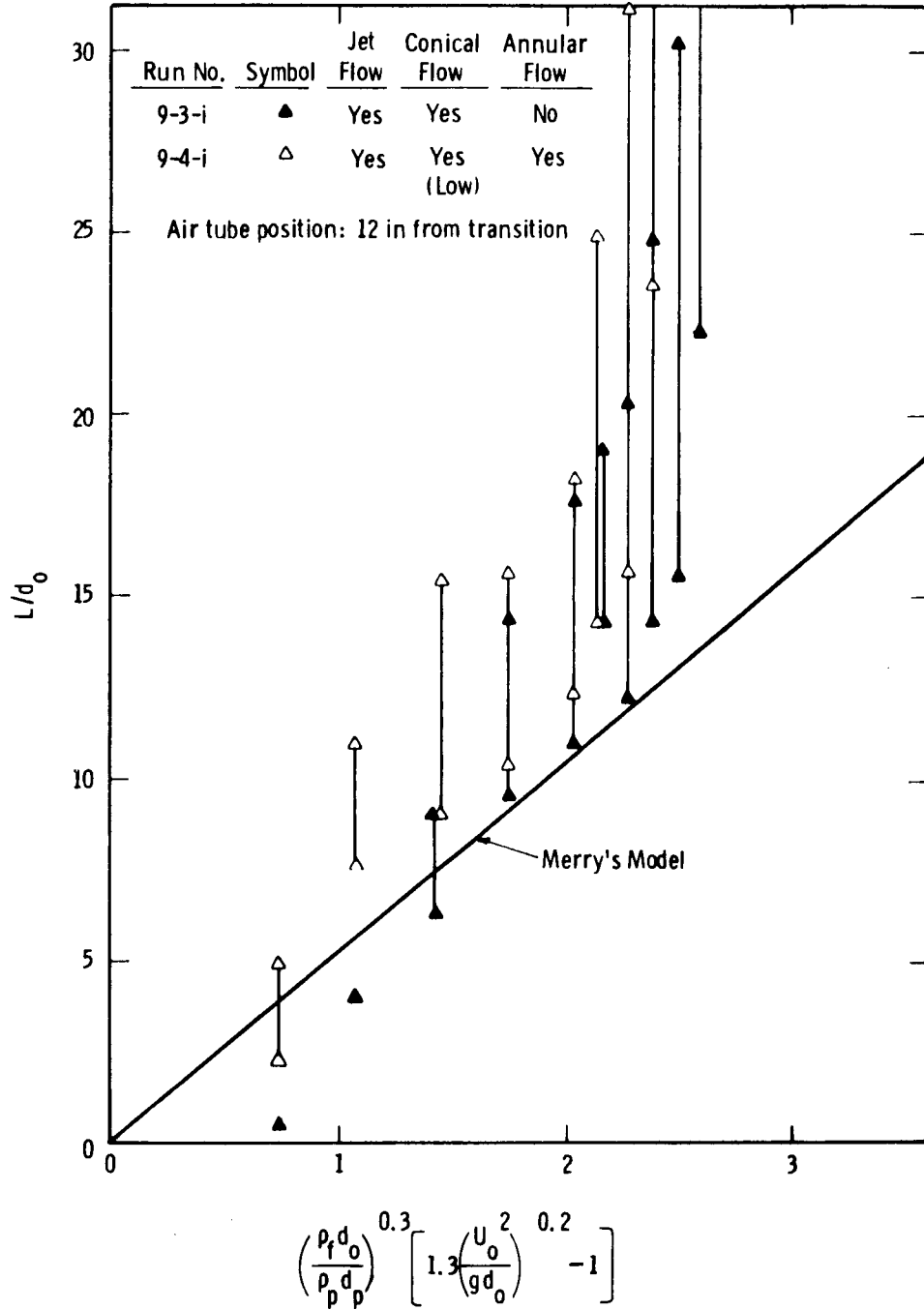


Figure 3.3-4 Observed Jet Penetration Depths at Different Operating Conditions - Test Runs 3 and 4

When all three flows (jet flow, conical flow and annular flow) were on, the relationship between the air tube velocity and the particle velocity showed similar dependency (Figure 3.3-2) except at air tube velocities less than ~ 24 m/sec where an increase of solid circulation rate up to 30% was obtained. In addition, the characteristic discontinuity in the air-tube-velocity/particle-velocity relationship is absent for Run Series 9-5 where higher conical flow was employed. The bed started to slug at an air tube velocity of ~ 27 m/sec in this series of experiments because of high flow rate.

