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Advanced Coal Gasification System for Electric Power Generation

WESTINGHOUSE ELECTRIC CORPORATION
GENERATION SYSTEMS DIVISION
LESTER, PENNSYLVANIA 19113

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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 WAS PREPARED FOR TEST OPERATION AND THE FIRST TESTS OF THIS SUBSYSTEM WERE CONDUCTED.

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FLUIDIZED BED PROCESSORS
COAL GAS
MANUFACTURED GAS
GASIFICATION
GAS GENERATORS
SYNTHESIS GAS GENERATORS*
GAS PURIFICATION
DOLOMITE
COMBUSTION
COMBUSTION DEPOSITS
EXHAUST GASES
DESULFURIZER
EXHAUST EMISSIONS
EROSION CORROSION
AGGLOMERATION
GASIFIER AGGLOMERATORS*
DEVOLATILIZER/DESULFURIZERS*
GAS TURBINE POWER GENERATION

* NEW TERM (NOT IN THESAURUS)

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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 but 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 for a large-scale generating plant can be achieved, a combination of analytical studies, bench-scale experiments and semi-works or pilot scale evaluations are essential, particularly 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 objective of Task 2 is operation of the PDU to evaluate the process feasibility and operability of the Westinghouse coal gasification process as it is currently conceived with the 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.

The initial work in this task involved the evaluation of the devolatilizer subsystem. Shakedown and operating tests, reactor design tests, and feasibility demonstrations were conducted with a variety of coal feedstocks. The present work involves evaluation of the gasifier-agglomerator subsystem through a series of tests similar to those conducted in 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 devolatilizer and gasifier.

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 initiated during this quarter to investigate design parameters (e.g., air tube location), operating parameters (e.g., air tube gas velocity), and startup and shutdown procedures. The unit was also used to investigate the effect of an expanded freeboard section on slugging.

The coal behavior program complements the fluidization model studies and includes coal behavior in the devolatilizer, car 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. Construction of the ash agglomeration test unit was completed for investigation of ash agglomeration.

The calcium-based sorbent studies provide data to support PDU testing or operation, 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. The primary objectives during this quarter were to support the analysis of PDU test results using dolomite sorbent.

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

The gasifier system was completed mechanically in October, 1976, and was precommissioned in November in preparation for the startup of the test program. The first scheduled test, TP-001/006, was run in November and was a plant shakedown consisting of an operational checkout of the F123 startup burner, a refractory cure of the C115 reactor and C119 cyclone and two low-temperature dynamics tests. Phase I, a demonstration of the F123 propane heatup burner, was accomplished by firing the burner over the side of the structure. Phase II concerned studies of solid circulation between the gasifier and combustor sections at 800°F using dead-burned dolomite. Phase III determined the ability to detect char-ash interfaces at temperatures 200°F to 400°F using dead-burned dolomite as the dense (ash) phase and coke breeze as the char-type phase.

All equipment and procedural problems encountered during the test were solved and all solids flow systems were commissioned.

The first hot gasification test, TP-011-1, was conducted in the gasifier test system in December and was run as the initial attempt to gasify char and agglomerate ash. Coke breeze from a Pittsburgh seam coal was used as the char material. During the test, hardware problems encountered were solved as the test was being run. One problem, the erosion of the 45-degree elbows in the char feed line, resulted in termination of the test. These 45-degree elbows will be changed to 90-degree elbows prior to subsequent tests.

In spite of a failure to complete the entire test plan, about 24 hours of operation were achieved. Gasifier temperature was 1750°F prior to shutdown, so no agglomeration took place. The test was successful in accomplishing these objectives:

1. Demonstrated the ability to start the gasifier from "cold" and bring it to a steady-state condition.

2. Demonstrated the ability to ignite char with hot air at 1000°F and to control reactor temperature with steam.

3. Demonstrated the ability to feed char, devolatilizer fines and recycled gasifier fines on a continuous, controlled basis while discharging ash product from the bottom of the unit.

4. Provided baseline data for fluidized bed operation in the ash agglomerator-combustor, in the gasifier, and for all transport lines.

5. Provided operator training for all PDU crews.

6. Provided a shakedown of a multitude of equipment problems that can be corrected by repair, replacement or redesign of PDU hardware or by procedural changes.

In addition to gasifier work, data analyses and correlation of the devolatilizer test series results were completed. Material and heat balances were calculated for TP-009 and TP-010. A study was conducted of char particle size in the bed to determine the effect of a number of variables on particle growth and attrition; freeboard velocity and coal rank appear to have had the most significant influence on bed particle size.

2.2 PHASE I, TASK 2A - INTEGRATED OPERATION OF THE PDU

Designs were completed for expanded freeboard sections for the reactors and for a conical distributor grid, and procurement packages for these items will be issued for quotations. The remainder of the bids for hardware and installation subcontracts were received for the integrated operation of the gasifier and devolatilizer. Bid summaries will be submitted to ERDA for their approval 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 the PDU in areas of fluidization and fluid-particle systems, coal behavior, ash behavior and reactor analysis.

2.3.1 Fluidization and Fluid-Particle Systems

Fluidization and fluid-particle systems studies were concentrated on the effect of air nozzle velocity on the performance of the combustor-gasifier and on the rate of solids exchange between the combustor and gasifier. Jet penetration data at different air nozzle velocities and under different operating modes were also collected. These experiments helped in the selection and verification of the location of the air tube in the PDU. The observed jet penetration depths are less than the predictions from previous work on jet penetration in minimally fluidized beds. Experiments are continuing, and the results will be used to update previous design criteria. Particle velocities in between the gasifier and combustor are reported to permit a comparison of the effect of operating conditions on solids circulation. Experiments were also conducted to study the effect of an expanded section on slugging. The expanded section will be effective in reducing the slugging height based on the initial experimental results and projections from a mathematical model of the system.

Two workshop sessions were held during this quarter to allow the test engineers and supporting engineers in the PDU to observe the operation of the transparent semi-circular model under different operating modes. These sessions helped the operating engineers visualize the bed operation in the PDU.

2.3.2 Coal Behavior

The rates of reaction of Minnehaha char with steam and carbon dioxide were studied at a pressure of 10 atm and temperatures of 1500°F, 1600°F, 1700°F and 1800°F for different inlet concentrations of steam and carbon dioxide in nitrogen. In tests in which a substantial proportion of the carbon in the bed was consumed, the reaction rate was found to increase with time, probably because of an opening up of the structure of the char and an increase in surface area as carbon was consumed. Because of this effect, a mean reaction rate will have to be determined and only one data point will be obtainable in each experiment.

Rate experiments with steam were run with Montour char and with a coke breeze that is to be used in the PDU tests. Minnehaha char was the most reactive of the three materials tested, and the coke breeze was the least reactive.

2.3.3 Ash Behavior

The ash agglomeration combustor has been completed, and testing of the equipment is under way.

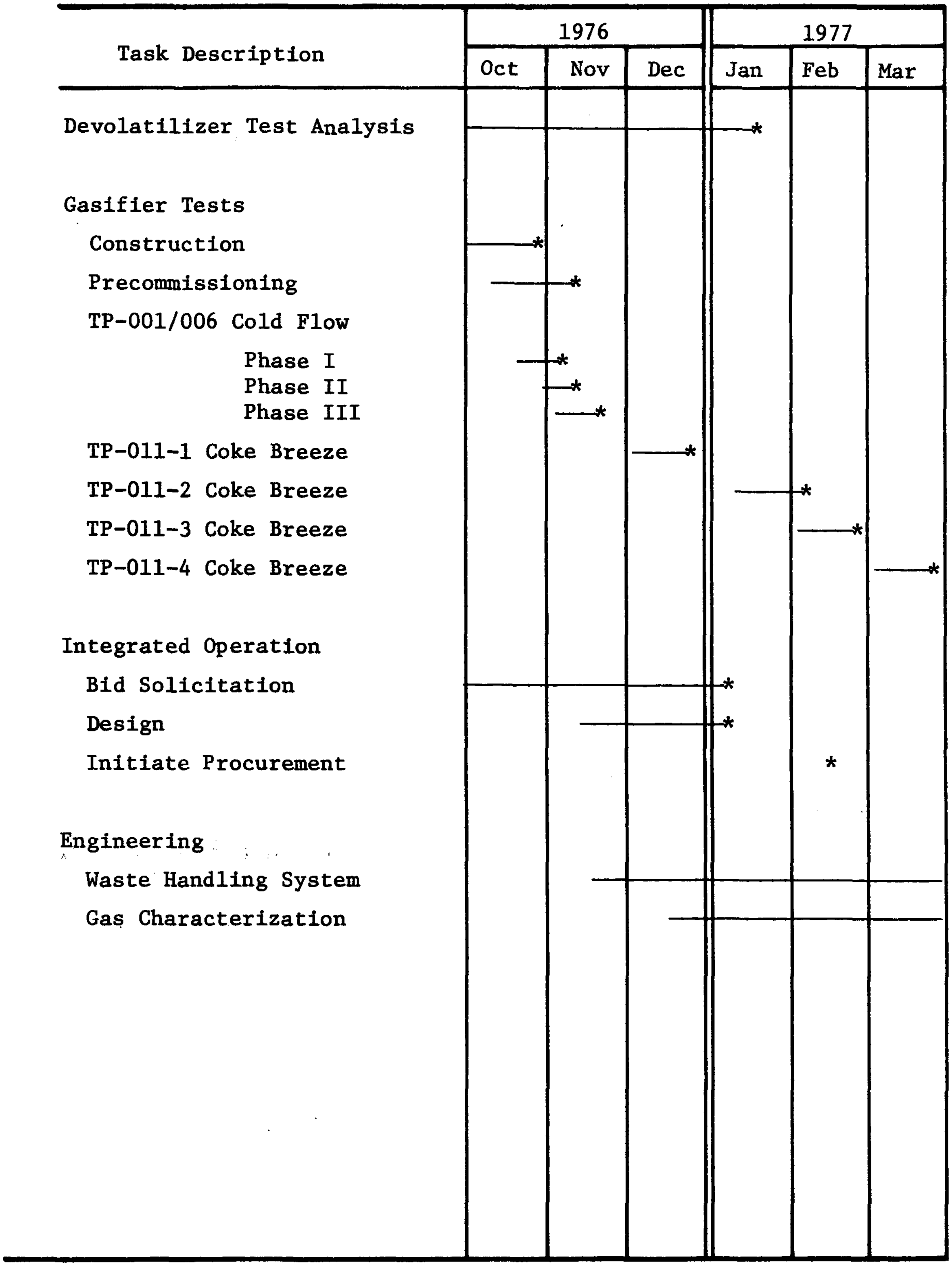
2.3.4 Reactor Analysis

Material and energy balances have been made on the combustor-gasifier unit for a wide range of operating conditions. These balances are used to develop a map of operating conditions for the PDU.

2.4 SUMMARY SCHEDULES

Summary schedules for Phase I, Tasks 2, 2A and 3 follow.

2.4.1 Summary Schedule - Phase I, Tasks 2 and 2A



2.4.2 Summary Schedule - Phase I, Task 3

Task Description	1976			1977		
	Oct	Nov	Dec	Jan	Feb	Mar
Fluidization & Fluid-Particle						
Combustor-Gasifier Hydrodynamics	———	———	———	———	———	———
PDU Operation Interface	———	———	———	———	———	———
Instrumentation	———	———	———	———	———	———
Coal Behavior						
Devolatilization	———	———	———	———	———*	
PDU Char Gasification 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 during this period.

3.0 DETAILED DESCRIPTION OF TECHNICAL PROGRESS

3.1 PHASE I, TASK 2 - OPERATION OF THE PDU

3.1.1 Devolatilizer Tests

3.1.1.1 Work Accomplished

The devolatilizer test program comprised three types of test: plant startup/shakedown, system sensitivity and feasibility demonstration runs. The work began with non-caking coal feedstocks, progressed to mildly-caking bituminous coal and concluded with highly-caking Pittsburgh and Upper Freeport seam coals. This test sequence is summarized in Table 3.1-1. Coal properties are shown in Table 3.1-2, and typical char product properties are given in Table 3.1-3.

The principal product of the devolatilizer reactor is decaked coal or char. To understand and predict the dynamics of the integrated gasification PDU, the effect of devolatilization on char production rates and on fluid dynamic properties of char particles is critical. These properties include char particle size distribution, the fraction of coal feed that becomes char product, and the split of that product between drawoff from the bed and overhead product taken from the gas stream in the particulate removal cyclone. To study these effects, the particle size of char samples withdrawn from the bed and expressed as a dimensionless ratio (geometric weight mean of char to geometric weight mean of coal) has been explored as a function of the operating parameters involved.

Figures 3.1-1 through 3.1-5 show the results of the above correlation study. Figures 3.1-1 and 3.1-2 show the correlation of the gas velocity through the reactor and the rank of the coal feedstock. To get a more complete picture, these data have been correlated in Figure 3.1-3 to include all of the pertinent effects, and several observations can be made from this plot. Due to the narrow temperature spread for the reactor gas, the constant freeboard velocity lines drawn through the data are constant gas input rate lines. Thus, proceeding to the right along a freeboard velocity line would indicate the effect due to increasing the coal feed rate. The increasing slope of the three lines drawn indicates greater sensitivity to the coal feed rate as the freeboard velocity and/or rank of the coal are increased. Because the reactor freeboard velocity and the coal rank were changed simultaneously, it will be necessary to conduct further tests and analyses to separate the effects of freeboard velocity and coal rank.

Summing the two char product flow rates, drawoff from the reactor and the overhead char separated from the product gas stream, and plotting the data as in Figure 3.1-4, we see that ∿65% of the coal feed leaves the reactor as char product regardless of the freeboard velocity.