Jet penetration depths for the air tube jet at different velocities were recorded, and they were plotted according to the dimensionless groups proposed by Merry (AIChE J., 21, 507, 1975) in Figures 3.3-3 and 3.3-4. A finite jet penetration depth was not observed as described by Merry and others even when the jet flow was the only flow into the bed. The jet penetration depth was observed to always fluctuate. The range of fluctuation depended on the total gas flow rate in the bed. It is reasonable to expect that the jet penetration depth will fluctuate because the fluidized bed itself fluctuates both in bed height and in pressure drop in the bed. Merry's model was derived for a jet penetrating into a minimally fluidized bed.

There are three distinguishable jet penetration regions observed as shown in Figure 3.3-3. At lower jet velocities, the jet penetrates into the bed for a finite depth without fluctuation. Although local solid circulation was observed inside the jet, mass solid circulation was absent. The second region was the region for jet penetration into a minimally fluidized or into a regular fluidized bed. Even the air tube jet was penetrating into a minimally fluidized bed; large fluctuation in penetration depth was observed contrary to that described by Merry. This may be because of the jet and bed dimensions employed here. When the jet dissipates its energy and becomes a bubble, the bubble has comparable dimensions with the bed. The passage of this bubble through the minimally fluidized bed is enough to cause large fluctuation of pressure in the bed and cause the fluctuation of jet penetration depth. However, Merry's model is seen to correlate the lower bound of jet penetration in this region fairly well. A model may be developed to correlate the upper bound of jet penetration in this region based on existing fluidized bed theories.

When the total gas flow is large enough, the fluidized bed begins to slug. Jet penetration depth into a slugging bed is much larger as shown in Figures 3.3-3 and 3.3-4. Soon after this region, the jet completely penetrates through the bed.

In response to the request from PDU personnel, a simulated thermocouple (1/4 inch in diameter) was installed inside the air tube, protruding 22.9 cm (9 in.) out of the air tube top. Several series of experiments have been run under this configuration with no visibly adverse effect due to the presence of the simulated thermocouple. The protruding

thermocouple did not preferentially divert the jet .

The semi-circular model is being converted to the devolatilizer configuration to accept a new conical distributor plate for simulation of devolatilizer operation in the future integrated operation in the PDU. The simulation of continuous char-ash separation in the combustor-gasifier configuration originally scheduled has been postponed in order to obtain design data for the grid.

3.3.1.2 Work Forecast For Next Quarter

Support PDU operation. Perform the experiments in the devolatilizer mode using the new distributor plate at different distances from the draft tube inlet to study the solid circulation rate and gas bypassing rate. Convert model and perform tests for continued combustor-gasifier support as needed.

3.3.2 Coal Behavior

3.3.2.1 Work Accomplished

A spare Inconel reactor is being modified for use in devolatilization experiments to investigate the effect of char dust on coal agglomeration.

Tests were also conducted to study the coke breeze-CO₂ reaction at partial pressures of CO₂ (P_{CO₂}) of 1, 2, 3 and 4 atmospheres over a temperature range of 1600 to 1900°F. The results are shown in Figure 3.3-5. The lines for different partial pressures of CO₂ were obtained from a regression analyses. It can be noted that the slopes of these lines are nearly the same. An arithmetic average of the activation energies was determined to be 93,030 Btu/lb mole. This compares favorably with values reported in the literature.

In order to determine the effect of the concentration of CO₂ on the reaction rate, the expression $R/\exp(-46,845/T)$ was plotted against the partial pressure of CO₂ and the results are shown in Figure 3.3-6. An arithmetic average of the values at each partial pressure was used in obtaining the following regression equation by the least square method:

$$R = 1.89 \times 10^6 \exp(-46,845/T) P_{CO_2}^{0.54}$$

where R is the reaction rate, min⁻¹ and T is the temperature in °R.