TABLE 3.1-1 PDU DEVOLATILIZER TEST PROGRAM SUMMARY

Test Number	Type Of Test	Type of Feedstock	Name Of Feedstock	No. of Hours Coal Processed
TP-007	PDU Shakedown	Lignite Derived Char	Husky Char	17
TP-007	PDU Shakedown	Subbituminous C Coal	Sorensen	13
TP-008-1	PDU Shakedown	High-Volatile Bituminous	Minnehaha, Indiana #7	30
TP-008-1 TP-009-2	System Sensitivity	High-Volatile Bituminous	Minnehaha, Indiana #7	191
TP-009-2	System Sensitivity	Medium-Volatile Bituminous	Champion (Montour) Pittsburgh	30
TP-009-1	Feasibility Demonstration	High-Volatile Bituminous	Minnehaha, Indiana #7	131
TP-010	Feasibility Demonstration	Low-Volatile Bituminous	Renton, Freeport	96
TP-010	Feasibility Demonstration	Medium-Volatile Bituminous	Champion (Montour) Pittsburgh	91

TABLE 3.1-2 COAL RAW MATERIALS

Coal Company	Kemmerer	Amax	Consol	Consol
Coal Mine	Sorensen	Minnehaha	Montour	Renton
Coal Seam	Adaville	Indiana #7	Pittsburgh	Upper Freeport
Analysis, %				
Volatiles	36.4	32.1	35.0	35.6
Carbon	41.0	43.3	49.0	53.8
Moisture	19.9	16.2	6.5	1.7
Ash	2.7	8.4	9.5	8.9
Sulfur	0.4	0.5	1.9	1.4
Ash Fusion, °F (Reducing)				
I.D.	N/A	2170	2270	2510
H=W	N/A	2270	2310	2570
H=1/2W	N/A	2320	2350	2600
Fluid	2160	2380	2400	2650
Free Swelling Index	0	1-1/2 to 2	7 to 9	8 to 9
Gieseler Plasticity, ddm	N/A	250	25,000	30,000
Heating Value, Btu/Lb, MAF	13,217	14,250	12,570	13,740
Bulk Density, Lb/Ft^3	45.0	43.8	43.6	44.6

TABLE 3.1-3 CHAR PRODUCT PROPERTIES

Coal Company	Kemmerer	Amax	Consol	Consol
Coal Mine	Sorensen	Minnehaha	Montour	Renton
Coal Seam	Adaville	Indiana #7	Pittsburgh	Upper Freeport
Analysis, %				
Volatiles	6.2	2.7	2.9	2.7
Carbon	83.1	77.1	76.4	78.0
Moisture	1.7	1.0	0.6	1.5
Ash	9.0	19.2	18.2	16.6
Sulfur	0.3	0.2	1.9	1.2
Free Swelling Index	N/A	N/A	0.0	N/A
Gieseler Plasticity, ddm	N/A	N/A	No Fluidity	N/A
Bulk Density, Lb/Ft^3	14.7	24.2	29.2	22.0

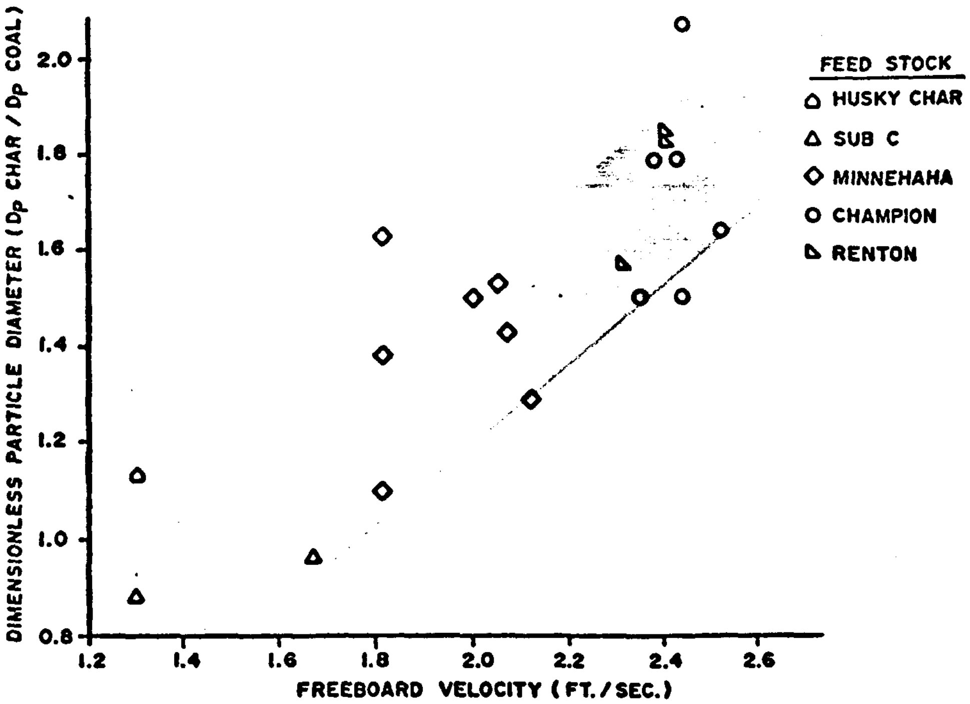


Figure 3.1-1 Bed Particle Size Vs. Reactor Freeboard Velocity

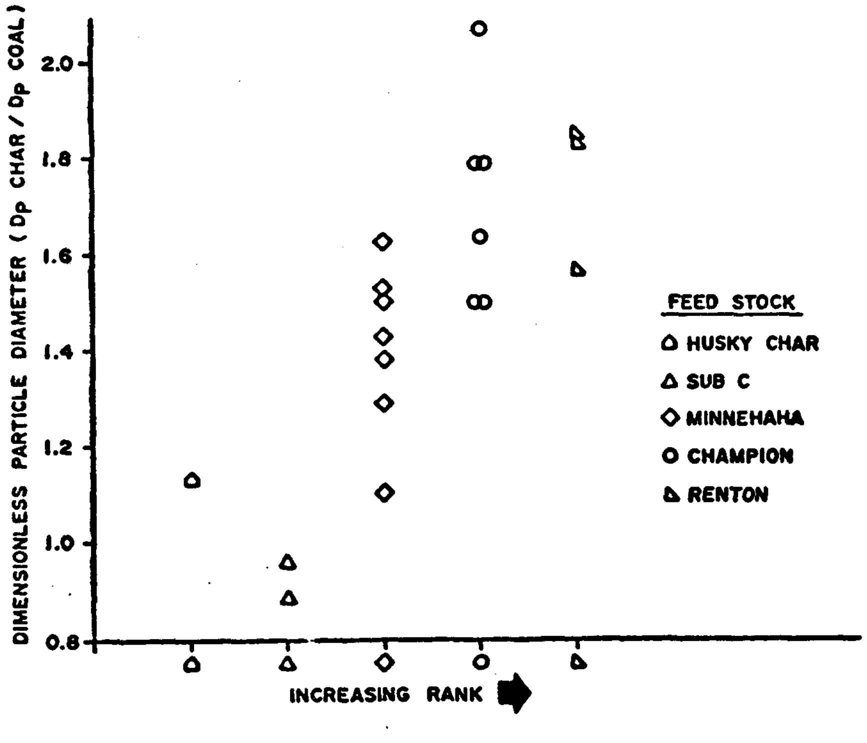


Figure 3.1-2 Bed Particle Size For Each Feedstock

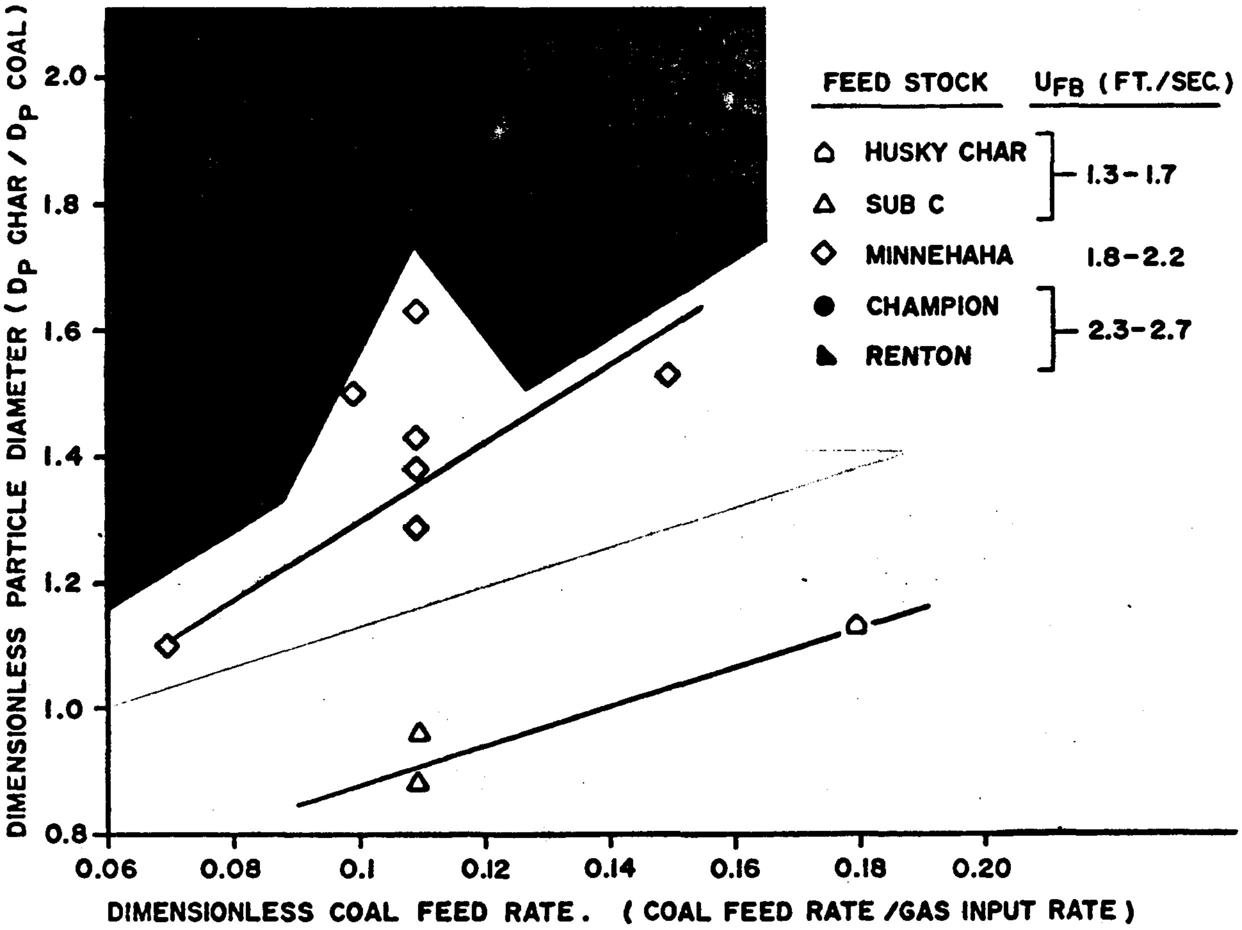


Figure 3.1-3 Bed Particle Size Vs Loading

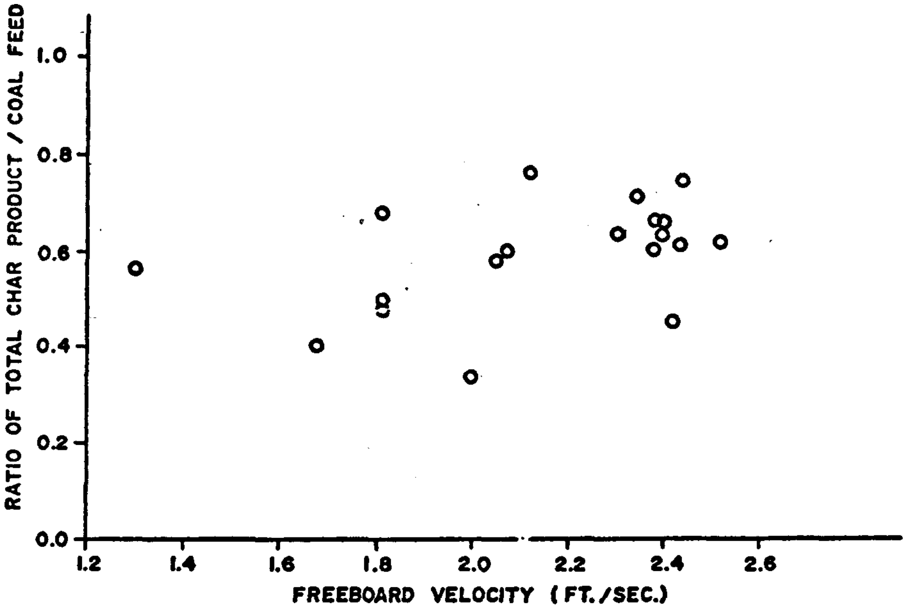


Figure 3.1-4 Total Char Production Vs Freeboard Velocity

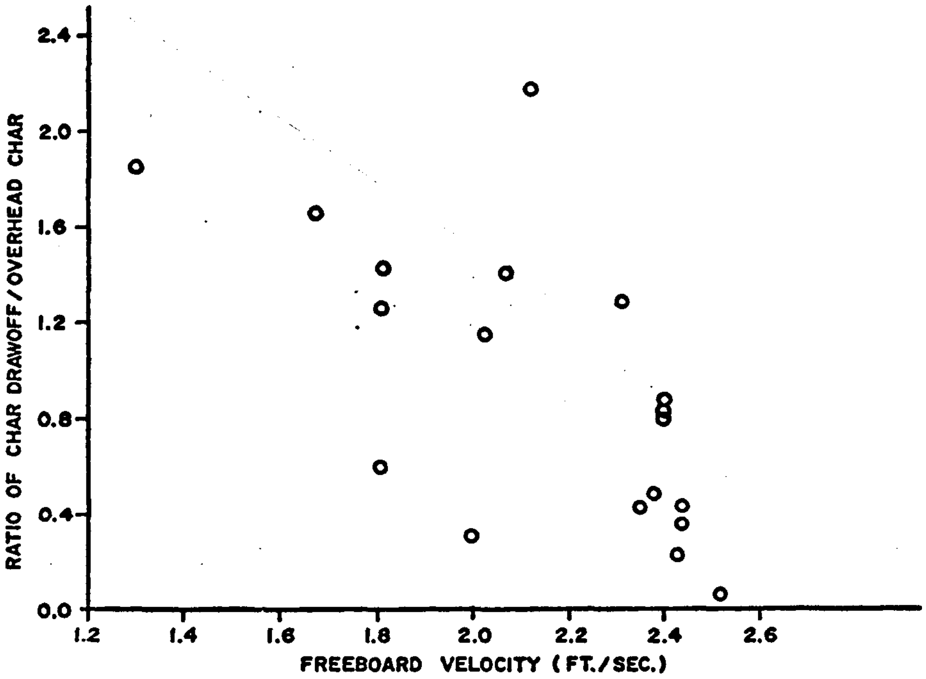


Figure 3.1-5 Affect Of Freeboard Velocity On Char Streams

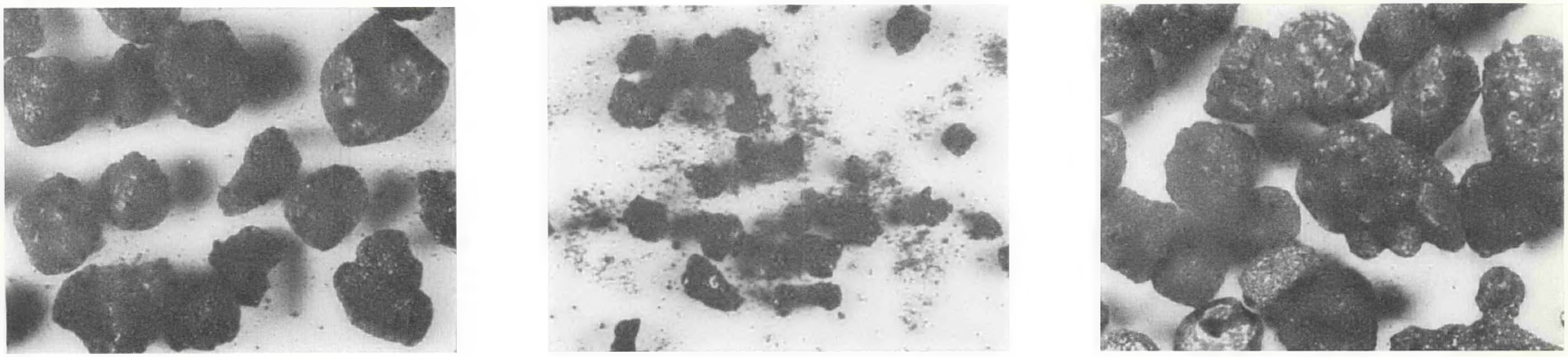
However, the split in the two streams is dependent on the freeboard velocity. In Figure 3.1-5, it has been shown that increasing the freeboard velocity will cause a relative decrease in the amount of char in the drawoff product stream. To distill these facts, increasing the reactor freeboard velocity appears to strip increased amounts of char from the bed leaving behind a larger mean particle.

With regard to the effect of the coals' caking and swelling properties on the char particle size, the data do not allow any strong conclusions. It would indicate that the higher free-swelling-index coals would grow more during devolatilization. It has been proposed that, as the coal goes through the sticky phase, it is likely to gather a coating of fines on its surface. The photomicrographs of char particle cross-sections as shown in Figures 3.1-6 and 3.1-7 reveal the pore structure but do not indicate any strong differences between comparable size char particles of different coals. In order to make a rigorous comparison of pore structure, one should look at the char product for identically sized coal. Because of the tenfold size spread in the coal feedstock, we cannot accomplish this from PDU char samples. There appears to be a different wall structure on some of the Champion coal char particles, as noted in Figure 3.1-7, which could be a result of the condensing and coking of tars from this highly-fluid coal or an accumulation of fines. It has not been determined if this wall structure difference is significant, and this phenomenon will be investigated during future tests.

Most of the solids samples taken during TP-009 and TP-010 were analyzed and permitted the completion of data analysis for these tests; in particular, the calculation of heat and material balances. A computer code was written to perform these calculations. The heat and material balances for the steady-state test points achieved during tests TP-009 and TP-010 are given in detail in Tables 3.1-4 through 3.1-10. Figures 3.1-8 through 3.1-14 present much of the same data in a different format, but stresses total quantities and composition for each stream rather than an elemental balance.

The TP-009-1 data is presented for three steady-state periods on June 1, 1976. This test was a feasibility demonstration test with Indiana #7 coal from the Minnehaha Mine of Amax Coal Company. Reaction heats calculated from this data were 810,000 to 910,000 Btu/hr net endothermic, or about 1550 to 1750 Btu/lb coal. These figures are dependent on calculated and measured heat losses from the system and are sensitive to small changes in gas composition. Therefore, they should not be used as a basis for estimating the "standard heat of reaction" for any of the reactions occurring (combustion, shift, steam gasification, devolatilization, cracking, methanation).

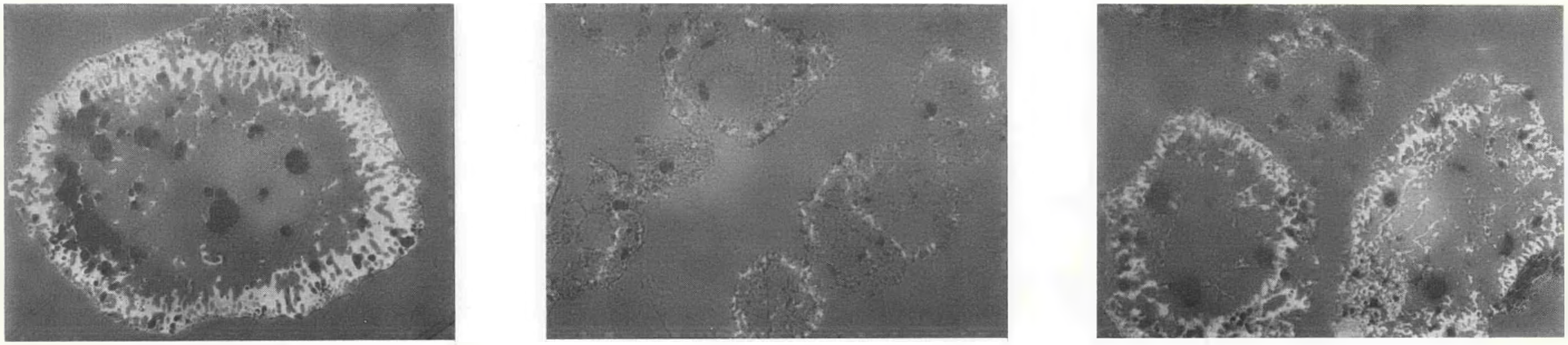
TP-009-2 data for the period during which Pittsburgh seam coal was being devolatilized shown in Tables 3.1-7 and 3.1-8 and in Figures 3.1-11 and 3.1-12. The primary difference in these two periods was in the synthesis gas composition. Carbon-dioxide was used in one instance and steam in the other as the diluent in both gas generators.



10 X MINNEHAHA BED
CHAR PRODUCT

10 X MINNEHAHA OVERHEAD
CHAR PRODUCT

10 X MINNEHAHA BED
CHAR PRODUCT

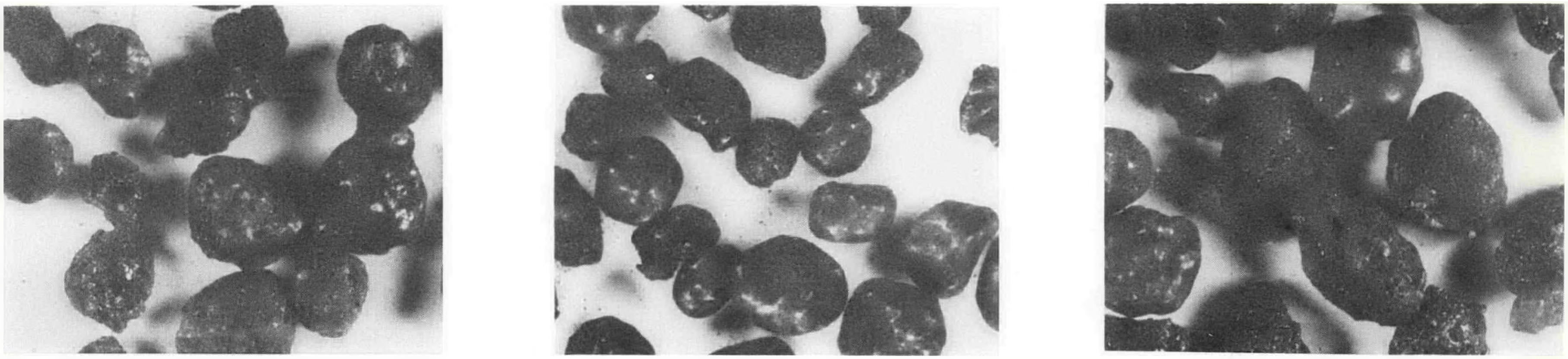


30 X MINNEHAHA BED
CHAR PRODUCT
−6 + 100 FEEDSTOCK

30 X MINNEHAHA OVERHEAD
CHAR PRODUCT
−6 + 100 FEEDSTOCK

30 X MINNEHAHA BED
CHAR PRODUCT
−6 + 30 FEEDSTOCK

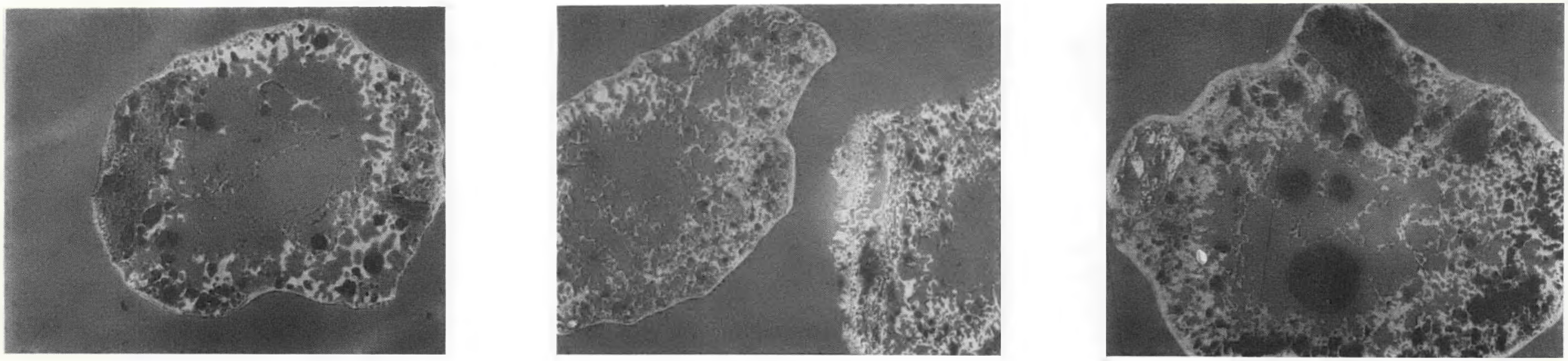
Figure 3.1-6 Char Particles From Indiana Coal With Two Inlet Size Distributions



10 X MINNEHAHA BED
CHAR PRODUCT

10 X CHAMPION BED
CHAR PRODUCT

10 X CHAMPION BED
CHAR PRODUCT



30 X MINNEHAHA BED
CHAR PRODUCT - CO_2 DILUENT

30 X CHAMPION BED
CHAR PRODUCT - H_2O DILUENT

30 X CHAMPION BED
CHAR PRODUCT - CO_2 DILUENT

Figure 3.1-7 Char Particles From Two Different Coals With Two Syn Gas Diluents

R69682

TABLE 3.1-4 TP-009 HEAT AND MATERIAL BALANCE, 06176-0200, MINNEHAHA COAL

	Total Flows, Lb/Hr	C	H	O	S	N	Ash	Energy* Content, Btu/Hrx10^{-3}
INPUT								
Coal	523	333	31	98	5	8	48	6020
Trans.Gas	530	68	10	130	-	322	-	380
F-110	1877	178	60	507	-	1132	-	5050
F-111	1331	140	43	338	-	810	-	3930
CO_2 Purge	430	117	-	313	-	-	-	-
TOTALS	4691	836	144	1386	5	2272	48	15,380
OUTPUT								
Product Gas	4667	531	131	1481	2	2522	-	8960
Char	133	103	1	1	1	1	26	1630
Fines	118	91	2	2	1	2	20	1440
Fines to Quench**	12	10	-	-	-	-	2	150
Heat Loss in Syn Gas Generators	-	-	-	-	-	-	-	1370
C101 Reactor Heat Loss	-	-	-	-	-	-	-	500
TOTALS	4930	735	134	1484	4	2525	48	14,050
% Closure	5.1	-12.1	-6.9	11.1	6.9	-20.0	-	-8.6

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* Heating Value at 77°F Plus Enthalpy Above 77°F

** This Quantity Was Estimated From Ash Loss

TABLE 3.1-5 TP-009-1 HEAT AND MATERIAL BALANCE, 06176-1600, MINNEHAHA COAL

	Total Flows, Lb/Hr	C	H	O	S	N	Ash	Energy* Content, Btu/Hrx10^{-3}
INPUT								
Coal	526	338	32	99	5	8	44	6110
Trans.Gas	590	100	4	222	-	264	-	540
F-110	1843	253	35	560	-	995	-	4210
F-111	1450	183	22	457	-	788	-	2660
CO_2 Purge	430	117	-	313	-	-	-	-
TOTALS	4839	991	93	1651	5	2055	44	13,520
OUTPUT								
Product Gas	4971	814	51	1954	1	2151	-	5490
Char	109	84	1	1	1	1	21	1300
Fines	99	77	1	2	1	1	17	1180
Fines to Quench**	34	28	-	-	-	-	6	410
Heat Loss in Syn Gas Generators	-	-	-	-	-	-	-	1550
C101 Reactor Heat Loss	-	-	-	-	-	-	-	500
TOTALS	5213	1003	53	1957	3	2153	44	10,430
% Closure	7.7	1.2	-43.0	18.5	-40.0	4.8	0.0	-22.3

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* Heating Value at 77°F Plus Enthalpy Above 77°F

** This Quantity Was Estimated From Ash Loss

TABLE 3.1-6 TP-009-1 HEAT AND MATERIAL BALANCE, 06176-1900, MINNEHAHA COAL

	Total Flows, Lb/Hr	C	H	O	S	N	Ash	Energy* Content, Btu/Hrx10^{-3}
INPUT								
Coal	518	333	31	98	5	8	43	6020
Trans.Gas	568	89	1	208	-	270	-	250
F-110	1971	269	37	600	-	1065	-	4490
F-111	1486	187	23	463	-	813	-	2840
CO_2 Purge	430	117	-	313	-	-	-	-
TOTALS	4973	995	92	1682	5	2156	43	13,600
OUTPUT								
Product Gas	5237	782	33	2051	-	2371	-	3670
Char	83	63	1	1	1	1	16	1020
Fines	116	90	2	2	1	2	19	1430
Fines to Quench**	45	37	-	-	-	-	8	550
Heat Loss in Syn Gas Generators	-	-	-	-	-	-	-	1770
C101 Reactor Heat Loss	-	-	-	-	-	-	-	500
TOTALS	5481	972	36	2054	2	2374	43	8940
% Closure	10.2	-2.3	-60.9	22.1	-60.0	10.1	0.0	-34.2

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* Heat Value at 77°F Plus Enthalpy Above 77°F

** This Quantity Was Estimated From Ash Loss

TABLE 3.1-7 TP-009-2 HEAT AND MATERIAL BALANCE, 062576-0400, MONTOUR COAL

	Total Flows, Lb/Hr	C	H	O	S	N	Ash	Energy* Content, Btu/Hr$\times10^{-3}$
INPUT								
Coal	500	370	27	43	10	8	42	6757
Trans.Gas	530	80	3	157	-	290	-	614
F-110	2787	362	44	887	-	1493	-	5386
F-111	1730	209	30	502	-	989	-	3585
CO_2 Purge	415	113	-	302	-	-	-	-
TOTALS	5962	1134	104	1891	10	2780	42	16,342
OUTPUT								
Product Gas	5606	790	70	1891	3	2851	-	8238
Char	110	85	1	-	2	1	21	1314
Fines	265	205	2	-	5	3	50	3164
Fines to Quench	-	-	-	-	-	-	-	-
Heat Loss in Syn Gas Generators	-	-	-	-	-	-	-	2063
C101 Reactor Heat Loss	-	-	-	-	-	-	-	500
TOTALS	5981	1080	73	1891	10	2855	71	15,279
% Closure	0.3	-4.8	-29.4	0.0	-6.9	2.7	69.3	-6.5

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* Heat Value at 77°F Plus Enthalpy Above 77°F

TABLE 3.1-8 TP-009-2 HEAT AND MATERIAL BALANCE, 062576-1630, MONTOUR COAL

	Total Flows, Lb/Hr	C	H	O	S	N	Ash	Energy* Content, Btu/Hrx10^{-3}
INPUT								
Coal	500	370	27	43	10	8	42	6757
Trans.Gas	530	54	6	111	1	358	-	651
F-110	2337	163	60	635	-	1478	-	4444
F-111	1669	152	49	433	-	1035	-	4110
CO_2 Purge	415	113	-	302	-	-	-	1
TOTALS	5451	852	142	1524	11	2879	42	15,963
OUTPUT								
Product Gas	5433	495	121	1524	4	3289	-	8313
Char	20	15	1	-	-	-	4	232
Fines	290	217	2	-	6	3	64	3371
Fines to Quench	-	-	-	-	-	-	-	-
Heat Loss in Syn Gas Generators	-	-	-	-	-	-	-	1024
C101 Reactor Heat Loss	-	-	-	-	-	-	-	500
TOTALS	5743	727	124	1524	10	3292	68	13,440
% Closure	5.4	-14.7	-13.4	0.0	-4.8	14.3	61.9	-15.7

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* Heat Value at 77°F Plus Enthalpy Above 77°F

TABLE 3.1-9 TP-010 HEAT AND MATERIAL BALANCE, 080576-1000, RENTON COAL

	Total Flows, Lb/Hr	C	H	O	S	N	Ash	Energy* Content, Btu/Hrx10^{-3}
INPUT								
Coal	515	388	29	32	7	14	45	7226
Trans.Gas	788	146	5	327	-	310	-	711
F-110	2736	280	53	829	-	1574	-	4980
F-111	1417	124	29	388	-	875	-	2690
CO_2Purge	415	113	-	301	-	-	-	4
TOTALS	5871	1051	116	1877	7	2773	45	15,611
OUTPUT								
Product Gas	5646	752	110	1878	-	2906	-	9674
Char	158	129	1	1	1	2	24	1969
Fines	186	149	1	1	2	2	31	2256
Fines to Quench	-	-	-	-	-	-	-	-
Heat Loss in Syn Gas Generators	-	-	-	-	-	-	-	900
C101 Reactor Heat Loss	-	-	-	-	-	-	-	500
TOTALS	5990	1030	112	1880	3	2910	55	15,299
% Closure	2.0	-2.1	-2.5	0.0	-49.3	4.9	20.1	-2.0

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* Heat Value at 77°F Plus Enthalpy Above 77°F

TABLE 3.1-10 TP-010 HEAT AND MATERIAL BALANCE, 080976-0500, CHAMPION(MONTOUR) COAL

	Total Flows, Lb/Hr	C	H	O	S	N	Ash	Energy* Content, Btu/Hrx10^{-3}
INPUT								
Coal	570	429	30	46	7	9	49	7781
Trans.Gas	1022	214	5	518	-	285	-	671
F-110	2924	282	59	813	-	1770	-	5764
F-111	1360	116	24	356	-	864	-	2482
CO_2Purge	415	113	-	302	-	-	-	4
TOTALS	6291	1154	118	2035	7	2928	49	16,702
OUTPUT								
Product Gas	5697	788	105	2033	-	2771	-	8752
Char	31	23	1	-	-	-	7	351
Fines	239	187	2	1	2	2	44	2903
Fines to Quench	-	-	-	-	-	-	-	-
Heat Loss in Syn Gas Generators	-	-	-	-	-	-	-	1203
C101 Reactor Heat Loss	-	-	-	-	-	-	-	500
TOTALS	5967	998	108	2034	2	2773	51	13,709
% Closure	-5.2	-13.6	-9.5	0.0	-64.3	-5.3	4.6	-17.9