Curve 689461-A

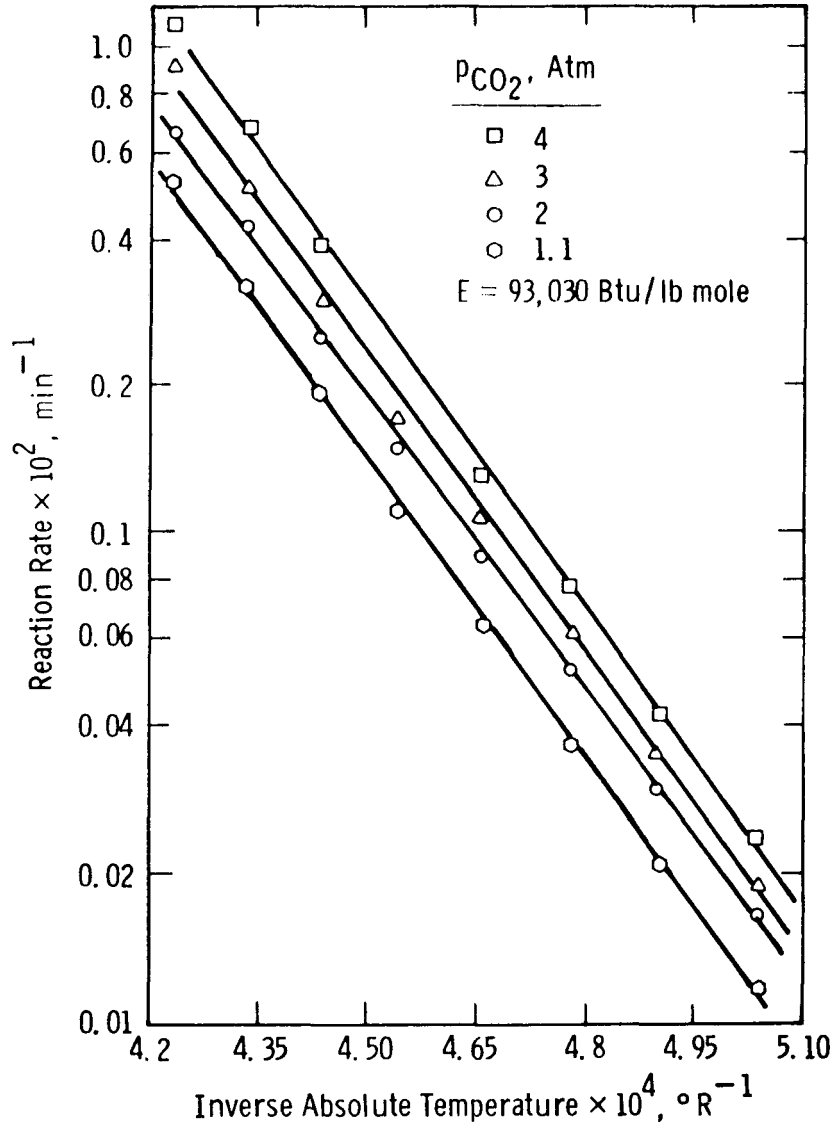


Figure 3.3-5 Reaction Rate of Coke Breeze with CO_2 as a Function of Temperature for Different Partial Pressures of CO_2