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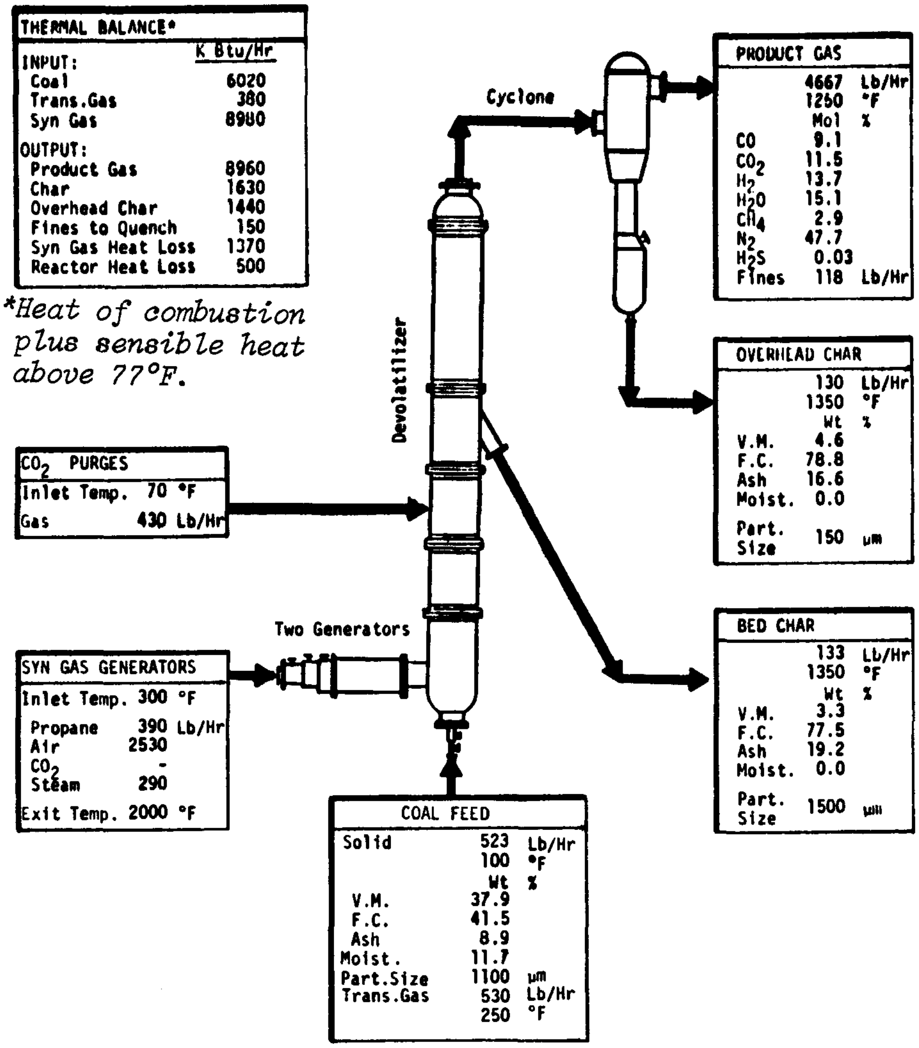
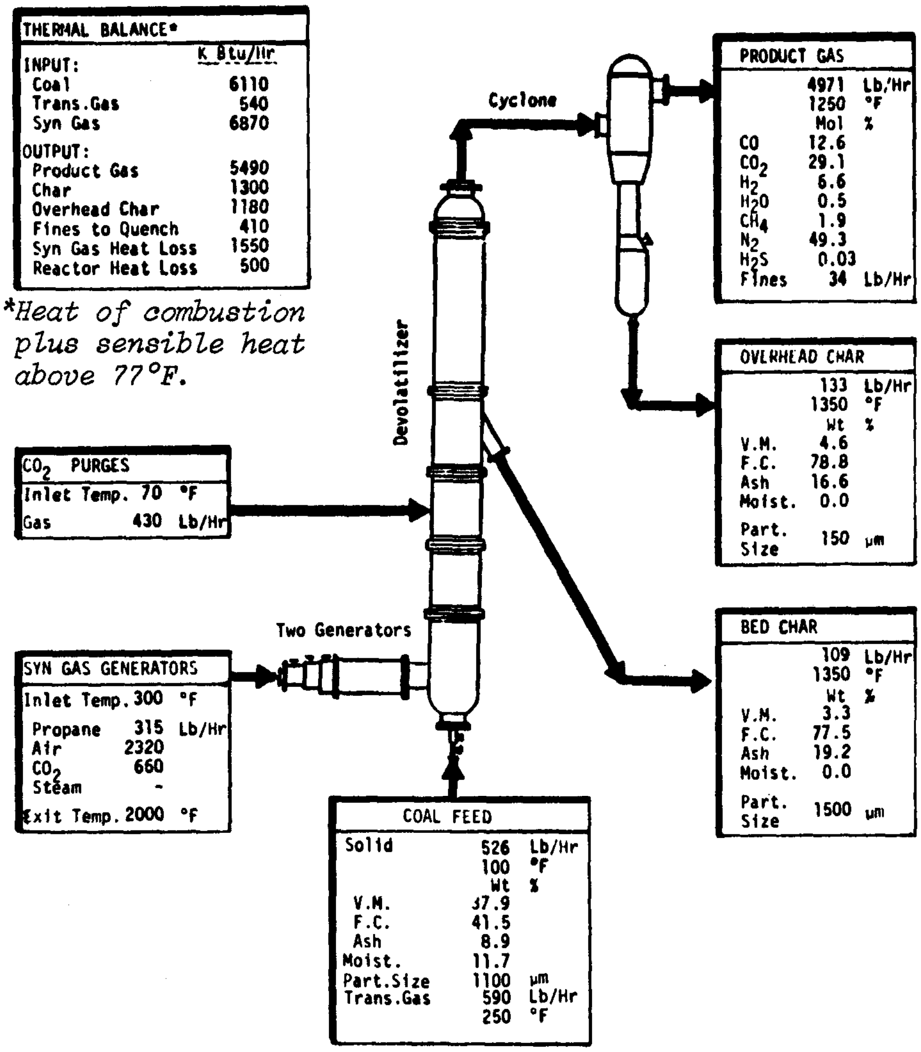
* Heat Value at 77°F Plus Enthalpy Above 77°F



**Heat of combustion plus sensible heat above 77°F.*

Figure 3.1-8 TP-009-1 Heat & Material Balance, 06176-0200, Minnehaha Coal



*Heat of combustion plus sensible heat above 77°F.

Figure 3.1-9 TP-009-1 Heat & Material Balance, 06176-1600, Minnehaha Coal

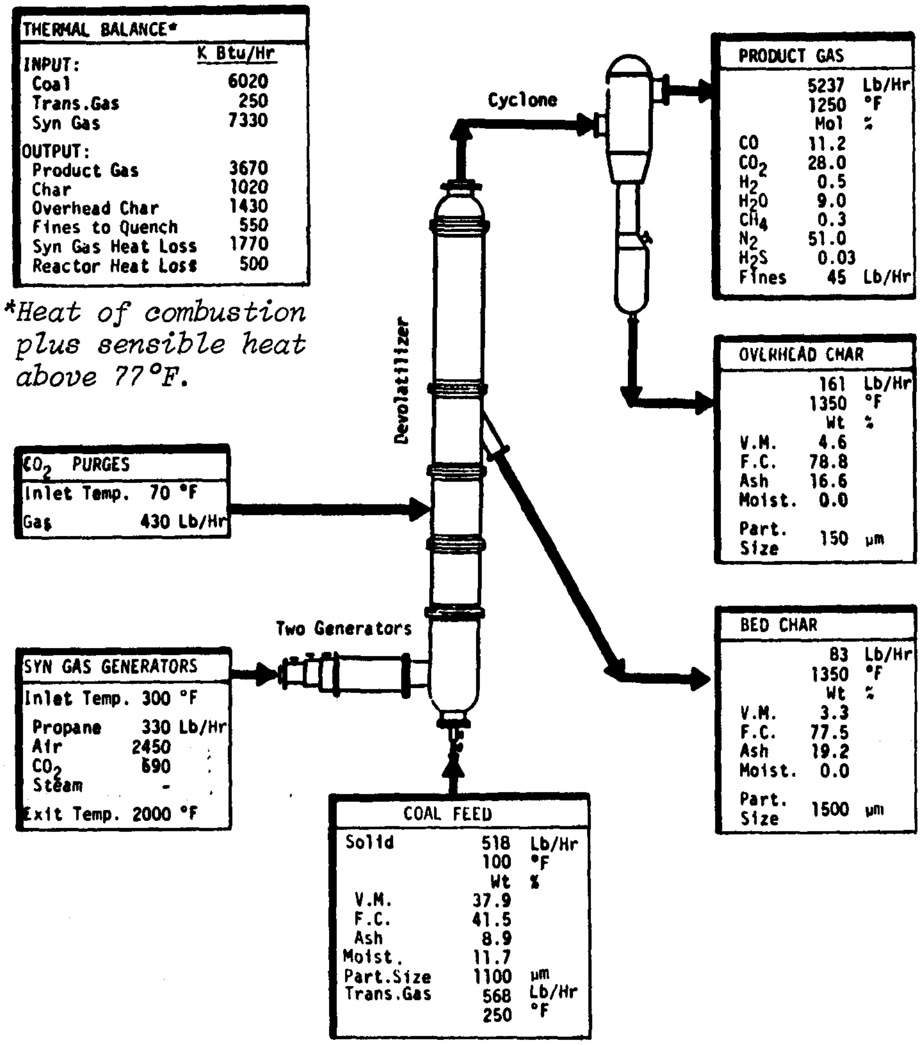
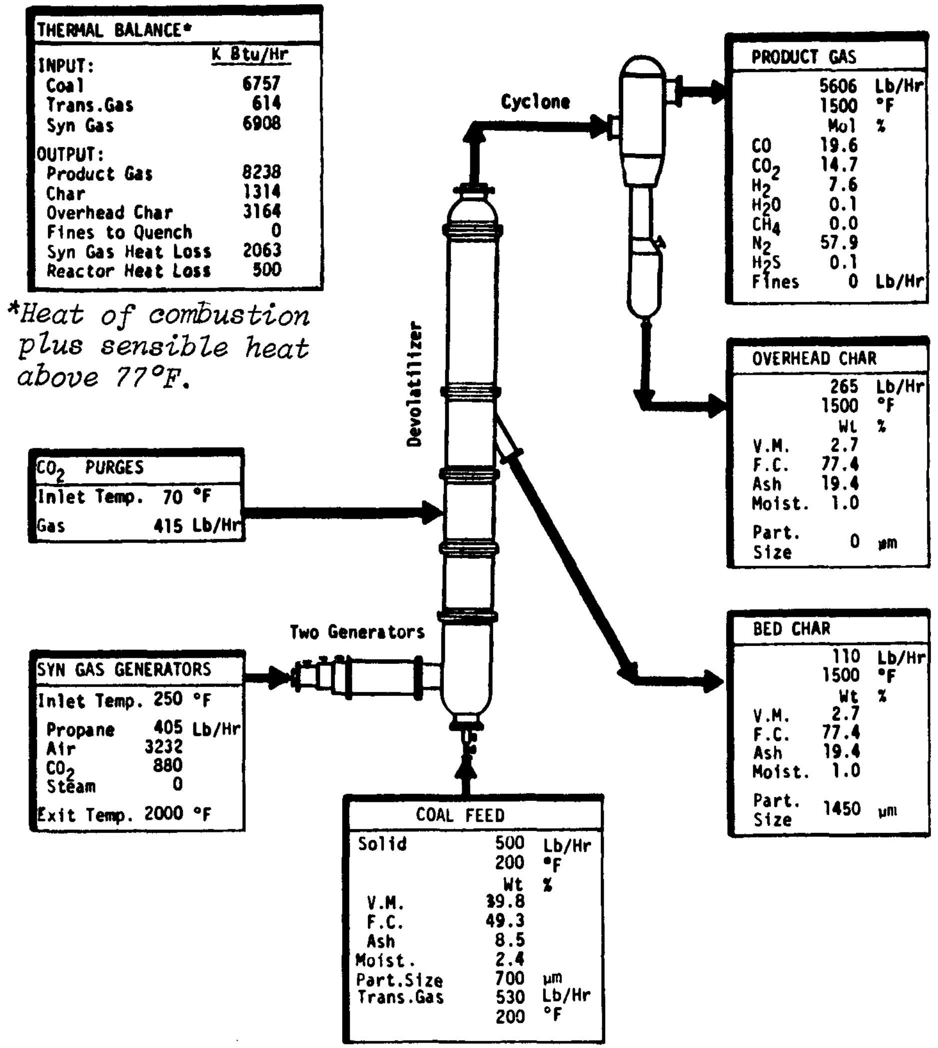
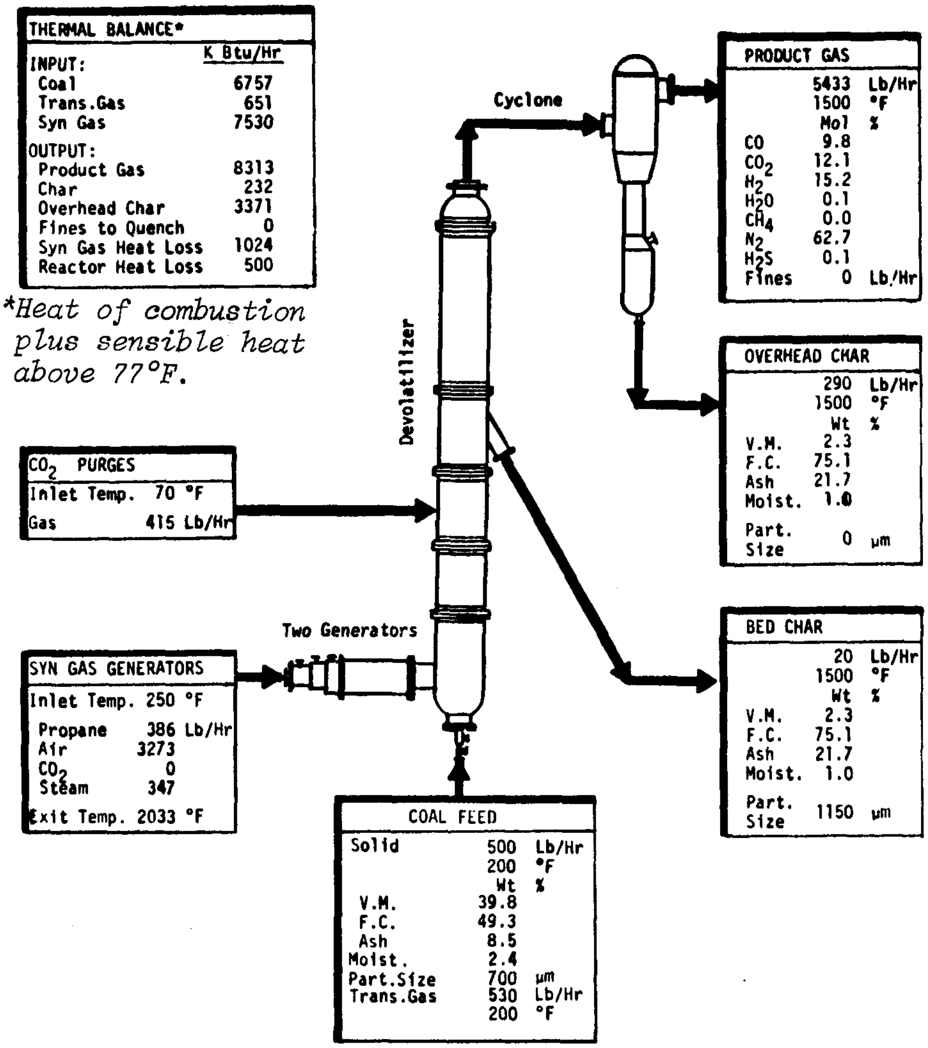


Figure 3.1-10 TP-009-1 Heat & Material Balance, 06176-1900, Minnehaha Coal



**Heat of combustion plus sensible heat above 77°F.*

Figure 3.1-11 TP-009-2 Heat & Material Balance, 062576-0400, Champion (Montour) Coal



*Heat of combustion plus sensible heat above 77°F.

Figure 3.1-12 TP-009-2 Heat & Material Balance, 062576-1630, Champion (Montour) Coal

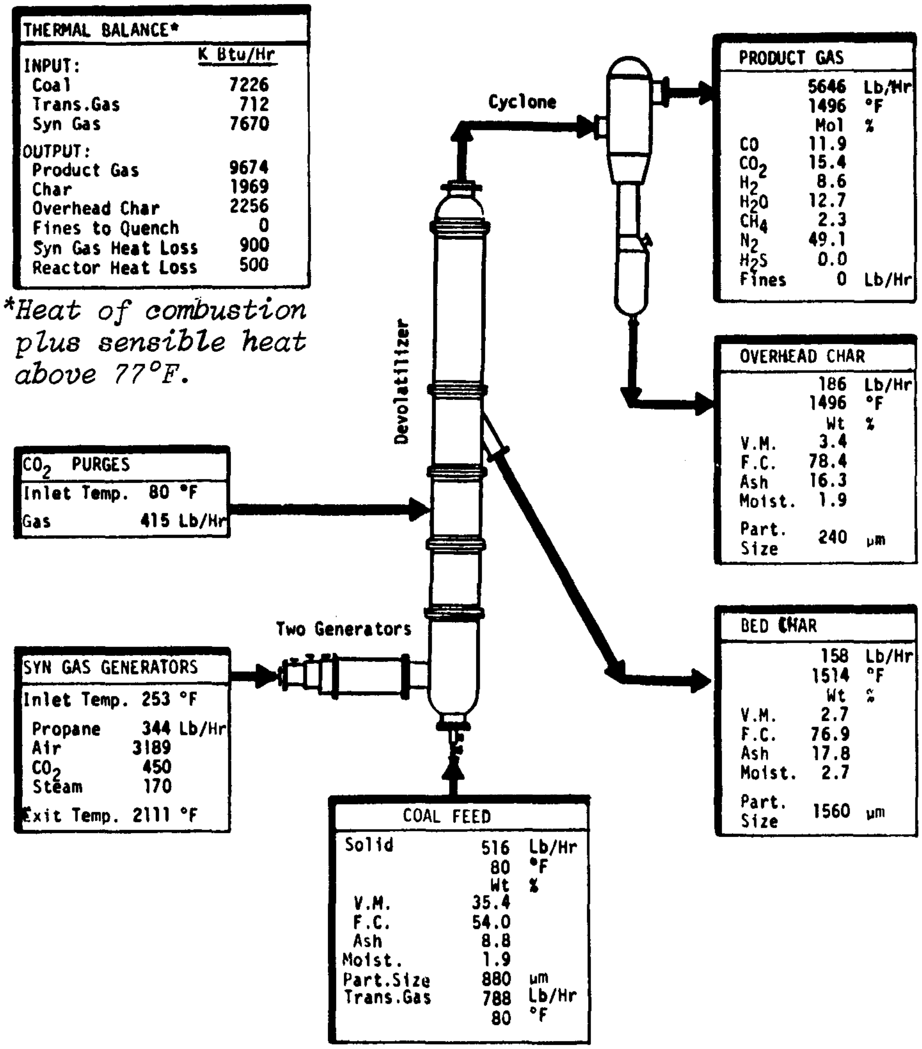
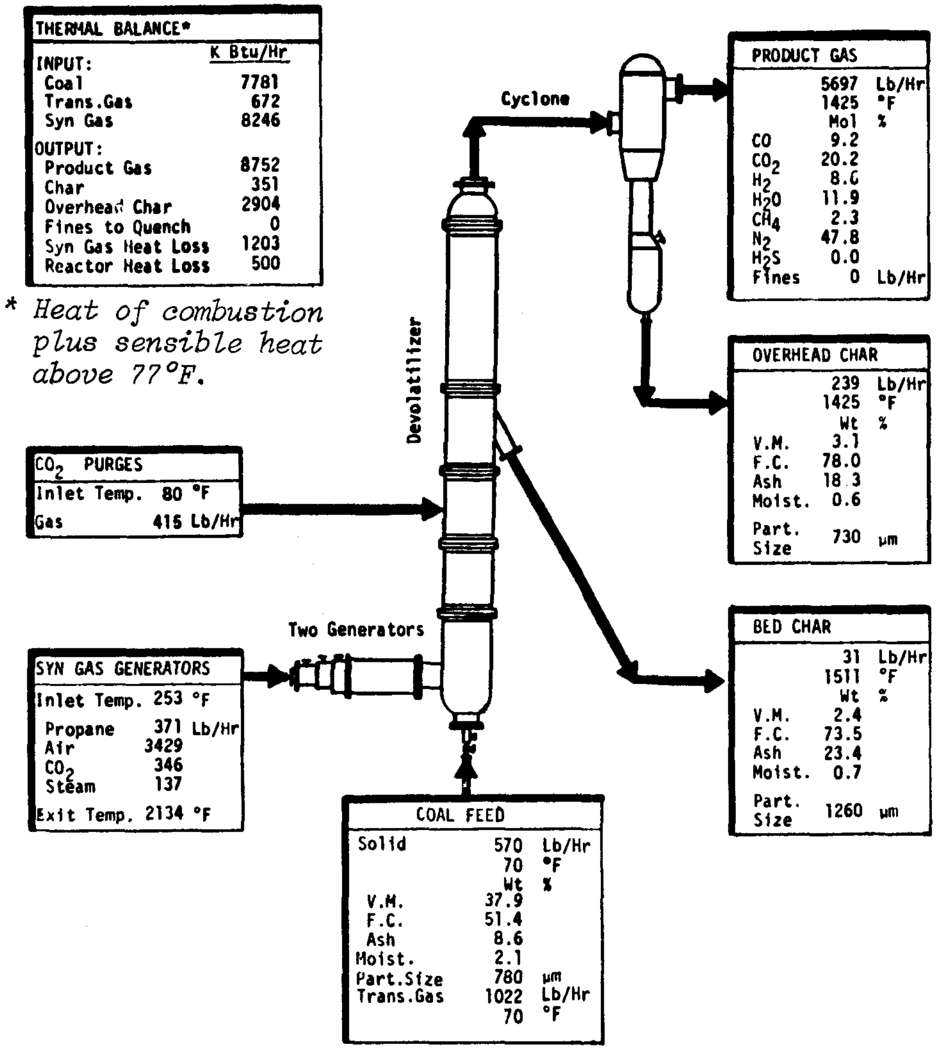


Figure 3.1-13 TP-010 Heat & Material Balance, 080576-1000, Renton Coal



* *Heat of combustion plus sensible heat above 77°F.*

Figure 3.1-14 TP-010 Heat & Material Balance, 080976-0500, Champion (Montour) Coal

The calculated heats of reactions were 400 Btu/lb and 1168 Btu/lb for these two periods, both endothermic. The use of steam as a diluent resulted in less CO and more H_2 in the product gas when compared with operation with the carbon-dioxide diluent. No significant effects were noted on char properties.

TP-010 data are presented for two periods: one with Upper Freeport coal from the Renton Mine of Consolidation Coal Company and one with Pittsburgh Seam coal from Consol's Montour Mine. The Renton data are presented in Table 3.1-9 and Figure 3.1-13, and the Montour data are presented in Table 3.1-10 and Figure 3.1-14. The Renton data produced an overall heat of reaction of no net exothermic nor endothermic content. The value was 990 Btu/lb endothermic for the Montour coal (Champion processing facility).

In making the balances, maximum use was made of measured flow and composition data. Elemental balances were only forced when a particular measured variable was unavailable. For example, the water analysis equipment which gives the water content of the product gas was often inoperative during the tests. Therefore, it was necessary to force the oxygen balance to obtain an estimate of water content in the gas. These deficiencies in measuring quantities in each stream will be solved prior to the next series of devolatilizer runs.

3.1.1.2 Work Forecast For Next Quarter

Devolatilizer test work is complete; however, additional analyses of the data will be performed as part of the work on integrated operation for 1977. These analyses will be conducted as part of the overall systems analysis that is required to determine compatible operating conditions of the devolatilizer and gasifier.

3.1.2 Gasifier Tests

3.1.2.1 Work Accomplished

The PDU was designed to permit separate operation of the devolatilizer reactor and the gasifier-agglomerator reactor, and the test program was designed to evaluate each reactor independently first before their eventual integration into an overall coal gasification system. In the gasifier mode, a char material made in the devolatilizer or obtained from another source is introduced into a hot combustion zone where it reacts with air to produce heat for the process and to heat the ash in the char to the point at which agglomeration takes place. Steam is added to the air stream, to the ash collection annulus and to the fluidized bed above the combustor-agglomerator to gasify the remaining carbon not combusted by the air.

Figure 3.1-15 is a schematic of the gasifier system showing the feed lockhopper system for the three feed solids: devolatilizer char, char fines from the devolatilizer, and recycled char fines from the gasifier. Lockhoppers for ash collection are also shown at the bottom of the reactor. The gasifier cyclone collects the overhead fines product which is recycled to effect a high carbon utilization. Finally, gases are cooled in the quench scrubber and gas cooling towers prior to being burned in the thermal oxidizer. A portion of these product gases are compressed and used as transport gas for the solids feed and recycle streams.

The PDU combustor-gasifier is designed to provide total carbon utilization of the char produced during devolatilization of coal: to be achieved by operation of the combustor in the self-agglomerating mode to produce a particle with greater than 80% ash content. The agglomeration of coal-ash has been reported to occur at temperatures above 1920°F regardless of the coal type. With temperatures above 1920°F, the sticking tendency of ash will increase up to the point where the ash slags, and the slagging can occur at a temperature as low as 2200°F for some types of coal. Thus, the nominal operating range for the combustor-agglomerator section of the reactor agglomerator is 1920°F to 2200°F.

The exact process configuration of the combustor-agglomerator section is shown in Figure 3.1-16 and depicts the combustion chamber (A), an ash-char separator (B), and a gasification chamber (C). Compressed air preheated to 800°F to 1000°F at 235 psig is injected into the air tube (D) and forms a combustion jet when char fines (∿-40+400 mesh) at 800°F to 1000°F are injected, (E), into the flow streams at the exit of the air tube. The combustion jet temperature is monitored via an optical pyrometer (F) which sights the center of the flame. The char is consumed, leaving an ash residue particle which becomes sticky and will preferentially agglomerate with other ash particles at the upper region of the jet. The momentum of the particles carries them into the gasifier section of the vessel where they cool and solidify due to the

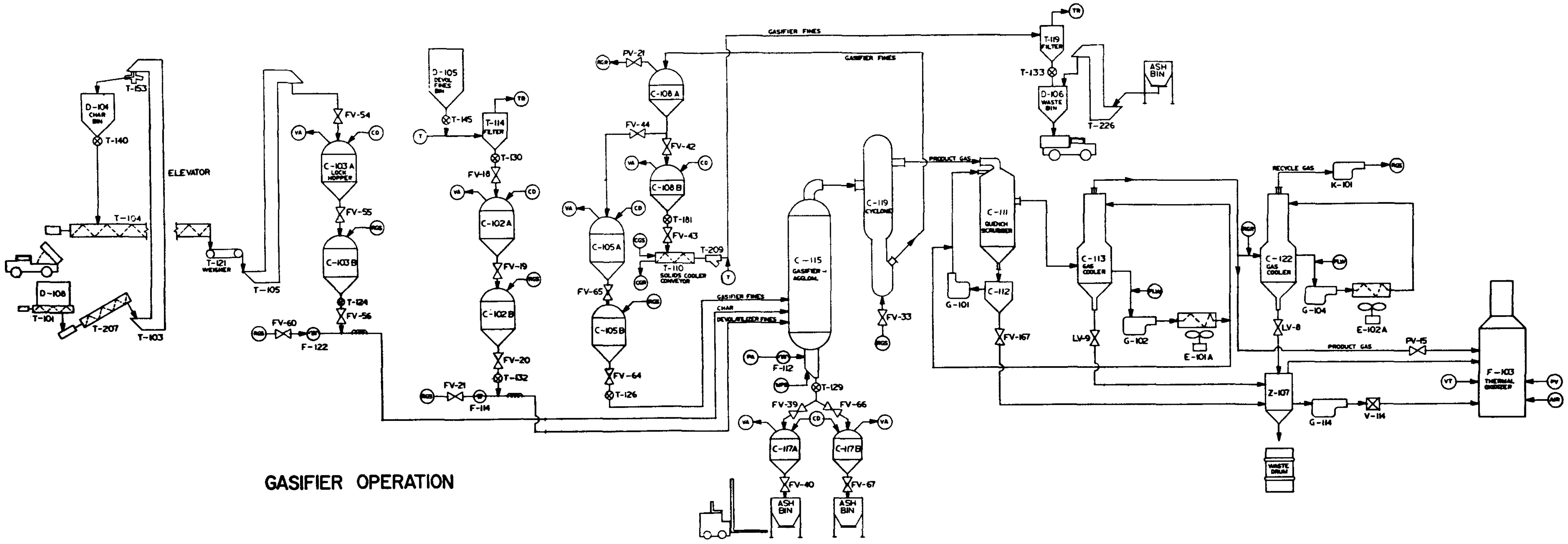


Figure 3.1-15 PDU Process Schematic for Gasifier Operation

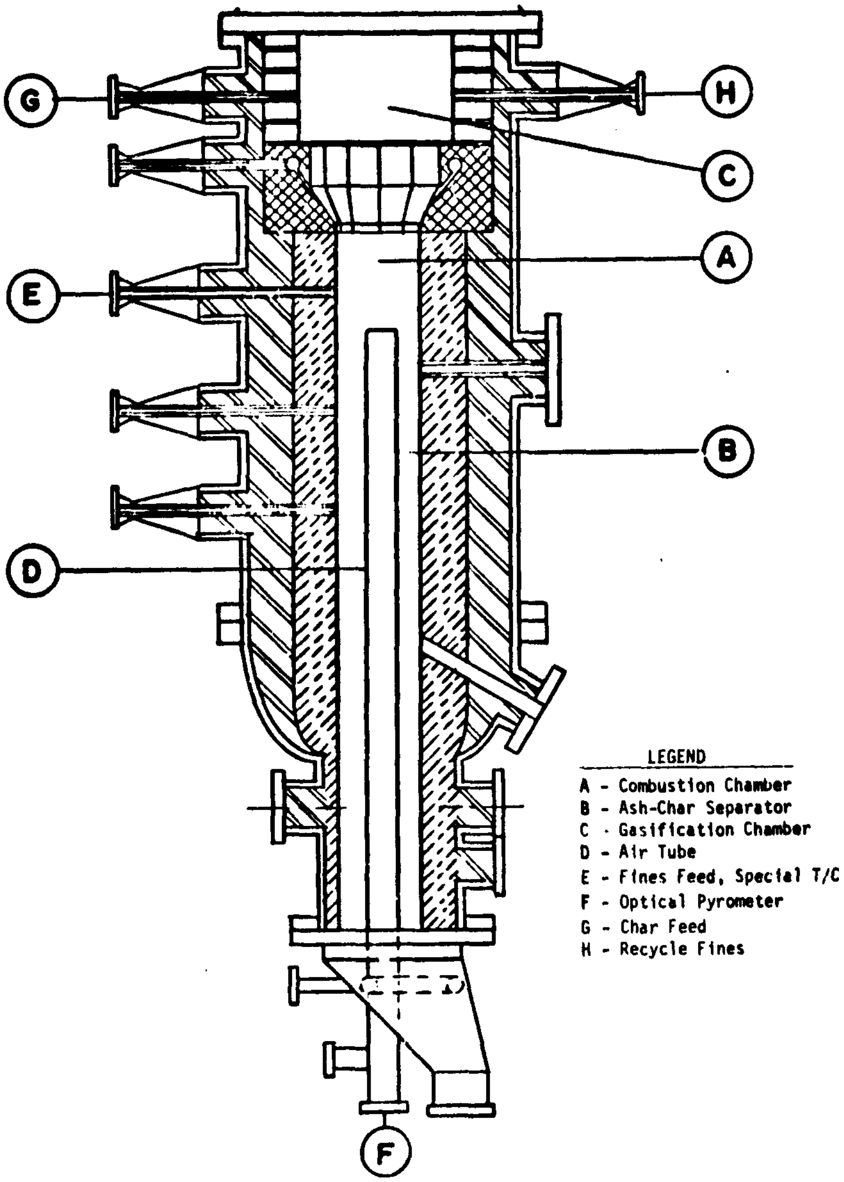


Figure 3.1-16 PDU Gasifier-Agglomerator

endothermic carbon steam reaction and the dilution with coarse char feed (G) and recycle fines (H). Because of the high density of the particles, they fall back down into the jet area where the smaller particles are swept, or recycled, into the jet and the larger particles fall into the char-ash separator. By using steam, this portion of the unit is maintained at the minimum fluidization limit for ash particles which assures that the high-carbon content material remains in the combustion zone and that the carbon content is lowered via gasification.