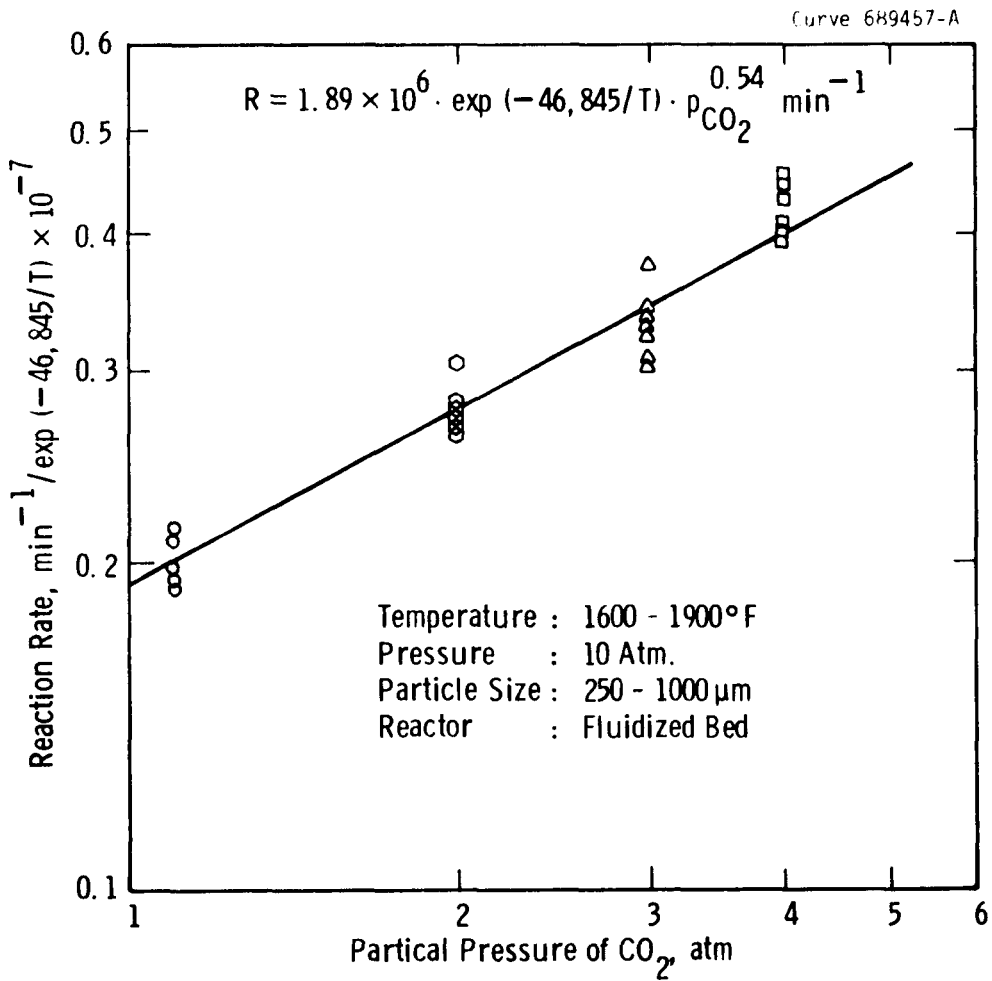


Figure 3.3-6 Reaction Rate of Coke Breeze with CO₂ as a Function of Partial Pressure of CO₂

Tests are underway to determine the effect of the carbon conversion which changes the surface area available for reaction on the reaction rate. After obtaining a correlation for this effect, a generalized rate equation will be obtained to show the effect of temperature, gas composition and the carbon conversion. Limited results obtained to date on the effect of carbon conversion on the reaction rate of coke breeze with steam are shown in Figure 3.3-7. The reaction rate versus the square of fractional conversion, X^2 , was plotted on a semi-logarithmic paper. It can be seen that the results are well represented by a straight line except in the initial stages showing that the following correlation can be expected:

$$R = A \exp (- \alpha X^2)$$

where α depends on the nature of the carbonaceous material.

Results obtained on Minnehaha char-steam reaction (reported in the 4th Quarterly Report of 1976) were analyzed in the same way and are shown in Figure 3.3-8. The results are well represented by a straight line up to a conversion of about 65%. The explanation for the decrease in the reaction rate with higher conversions requires additional experimentation and further analysis. It is interesting to note that the reaction rate increased with conversion in the case of Minnehaha char while the opposite trend was observed for coke breeze.

A test was conducted to obtain the reaction rate of coke breeze with steam at a partial pressure of 1 atm of steam over a temperature range of 1600 to 1900°F. The results are shown in Figure 3.3-9. The activation energy was determined to be about 98,860 Btu/lb mole.

3.3.2.2 Work Forecast For Next Quarter

Char gasification studies will continue with coke breeze to study the C-H₂O reaction and C-CO₂ reactions. Tests will subsequently be conducted with chars from the PDU devolatilizer.

3.3.3 Ash Behavior

3.3.3.1 Work Accomplished

Hot operation of the ash agglomeration combustor was started in January. The immediate objectives were to demonstrate the operability of the equipment and the ability to agglomerate ash. To simplify the initial operations, nitrogen has been used to fluidize the ash separation section of the combustor. In later experiments, the nitrogen will be replaced with steam.

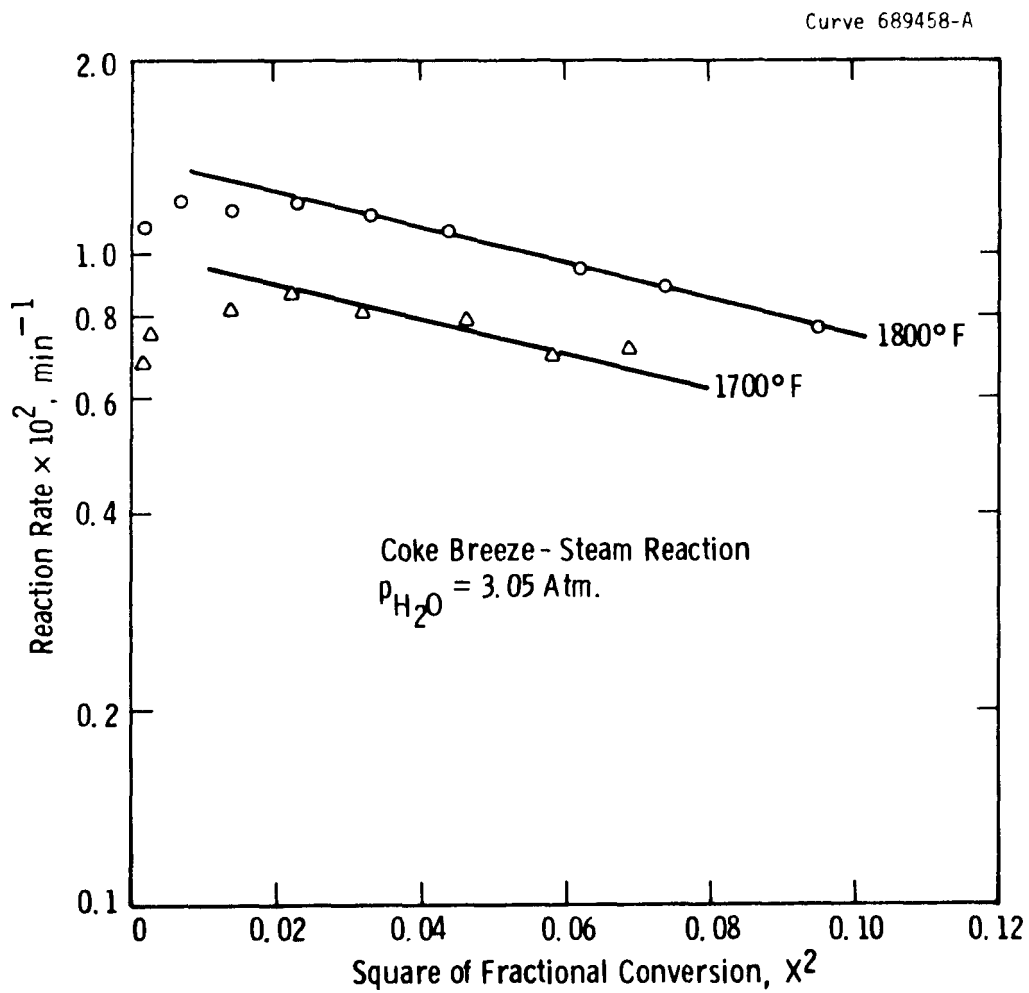


Figure 3.3-7 Effect of Carbon Conversion on the Reaction Rate -
 Coke Breeze/Steam