High solids recirculation rates must be achieved between the gasifier and the combustor sections to assure high heat transfer rates which promote favorable gasification rates and prevent the high ash content bed in the combustor from overheating and slagging. The steam used to fluidize the separator zone creates a char-ash interface which can be measured via a bed density device such as a differential pressure sensor or a nuclear densitometer. The rate of ash withdrawal is controlled by a Starwheel feeder, and the speed of the feeder is controlled by either the density measurement or by the differential temperature difference between the char-ash interface and ash boot temperatures. Figure 3.1-17 is a more detailed schematic of the gasifier showing the location of these control and data acquisition instruments.

Final test plans were issued for TP-001/006 and TP-011-1, the two gasifier tests conducted this quarter. TP-001/006 was a shakedown and operability test run with coke breeze at relatively low temperatures to evaluate the startup burner and define the fluid dynamics of the char bed. TP-011-1 was the first hot gasification-agglomeration trial. Both test plans were reviewed by the WESO Safety Committee along with the hazards analysis, failure mode analysis and failure mode action plans. The gasifier system process description, the proposed operating sequence and the failure mode and hazards analyses were presented to the Committee, and particular attention was given to review of: propane startup heater operation, sequence of operations, logic and safety aspects of the flame management system, and startup ignition of char. Approval was granted for both test plans.

Local and State agency reviews were conducted, and permits or approvals were granted as noted below:

1. Pennsylvania Department of Environmental Resources inspected the site and granted a one-year operating permit.

2. Pennsylvania Department of Labor and Industry inspected pressure vessels and steam boilers for coding requirements, and they reissued operating permits.

3. Factory Mutual Insurance granted approval for operation and design of the startup propane burner for the gasifier.

4. Westinghouse Advanced Reactors Division amended the operating license to provide for operation of the K-Ray nuclear densitometer on the gasifier test system.

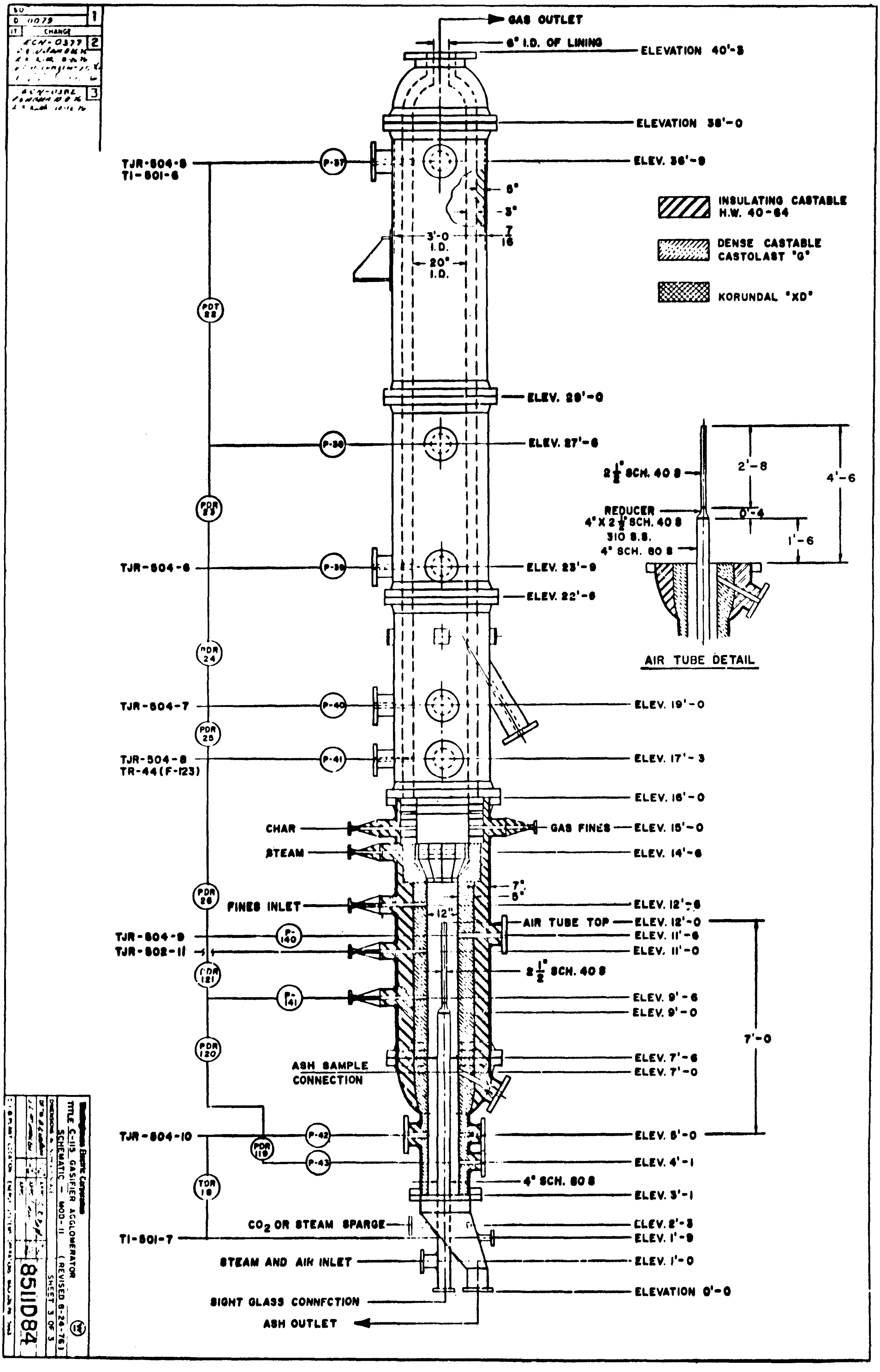


Figure 3.1-17 Gasifier Reactor And Instrumentation

The on-line data acquisition ALARM program was modified to provide additional alarm functions for critical parameters in the gasifier test system, including output temperatures of gas heaters that failed in previous tests, transfer line differential pressure for lines that have the potential for plugging, and transfer line flow rates.

Modeling of the gasifier reactor from the standpoint of chemical kinetics, chemical equilibrium, heat transfer and fluid mechanics continued. The program presently uses solid circulation rate, combustor and gasifier temperatures and total steam flow as inputs with air flow rate, char combustion, char gasification and both combustor and gasifier exit gas compositions as outputs.

Online programs for use during gasifier runs were developed. First, bed densities are calculated along the entire gasifier height based on measured differential pressures, and the bed height is calculated and displayed based on the location of a discontinuity in bed density. Second, several gas velocities in the reactor are calculated and displayed in real time; these include air-tube velocity, velocity in the ash collection annulus, and freeboard velocity in the gasifier.

Calculations were performed to specify orifice and valve trim sizes for use in the gasifier tests. With few exceptions, the existing valves and orifices initially installed in the plant by Bechtel are adequate. Changes include orifices for devolatilizer fines and gasifier fines transport gas and the orifice for carbon-dioxide supply to the ash removal section of the gasifier. Computer constants were changed to reflect the changes in the PDU.

Gasifier feedstock char samples were sent to IGT for analysis of acid-soluble and acid-insoluble iron in the ash using a technique developed by IGT. These analyses will be used in an attempt to define the agglomerability index for various char feedstocks. IGT has observed that chars which have higher contents of acid-insoluble iron tend to produce ash agglomerates more readily in their atmospheric pressure agglomerating unit.(1) This may be a result of the presence of a ferrous aluminum silicate eutectic that melts at 1990°F, a temperature significantly lower than the ash fusion temperature of the feedstock ash. Since the iron in this eutectic is not soluble in HCl, the acid-insoluble iron content may be an index of agglomerability. Of the char feedstocks listed in Table 3.1-11, only the Illinois coke breeze and COED char have been employed in the IGT agglomerator. The coke breeze was much easier to agglomerate in their apparatus. Based on these observations, it would appear that an index of greater than 20% is desirable. Both the Upper Freeport and Pittsburgh chars produced in the Westinghouse PDU devolatilizer, as well as the McCormick coke breeze, have indices above 20. The Minnehaha char has an index more in line with the FMC char.

TABLE 3.1-11 ANALYSIS OF CHAR FEEDSTOCKS FOR ACID INSOLUBLE IRON

Char	Source	Typical Acid-Insoluble Iron, % of Total Iron
Pittsburgh Coke Breeze	McCormick Co.	30
Illinois Coke Breeze*	Bethlehem Steel Company	58
Indiana #7, Minnehaha	Westinghouse Devolatilizer	14
Upper Freeport, Renton	Westinghouse Devolatilizer	27
Pittsburgh, Montour	Westinghouse Devolatilizer	26
Illinois #6 Char*	FMC, COED	19

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* Used by IGT in agglomeration tests.

1. TP-001/006 Test Plan

Test Plan 001/006 combined the operability tests for the PDU gasifier subsystems (TP-001) with cold flow dynamics testing (TP-006), and it was separated into three distinct phases, compatible with the purposes noted below.

Phase I - F123 Gasifier Ignitor Burner Checkout:

- Demonstrate the suitability of the flame management system for F123 and the type of scanning arrangement to be used, i.e., viewing through 14 feet of 2-1/2-inch piping with an infrared scanner.
- Determine the ability of the burner to operate adequately in its present configuration at fuel-to-air ratios in the range of 0.020 to 0.028 as a normal operating range for gasifier heatup.
- Determine minimum (flashback) and maximum (blowoff) velocities for the burner at one atmosphere.
- Determine minimum flow settings for pressure switches and valves to guarantee satisfactory operation when the burner is installed in the vessel.

Phase II - Solid Circulation Studies:

- Determine the overall effect of jet velocity on the solid circulation rate between the combustor and gasifier.
- Establish a general relationship concerning the solids circulation between the combustor and gasifier sections as a function of the gas velocity in the annulus of the combustor section, jet velocity and other fluid dynamics parameters.

Phase III - Char-Ash Interface Studies:

- Determine the best means of controlling an interface between the char-rich (coke breeze) and the ash-rich (dead burned dolomite) regions of the combustor-ash agglomerator using differential pressure measurements.

Operation of the gasifier system for Test Plan TP-001/006 was initiated on November 6, 1976, and Phase I of the test plan was completed. Initial attempts to light the burner were unsuccessful at air flow rates of nominally 400 lb/hr with fuel-to-air ratios ∿0.025 pound of propane per pound of air. Conversations with the manufacturer indicated that the burner was designed as a diffusion-type burner for operation at high fuel-to-air ratios, on the order of 0.1 to 0.2. Further attempts to light the burner under these conditions were successful, using air flows of ∿50 lb/hr and propane flows of 5 to 6 lb/hr. Burner capacity was increased by increasing the air flow to ∿340 lb/hr at a propane rate of 35 lb/hr, and these conditions were very close to the blowoff condition for the burner. Following a successful demonstration of the startup burner, TP-001/006 continued with hot air dryout of the refractory on November 12 in preparation for Phase II of the test plan.

On November 15, problems were experienced with startup of the recycle gas compressor. Disassembly of the discharge valves indicated that the seat ring gaskets were not properly assembled. Following repair and reassembly of the compressor, the gasifier system was repressured to 100 psig on November 16, and an attempt was made to feed dolomite into the reactor through the Starwheel feeder on C103 lockhopper system. Feeding of material was not continuous during the day due to problems with frozen or wet material in the bottom of the lockhopper which resulted in shear pin failures and plugged lines. These problems were solved, and Phase II was conducted on November 17, 18 and 19. The bed was established with dead burned dolomite to a level of ∿20 feet, and solid circulation studies were conducted at four test points as shown below.

	Test Point 1	Test Point 2	Test Point 3	Test Point 4
Air Tube Velocity, fps	66.00	110.00	110.00	60.00
Ash Annulus Velocity, fps	0.90	0.68	0.32	0.15
ΔT Gasifier-Combustor, °F	35.0	30.0	30.0	45.0

Based on these measured temperature differences, between the combustor and gasifier sections of the reactor, solid circulation rates were calculated using a simple heat transfer model which takes into account the heat flux to and from the combustor section by way of gas flows and solid circulation. Solid circulation rates on the order of 5,000 to 15,000 lb/hr were calculated. Because of the very small differential temperatures observed, it is likely that these calculated values are not precise; however, they are of the right order of magnitude and do represent a positive indication of circulation between the two sections of the reactor.

Phase III of Test Plan TP-001/006 was conducted on November 20, 21, 22 and 23. The purpose of this portion of the test was to demonstrate the capability for continuously feeding char and char fines to a fluidized bed, continuously monitoring and controlling the bed height, withdrawing simulated ash product and controlling the ash-to-char interface in the agglomerator. A portion of dead burned dolomite was removed from the reactor, and the bed was established using coke breeze fines from C102 lockhopper. With the char bed fluidized, dead burned dolomite was fed through the char feed line from C103 to simulate the presence of ash agglomerates in the bed. Six test points were established as shown in Table 3.1-12.

The PDU was successfully operated during this entire period with adequate process control of pressures, temperatures and flow rates. Good separation of the heavier dolomite, which simulates the ash agglomerates from the char phase in the combustor-agglomerator, was achieved at air tube velocities of 80 fps and higher and at ash annulus velocities on the order of 0.6 fps or less. It was determined that this annulus velocity was required to avoid slugging of the dolomite bed which prevented adequate solid phase separation. The air tube velocity was required to achieve good jet penetration and solid circulation, both of which enhance phase separation.

TP-001/006 was conducted and was successful in achieving the following:

- Shakedown of problems relating to Starwheel feeders.

- Shakedown of logic and wiring problems on C117A and C117B ash hoppers and on C102A and C102B fines feed hoppers.

- Demonstration of gasifier fines recycle through C108 and C105.

- Transport velocities for coke breeze, coke breeze fines and gasifier fines established at 50, 40 and 35 fps, respectively.

- Demonstrated continuous controlled operation of C119 fines removal cyclone.

- Demonstrated continuous and controlled feeding and discharge of material from the reactor, control of bed height, and control of annular and air tube velocities.

- Calibration and demonstration of the adequacy of the nuclear densitometer for bed level control.

- Demonstrated that solids of different density could be separated in the agglomerating region of the reactor and that the interface between two solid phases could be controlled at a given bed level.

- Indicated solid circulation between the gasifier and combustor by an analytical-empirical approach.