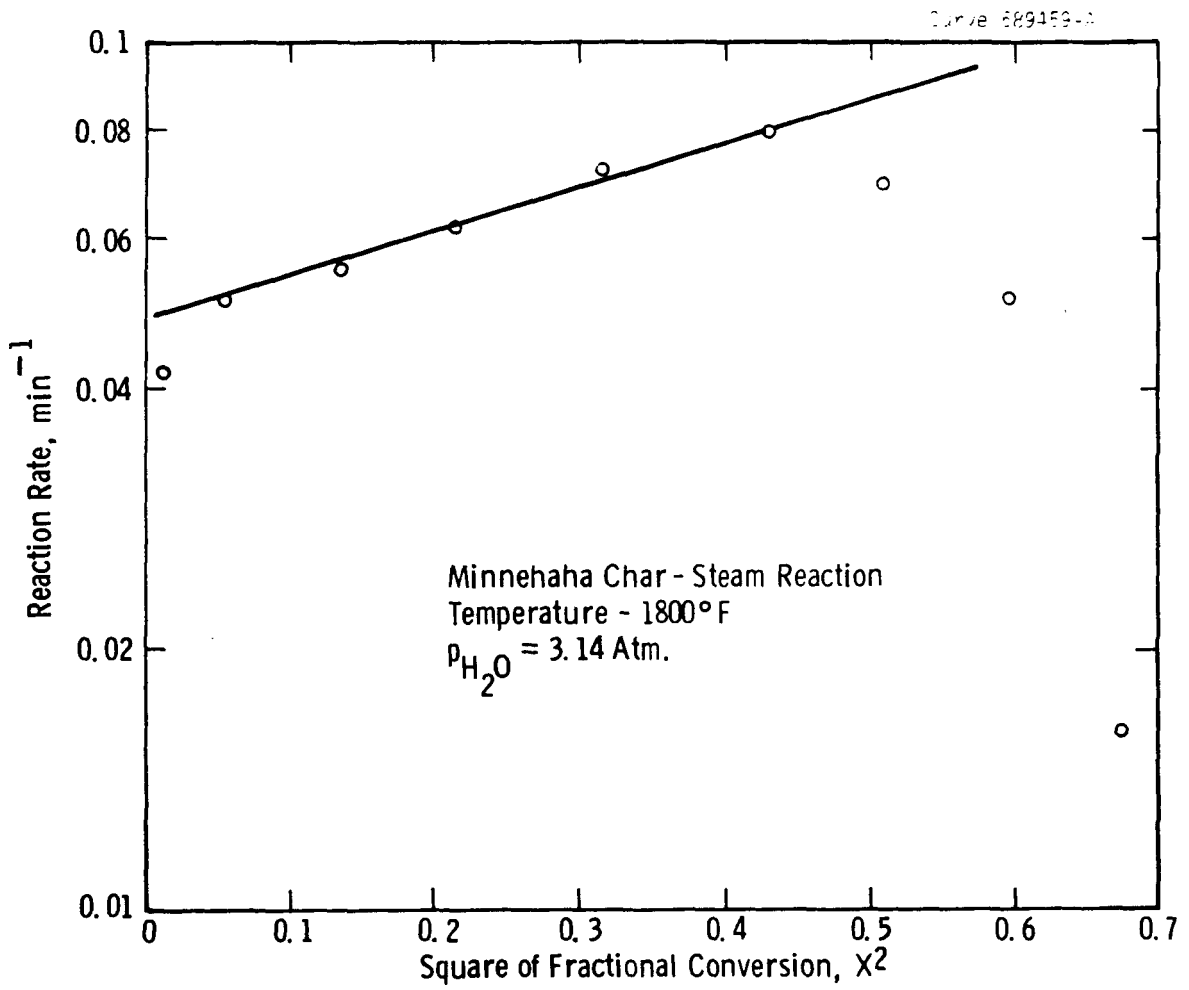


Figure 3.3-8 Effect of Carbon Conversion on the Reaction Rate - Minnehaha Char/Steam

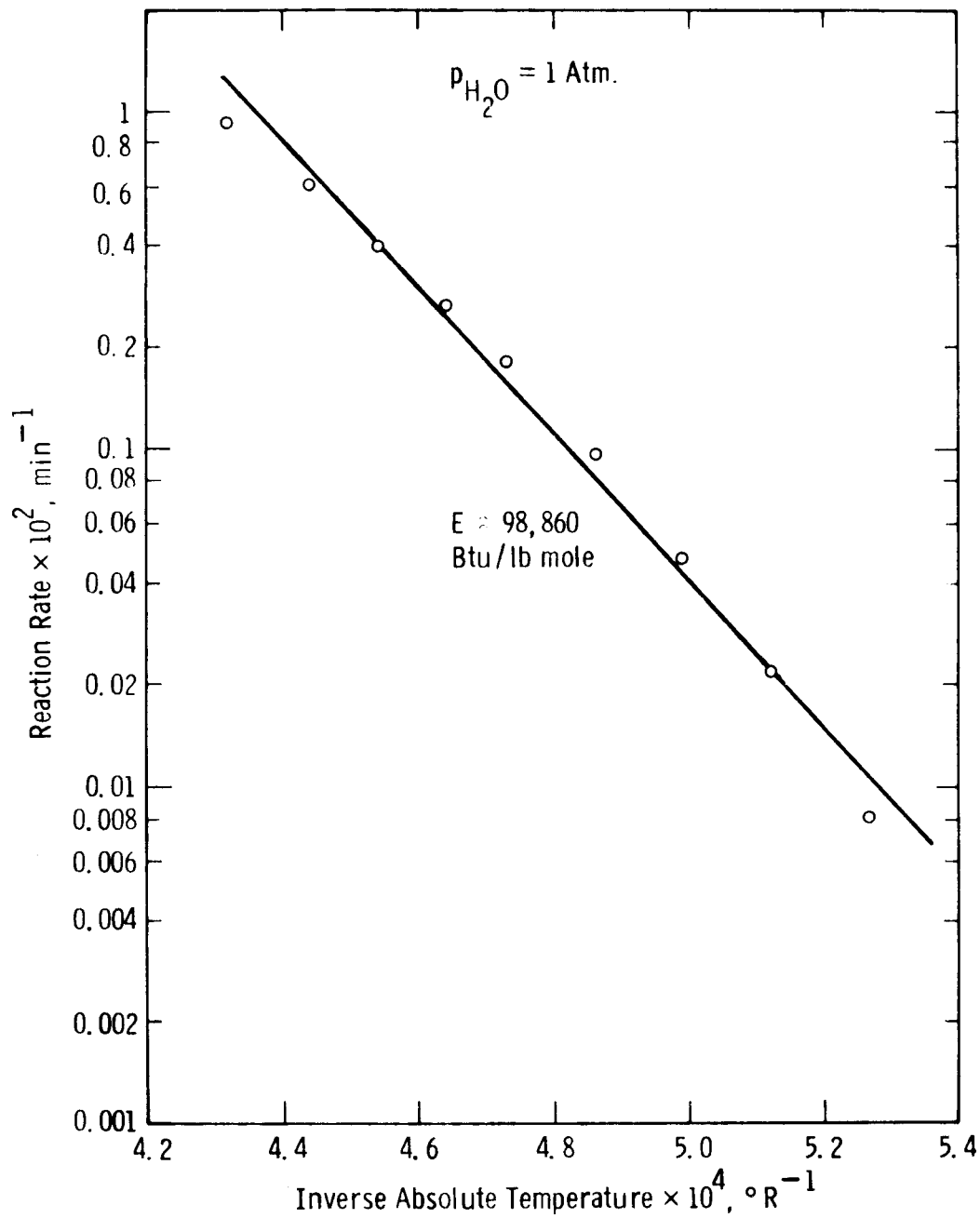


Figure 3.3-9 Reaction Rate of Coke Breeze with Steam as a Function of Temperature

Four tests have been completed. All were run with an FMC char made from Western Kentucky bituminous coal. The char bed was heated overnight in the reactor to about 1400°F with nitrogen flowing through the bed. The test was started by replacing the nitrogen with air. After the bed had reached a temperature of 1600°F, continuous feeding of char fines and a slow discharge of material from the ash separation leg were started. The bed temperature was raised to 1950°F and 2000°F and was controlled in this range by adjusting the furnace power and by replacing part of the air feed with nitrogen whenever the temperature rose above 2000°F. To make up bed losses due to entrainment and ash removal, coarse char was added intermittently directly to the bed.