TABLE 3.1-12 TEST POINTS ESTABLISHED IN PDU GASIFIER SHAKEDOWN TESTS, TP-001/006

	Test Points					
Measured Data	#1	#2	#3	#4	#5	#6
Air Tube Velocity, fps	40	60	80	100	100	80
Ash Annulus Velocity, fps	0.5	0.5	0.5	0.7	0.4	0.5
Freeborad Velocity, fps	1.02	1.17	1.45	1.65	1.59	1.45
Coke Feed Rate, lb/hr	∿230	--	--	--	--	--
Coke Fines Rate, lb/hr	--	∿310 intermittently, as needed.				
Recycle Fines Rate, lb/hr	--	--	--	--	--	∿375
Dolomite Feed Rate, lb/hr	∿1100	intermittently, as needed.				
Ash Withdrawal Rate,∿lb/hr	630	630	140	140	140	140
Reactor Pressure, psig	100	100	100	100	100	100
Air Inlet Temperature, °F	456	456	438	438	438	456
CO_2 Inlet Temperature, °F	456	456	456	456	456	456

- Established operating conditions to guide the use of the F123 startup heater.

2. TP-011-1 Test Plan

Test TP-011-1 was the first gasifier system test at design conditions of pressure and temperature. Initial hot operation of the gasifier/ash-agglomerator was accomplished with a Pittsburgh area coke breeze material that contained 10% to 12% ash and less than 2% to 3% volatile matter. This compares to a Minnehaha char produced in the PDU with 17-19% ash and 4-6% volatile matter, or to a Renton char with 18-24% ash and a 2-4% volatile matter. The ash initial deformation temperature of the coke breeze material is 2450°F oxidizing and 2370°F reducing.

Hot operation of the gasifier-agglomerator at design conditions was intended to determine the initial operability of the as-built configuration of the unit. Data obtained during TP-001/006 testing were used to help define TP-011-1 operating conditions, and the basic parameters of TP-011-1 were to include:

- Measurement and calculation of: (1) char-ash interface, (2) bed level using ΔP instrumentation and the nuclear bed level device.
- Investigation of cyclone collection rate.
- Investigation of slugging bed height in the gasifier region.
- Separation of the dense phase (ash) from the light phase char (coke breeze).
- Investigation of the size and composition of: (1) the bed material during combustion and gasification, (2) the ash agglomerates separated from char in the annular region around the air tube.
- Investigation of bed height effects on cyclone collection rate.
- Effects of varying air/steam/carbon input ratio in the combustor on the control of agglomeration in this region.
- Product gas composition and exit gas temperature as a function of air/steam/carbon ratio to the gasifier-agglomerator.

TP-011-1 was initiated on December 9 and was completed on December 19, 1976. Whereas all planned test objectives were not achieved, the test was considered a major accomplishment which did achieve the following objectives in spite of a number of hardware problems.

- Demonstrated the ability to start the gasifier from "cold" and bring it to a steady-state condition.
- Demonstrated the ability to ignite char with hot air at 1000°F and to control reactor temperature with steam.
- Demonstrated the ability to feed char, devolatilizer fines, and recycled gasifier fines on a continuous, controlled basis while discharging ash product from the bottom of the unit.
- Provided baseline data for fluidized bed operation in the ash agglomerator-combustor and in the gasifier for all transport lines.
- Provided a shakedown of equipment problems which can be corrected by repair, replacement or redesign of hardware or by procedural changes.
- Provided operator training for all PDU crews.

A summary of the test plan, as it was conducted, follows. The test was initiated on December 9 with pressurization of the unit. An excessive leak rate was observed at 100 psig. A number of small leaks were repaired; however, the pressure decay rate for the system was still 40 psi per hour. Investigations uncovered a major leak located on the hand valve downstream of the air preheater. The valve was rebuilt with new gaskets on the flange faces and the bonnet, and the leak rates were reduced to 19 psi per hour. Hot air dryout was begun on December 11, 1976.

Attempts were made to light the F123 startup burner at an air flow rate of 100 lb/hr and a propane flow rate of 15 lb/hr in order to continue the refractory cure cycle. Temperature rises were observed on reactor thermocouples indicating that the burner had ignited; however, no reading was observed on the infrared scanner. Observations of the flame through the scanner viewport at the base of the reactor indicated that the target flame area was too small to produce an adequate infrared signal for the scanner. This made it impossible to satisfy the flame management logic circuitry. The scanner assembly was moved to a 6-inch flange located at a nozzle ∿90° circumferentially from the burner nozzle, and strong infrared signals were obtained from the flame. The burner was relit and heatup of the refractory to 1400°F was achieved. Following a 16-hour cure cycle at 1400°F, the burner was shut down on December 14 at 0045 hours. The burner was removed and replaced with the P-41 pressure tap, and the infrared scanner was replaced by a thermocouple.

The system was then repressurized to 200 psig; however, a problem developed in the operation of PV-171 on the recycle gas system. The pressure control valve was removed, after isolating the recycle gas system, and inspected. It was discovered that the packing was so tight that it made the valve inoperative. The packing was reworked, and the valve was replaced in the system.

Coke breeze feed was halted with the first of numerous steam boiler failures which resulted from a sludge-laden low-water level cutout device on the boiler. With boiler problems resolved, a heater failure on the CO_2 vaporizer during high CO_2 flow was discovered when liquid CO_2 was viewed in the purge rotometers. The recycle gas system was isolated along with the CO_2 system to remove the liquid CO_2 from the compressor and CO_2 header.

By 0200 hours on December 15, the CO_2 system had recovered temperature sufficiently, using the auxiliary propane heating system, and recycle gas flows were established to begin coke breeze feed. However, high CO_2 flows in excess of 3000 lb/hr, were noted; these were found to be due to a restriction in the recycle gas return header on the inlet to C122. The system was depressurized, repairs were made to the CO_2 system heaters, control valve PV-14-1 was removed and inspected, and the recycle gas system restriction was removed. A sample of the plug was analyzed; it appeared to be made up of dolomite and char.

Repressurization was begun at 1500 hours on December 15, and the air heater was reset to 1000°F to regain the heat lost from the system over the previous 36 hours. Upon initiating coke breeze feed (-4+34 mesh), a plug was immediately noted in the feed line even though the line velocity at the heater exit was 50 fps. Less than one hour later, the plug was cleared and feed was reestablished, using a 60 fps line velocity. After about two hours of feeding through this line, a pin hole developed on the first 45° bend in the line. Since the line could not be isolated from the reactor system, the reactor was depressurized again to replace the 45° section. The material in the C115 gasifier was removed down to the top of the air tube using T129 Starwheel feeder into lockhoppers C117A and C117B. The 45° Incoloy spool piece was repaired and replaced, and repressurization was begun on December 16 at 2000 hours.

An attempt was made to reestablish the sparger flow of CO_2 into C115, but this could not be achieved due to a char blockage in the sparger. The block was removed by increasing CO_2 pressure to 290 psig, and the blockage material (coke breeze) was removed to C117A and C117B using T129 Starwheel feeder.

The air heater was set at 750°F at an air rate of 2000 lb/hr, and char feed was resumed when the recycle gas compressor was started at 100 psig system pressure. A bed level of 17 feet was achieved at 2210 hours on December 16, when signs of ignition were observed by a bed temperature rise from 380°F to 410°F. As char feed continued, bed temperature rose to 610°F in the next ten minutes and began a more rapid climb, to 1300°F, in the next four minutes. Steam was then added simultaneously to the grid plate and air tube at 160 and 500 lb/hr, respectively, and the temperature ramp began leveling out three minutes after steam addition. Steam to the grid plate was increased to 250 lb/hr and the bed temperature began falling at a slow rate of 5°F per minute from 1520°F to about 1480°F.

At this point, a leak in the second 45° bend on the coke breeze feedline was noted. Coke breeze feed via T124 Starwheel feeder was terminated, the air heater was deenergized, and coke breeze fines feed was begun to quench the combustion zone. Steam flow was increased at the grid plate to 300 lb/hr, and depressurization of the system was begun at 30 psig/hr. As reactor temperatures fell to 750°F, air flow was reduced to 1850 lb/hr and CO_2 flow to the annulus was increased to 1020 lb/hr. At 480°F, steam was reduced to zero flow. As the system depressurized, it was extremely difficult to remove coke breeze material from the bed because the material became saturated by moisture during the shutdown sequence. The inspection plate was removed on T129, and wet material was found packed in all four pockets.

Repairs were made to the second 45° elbow, the system was repressurized to 200 psig, and coke breeze feed was begun at ∿2100 hours on December 17, using a 600°F air preheat and an air flow of 2200 lb/hr. A bed level of 22 feet was established and the bed temperature equilibrated at 320°F.

At 0215 hours on December 18, the air heater was reset to 1000°F, and bed temperatures rose sufficiently about one hour later to allow combustion to take place. Steam was added through the air tube alone to moderate the temperature ramp, and fines feed was initiated at 390 lb/hr on the initial temperature ramp between 1000°F and 1500°F. After four hours, the temperature in C115 lined out to 1600°F with 700 lb/hr of steam and the air heater set at 900°F. Carbon-dioxide flow to the annulus was set at 700 lb/hr and 650°F. A steam flow to the grid plate of 100 lb/hr was established, and a plan was begun to reduce steam flow to the air tube to effect a 50°F rise in gasifier temperature every six hours. Coke breeze withdrawal continued at full speed on T129, and fines that were collected were returned to the gasifier for further combustion and gasification. Coarse coke breeze feed via C103B lockhopper was performed intermittently, as needed, to maintain a 22-25 foot bed.

A pin hole again developed on December 18 on the second 45° elbow that had been repaired the previous day. Depressurization was begun, and total air flow, steam flow and temperature were reduced to maintain combustion but limit heat release during shutdown. At ∿80 psig system pressure, combustion was quenched by rapidly dropping air flow from 1000 to 500 lb/hr, and all steam flow was shut off when the reactor temperature dropped to 1300°F. All material was quickly removed from the bed via sample connection SC-39 and all systems were secured. Because of a lack of sufficient Incoloy 90° elbows to replace the 45° elbows in the line, the run was terminated on December 19.

Data for TP-011-1 test are being played back from computer tapes and are being reduced and compiled. The maximum temperature reached in the reactor was 1750°F, as measured about five feet above the combustor air tube. Total run time with a gasification reaction taking place was about 23 hours. No ash agglomerates were noted in the ash-char mixture drawn from the bed, primarily because reactor temperatures did not reach 1950°F where agglomeration was expected to take place. Figure 3.1-18 summarizes the process data for the final hold period prior to shutdown.

3.1.2.2 Work Forecast For Next Quarter

The gasifier program will continue with TP-011-2, the third in a series of shakedown tests with coke breeze. The TP-011 series of shakedown tests will conclude when procedures and hardware are defined that will provide consistent operation of the gasifier to produce a product gas, high-ash content bottoms and continuous recycle of elutriated char. Following this series of tests, a TP-012 series of reactor evaluation tests will be run to define reactor operating parameters over a range of process conditions. These tests will be partially completed in the next quarter.

In subsequent quarters, the TP-013 series of tests with various PDU char materials will be conducted, again as reactor evaluation tests. Finally, the TP-014 feasibility demonstration test will be conducted with Pittsburgh seam char made in the PDU devolatilizer.

3.1.3 PDU Engineering and Design

3.1.3.1 Work Accomplished

Safety and system reliability of piping in the cooling water and waste handling systems were evaluated. The original systems were designed by Bechtel with sufficient corrosion and erosion allowances to permit operation of the plant for about 18 months. After completion of devolatilizer testing, inspections indicated that significant corrosive and erosive damage had occurred in certain areas. All piping was reviewed for conformance of design to the Petroleum Refinery Piping Code, ANSI-B31.3, and to

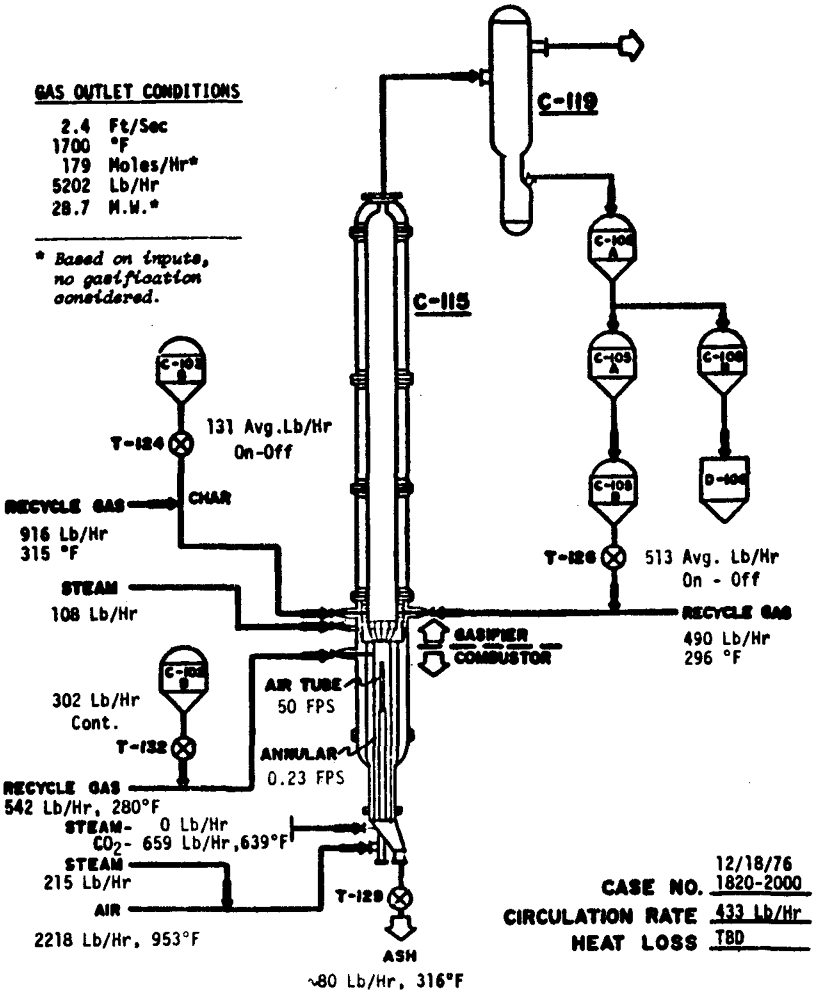


Figure 3.1-18 TP-011-1 Test Conditions & Results

Bechtel Specification 9874-02-L-101 for piping systems. Piping and vessel wall thicknesses were measured physically, where accessible; where inaccessible, they were measured by ultrasonic probe. From this data, an overall plan was prepared and implemented for upgrading the piping systems. Critical repair tasks were completed prior to TP-011 testing.

In order to fill Bin D105 with coke breeze, a vacuum conveying system was leased to transfer material from trucks. A permanent 4-inch fill line was designed to extend from the truck station to the top of Bin D105 and enters directly through the top surface. Fines can disengage in the freeboard area of the bin, and transport gas can be vented through the existing bag filter.

To increase recycle gas compressor operating time, a large Cuno filter housing was selected as an interim fix to protect the compressor from particulates transported in the recycle gas stream. The filter will contain elements to filter out particles one micron and larger and block valves to isolate them from the system during element replacement.

A review of the gas chromatograph filtering system was made to define design deficiencies and operating problems. Modifications are being considered on both short-term and long-term bases. From experience obtained during devolatilizer testing, considerable development effort will be required to provide a reliable, low-maintenance unit. The first phase of design upgrading for the gas sampling systems was completed. The isokinetic probe previously employed during devolatilizer tests was modified to permit purging and rodding out of the sample probe during the test. In addition, filters were installed in the gas chromatograph conditioning train to protect the chromatograph column from contamination with fine particles.

Weld failures on the CO_2 vaporizer system were analyzed to determine the cause of overstress conditions. The distribution manifold was overstressed as a result of temperature differences in the ringlike structure, and a design was completed to relieve these stresses. The ring will be split at one point and capped at both sides of the split to provide an expansion and contraction capability. Schedule 40 stainless pipe was specified for the new ring to replace the present Schedule 20 ring.

Two problems were investigated with respect to heat tracing and pressure vessel skin temperature sensing and alarming. A supplier of high-temperature sensor bulbs for Chromalox heat tracing was located, and sufficient 500°F bulbs were procured to repair existing damaged low-temperature bulbs. The manufacturer of skin temperature sensors indicated that the eutectic-salt type of sensor now used in the PDU is not available in the 700-800°F range. The use of thermistor strips is an option available for use on cyclone C119, which is expected to run at 750°F during gasifier tests.