No agglomeration of ash occurred in the first two experiments. In both tests, the air velocity was very high and the jet apparently penetrated the bed. (A baffle was installed at the reactor outlet for the second test to reduce entrainment losses.) Oxygen utilization was low and, in the first test, the agglomeration temperature was never reached. A temperature of 2000°F was attained in the second test but the test had to be shut down a short time later because of the failure of a brazed joint in the air feed line.

For Tests 3 and 4, the air jet velocity was decreased by increasing the diameter of the air feed orifice. This step greatly improved the operation of the combustor. Entrainment losses decreased, the desired bed temperature was attained more quickly, and the concentration of CO in the exhaust gas rose substantially. Ash agglomeration occurred in both tests, forming both well rounded pellets and unsymmetrical particles.

The third experiment was run for two hours and was stopped so that the bed could be examined. The fourth test lasted four hours and was shut down unintentionally by a blockage of the air feed tube. Later inspection revealed the presence of dense metallic-appearing pellets in the air tube. These were found to be nickel sulfide which was formed by H₂S corrosion of the Inconel thermocouple protection tube. The char contained 2.6% sulfur.

The production of considerable unpelletized ash in these two experiments suggests that the bed temperature should have been somewhat higher and that the bed should have been more vigorously stirred. To achieve these ends, the internal configuration of the combustion section of the reactor will be changed from the present cylindrical shape to a conical shape. This should give more uniform fluidization and permit higher air flows. In addition to this change, a higher freeboard will be provided to reduce entrainment losses. The thermocouple protection tube problem will be corrected by using ceramic tubes.

The air feed rate in the experiments ranged from 1.00 to 1.25 scfm. The particle size of the bed char was -1400 μm + 500 μm and the size of the char fines fed with the air was -500 μm + 106 μm. Spot samples of off-gas analyzed are shown in Table 3.3-1.

TABLE 3.3-1 OFF-GAS SPOT SAMPLES FROM EXPERIMENTS ON THE AIR FEED RATE

<u>Test Number</u>	<u>Bed Temperature, °F</u>	<u>Volume, %</u>		
		<u>CO</u>	<u>CO₂</u>	<u>O₂</u>
1	1430	0.2	10.0	3.3
2	1870	10.6	9.5	0.7
3	1860	16.7	5.1	0.7
3	1960	17.8	3.4	0.6
4	2000	--	4.0	0.5

3.3.3.2 Work Forecast For Next Quarter

Run several agglomeration experiments with coke breeze, using the present combustor. Modify combustor to improve fluidization characteristics and increase freeboard height. Continue ash agglomeration experiments with the modified combustor to determine the optimum conditions for ash agglomeration and to define the limits of operability.

3.3.4 Reactor Analysis

3.3.4.1 Work Accomplished

Material and energy balances were performed on the combustion and gasification zones of the agglomerating combustor-gasifier for specified operating conditions to help generate an operating map for the PDU. These are based on the rate of char gasification predicted from a gasification model for specified temperatures of the combustor and the gasifier and the temperatures of all the streams. The calculations estimate the flow rates of char, air, steam and product gas for a given solid circulation rate between the combustion zone and the gasification zone and other parameters. The effect of the operating conditions on the flow rates of char and air, the freeboard velocity and the heating value of the gas has been examined from these material and energy balances.

The gasification model is based on the plug flow of gas and the back mix flow of solids and rate equations for the carbon gasification reactions obtained from the literature.

A document is being prepared to report the details on the char gasification model and on the procedure to carry out material and energy balances.

3.3.4.2 Work Forecast For Next Quarter

Update combustor-gasifier material and energy balances and the char gasification model as new data are available from the present experimental program.