Substantial engineering activity was directed to preparations for TP-001/006 and TP-011 in computer and analytical support and test engineering as follows:

1. Modeling of the gasifier system continued. A short analytical model was written for determining the solid circulation rate between the gasifier and combustor and to interpret TP-001/006 Phase II testing results which involved the use of a circulating bed of dead burned dolomite. Online programs for determining bed height and fluid velocities in the gasifier were also completed and installed on the computer. Computer support work included updating the signal list for measured process variables, updating user application programs and generation of new gasifier CRT displays.

2. Calculations were performed to determine flow ranges of orifices and valve trims in the flow system used for TP-011. Orifice plate changes were specified, and the valves on the startup heater flow loop were changed based on experiences encountered in firing the burner during TP-001/006.

3. Failure mode analyses were performed on the gasifier test system to augment those previously done during the initial design phase. In particular, the problem of slag formation in the gasifier or in the outlet piping was analyzed. It appears that existing hardware designs are adequate to meet any anticipated test anomalies. A failure action plan was defined for use by operating personnel to correct process problems or equipment failures experienced during the test to avoid temperature and pressure excursions or slag formation in the unit.

During and after TP-011-1 testing, engineering activities were related to troubleshooting problems and to equipment designs and modifications required to solve these problems, as noted below.

1. Erosion of Char Feed Line - The Incoloy-800 feed line eroded in the downstream legs of the 45° elbows, in less than 24 hours on three occasions, as a result of transporting coke breeze at 50 to 60 fps. Sectioning of the pipe and measurement of the eroded zone confirmed that erosion was caused by impact of abrasive particles on the pipe wall after being deflected by the normal buildup of char in the dead leg of the elbow. These lines will be changed to 90° elbow configurations prior to the next test run.

2. Plugging in the Recycle Gas System - Residual material from the last devolatilizer tests apparently remained in the return header as both char and dolomitic materials were found in the system. All lines will be thoroughly cleaned prior to the next test run. This phenomenon was also responsible for the high CO_2 makeup flows experienced during TP-011-1 testing.

3. CO_2 Vaporizer - Spare electrical heaters were ordered, and a capacity limit check was performed with the backup propane heater. This unit will work adequately if CO_2 rates are maintained at 2000 lb/hr or less.

4. Steam Boiler - More frequent boiler blowdowns were specified to alleviate the problem of sludge buildup in the level controller.

5. Pryometer - No signal was recorded on the pyrometer which sights on the combustor zone through the air tube due to an excessive sighting distance, a small target area, and water condensation on the sight glass. The pyrometer will be replaced by two thermocouples which will be inserted through the air tube at the bottom of the reactor to monitor the combustor temperature.

3.1.3.2 Work Forecast For Next Quarter

Major tasks to be initiated or continued include the development of product stream analysis and sampling hardware, cooling system and waste handling system upgrading, and test engineering in support of the gasifier evaluation.

3.1.4 PDU Maintenance, Construction and Operation

3.1.4.1 Work Accomplished

Mechanical completion and precommissioning of the gasifier test system were completed on schedule for a planned startup the second week in November and included the following tasks:

1. Cooling Water System - Following a thorough cleaning, all water circulation pumps, piping and valves were installed and the system was leak tested. Modifications to the C111 quench scrubber, spray box and downcomer were completed, and the unit was assembled and connected to the C119 cyclone outlet. Fabrication of the new dump valve system for C113 and C122 cooling towers was completed and the system was installed.

2. K-Ray Level Detector - The densitometer was installed and a radiation survey was completed that indicated the new installation will provide a 50% greater level of radiation intensity over the 4-foot length of the detector tube than the previous installation.

3. F123 Startup Burner - Installation was completed including the final hookup of the infrared scanner and pyrometer for monitoring combustor temperature. Piping and controls for propane and air delivery to the burner were completed along with all flame management controls.

4. C119 Cyclone - Modifications were completed to the cyclone J-leg and the cyclone was assembled on the structure. Instrumentation and purge lines were connected.

5. C115 Gasifier - The 4-inch air inlet line was connected to the gasifier, thermocouple flanges were installed, char feed lines were connected and instrumentation was installed.

6. Plant Winterization - Temperature limit control parts for the Chromalox circuits were ordered, and completion of winterization will be effected upon receipt of these parts. Faulty circuits and damaged heat tracing elements were repaired and numerous lines were insulated.

7. Lockhoppers - All lockhoppers were cleaned, and spool pieces were installed to change the dual-purpose hoppers from the devolatilizer to the gasifier operating mode. Controls were functionally checked, and all Starwheel feeders were modified to gasifier flowrate specifications by appropriate speed sprocket or cavity volume changes.

8. Utilities - A new pressure relief device was installed on the steam supply system, and the system was inspected, cleaned, repaired and reassembled. The air compressor, steam boiler, and glycol systems were repaired and system checkouts were completed. Repair of the CO_2 vaporizer was completed. Recycle gas and instrument air compressors were disassembled, repaired, reassembled and placed on line.

9. Materials Handling - A transfer line was installed on Bin D105 for filling the bin from trucks at ground level. Coke breeze was procured for TP-001/006 and TP-011 testing and was loaded into D105.

A number of small installation and maintenance tasks, not previously completed during preparations for TP-001/006, were completed in preparation for TP-011. The new ash sampling system was installed at the base of the reactor, chromatograph and isokinetic sampling trains were modified and installed, the startup burner was installed in the reactor after modifying the inlet flange refractory lining, and the flow range of the ash withdrawal Starwheel feeder was changed using speed changes and pocket volume changes.

Several instrumentation installations were completed prior to TP-011. The automatic pyrometer was installed and wired to the Control Room. Changes were made to the startup heater flow loop based on TP-001/006 test results. A number of valves were repaired and restroked.

Following the TP-011-1 test that was run in December, the PDU was inspected for damage. All systems, including refractory linings, were intact. Pipe erosion damage, as noted above, was the major problem encountered during this period.

3.1.4.2 Work Forecast For Next Quarter

Repair eroded piping, clean plugged portions of the cooling system and recycle gas system, repair the CO_2 vaporizer heater and install the new combustor zone thermocouple in January 1977.

Future maintenance work will be dictated by test results of Test TP-011-2 and TP-012 that will be conducted in the next quarter.

3.2 PHASE I, TASK 2A - INTEGRATED OPERATION OF THE PDU

3.2.1 Work Accomplished

Conversations were held with ERDA concerning procurement actions on the integrated system, and they indicated a preference to complete all bid solicitations prior to release of any packages for procurement. Initial purchases, therefore, will probably not take place until 1977.

Purchasing activity was initiated to obtain bids on all integrated piping packages that were prepared by Bechtel, Job No. 9874-010. Purchasing policies and guidelines that will be used to expedite this effort were reviewed with Purchasing, and agreements and commitments were established. All material requisitions included in the Bechtel design for integration of the gasifier and devolatilizer were issued to Purchasing, i.e., subcontract packages for installation work on mechanical, electrical, insulation and instrumentation systems. Pre-bid meetings were held with prospective suppliers, and essentially all bids were received by 12/31/76. These bids are being evaluated, and bid summaries for ERDA approval are being prepared.

A grid plate design was developed for the devolatilizer for use in the unit during integrated operations with the gasifier. The new grid design provides for either one gas source or two gas sources (synthesis gas generators) as the unit is presently designed. The design includes a 60-degree conical surface to prevent stagnation of the char layer circulating at the base of the draft tube. Detailed drawings were completed and will be used to solicit bids in the near future.

A second devolatilizer modification which would provide expanded freeboard section, was designed. If used during integrated operations, this would provide for higher coal throughputs at higher bed temperatures with less fines carryover to the cyclone. This expanded freeboard design has twice the cross-sectional area of the present reactor upper section.

3.2.2 Work Forecast For Next Quarter

Bid summaries will be prepared and ERDA approval will be solicited to proceed with procurements. Procurements will then be initiated.

3.3 PHASE I, TASK 3 - LABORATORY SUPPORT STUDIES

3.3.1 Fluidization and Fluid Particle Systems

3.3.1.1 Work Accomplished

The work on fluidization and fluid particle systems concentrated, this past quarter, on the effect of air nozzle velocity on the performance of the combustor-gasifier and on the rate of solids exchange between the combustor and the gasifier. The jet penetration data at different air nozzle velocities and under different operating modes were also collected. These experiments helped to select and verify the location of the air tube in the PDU. Experiments were conducted to study the effect of an expanded section on slugging. Two workshop sessions were held to allow the test engineers and supporting engineers in the PDU to observe the operation of the transparent semi-circular model under different operating modes. These sessions helped the operating engineers to visualize the bed operation in the PDU.

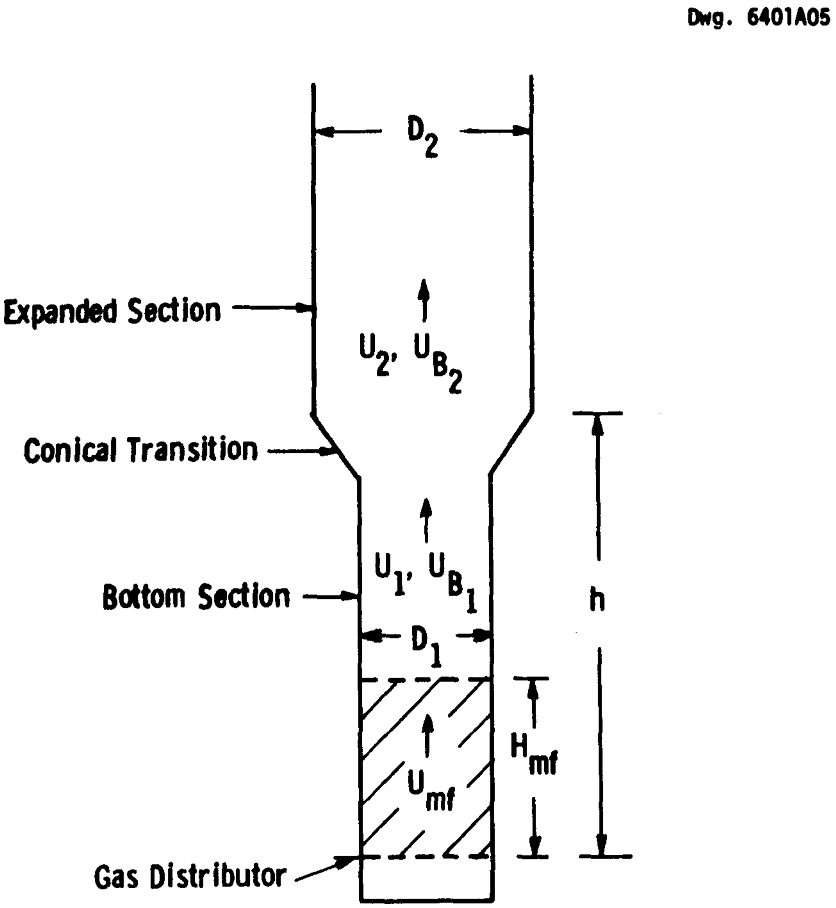
With regard to the effect of an expanded section on slugging, it is generally agreed that, when the bed cross-sectional area is expanded toward the top of a fluidized bed reactor, the expanded section will not only reduce the entrainment due to lower exit velocity but also suppress the slugging. No correlation is available in the literature on how to design an expanded section for these purposes. This problem was studied both theoretically and experimentally, and the theoretical model and initial slugging results are presented here.

Development of this model followed closely that of Matsen et al (1969)$^{(2)}$ for expansion of fluidized beds in slug flow. Before any slugs reach the bed surface, the bed height will increase at a velocity of (U_1-U_{mf}) in the bottom section (See Figure 3.3-1 for nomenclature) and (U_2-U_{mf}) in the expanded section. The bed height will reach the maximum when the first slug breaks the surface. This maximum bed height can be derived as follows.

For $H_{mf}<h$

$$H_{max} = H_{mf} + \frac{(h-H_{mf})}{(U_1-U_{mf})}(U_1-U_{mf}) + \left[\frac{H_{mf}}{U_{B1}} - \frac{(h-H_{mf})}{(U_1-U_{mf})}\right](U_2-U_{mf})$$

$$= h\,\frac{(U_1-U_2)}{(U_1-U_{mf})} + H_{mf}\left[\frac{(U_2-U_{mf})}{U_{B1}} + \frac{(U_2-U_{mf})}{(U_1-U_{mf})}\right] \qquad (1)$$



D : Diameter of the vessels
h : Height of the conical transition
H_{mf} : Bed height at minimum fluidization condition
U : Superficial gas velocity
U_{mf} : Superficial minimum fluidization velocity
U_B : Bubble Velocity

Subscripts
1 for the bottom section
2 for the expanded section

Figure 3.3-1 Nomenclature For The Development Of Slugging Equations For Fluidized Beds With Expanded Sections

For $H_{mf} > h$

$$H_{max} = H_{mf} + \frac{h}{U_{B1}} (U_2 - U_{mf}) + \frac{(H_{mf} - h)}{U_{B2}} (U_2 - U_{mf}) \qquad (2)$$

where

$$U_{B1} = 0.35 \sqrt{gD_1} \qquad (3)$$

$$U_{B2} = 0.711 \; g^{1/2} V^{1/6}, \; V = \frac{\pi}{6} (D_1)^3 \qquad (4)$$

Eq.(1) is applicable only when H_{mf}/U_{B1} is larger than $(h-H_{mf})/(U_1-U_{mf})$. At the limiting case where H_{mf}/U_{B1} is equal to $(h-H_{mf})/(U_1-U_{mf})$, $H_{max}=h$. That means the expanded section does not have any effect on the slugging. At $H_{mf}=h$, both equations (1) and (2) reduce to a common equation.

$$H_{max} = H_{mf} + H_{mf} \frac{(U_2 - U_{mf})}{U_{B1}} \quad \text{at } H_{mf} = h \qquad (5)$$

Eq.(5) is similar to the slugging equation for a bed of uniform cross-section except that U_2 is used in the place of U_1. Hence, Eq.(5) predicts a decrease of slugging bed height by expanding the vessel diameter above the height at H_{mf}.

Eq.(1) can be rearranged also to give

$$H_{max} = H_{mf} + \frac{(U_2 - U_{mf})}{U_{B1}} H_{mf} + (h - H_{mf}) \frac{(U_1 - U_2)}{(U_1 - U_{mf})} \qquad (6)$$

Since $U_1 > U_2$, $U_1 > U_{mf}$, and $h > H_{mf}$, the maximum bed height (H_{max}) calculated from Eq.(6) will be always larger than that obtained from Eq.(5). Thus, the expanded section will be most effective in cutting down the maximum slugging bed height if it starts at the height of H_{mf}.

For the cases where $H_{mf} > h$, Eq.(2) can be rearranged into

$$H_{max} = H_{mf} + \frac{(U_2 - U_{mf})}{U_{B1}} H_{mf} + (H_{mf} - h) \frac{(U_2 - U_{mf})}{U_{B1} - U_{B2}} (U_{B1} - U_{B2}) \qquad (7)$$

Since $H_{mf} > h$, $U_2 > U_{mf}$, and $U_{B2} > U_{B1}$, the third term in Eq.(7) will be always negative.

Thus, the maximum bed height calculated from Eq.(7) will be always less than that from Eq.(5). At the extreme case where $H_{mf} >> h$, Eq.(7) reduces to

$$H_{max} = H_{mf} + \frac{(U_2 - U_{mf})}{U_{B2}} H_{mf} \tag{8}$$

Eq.(8) is a slugging equation for a bed of uniform diameter D_2.

Experiments were conducted to check out the theoretically-derived equations. Seven different bed heights were used ranging from H_{mf}/D ratio (bed height at minimum fluidization/diameter of the column ratio) of 4.5 to 8.8. The cross-sectional area of the expanded section in the present configuration is two times the area of the bottom section. The experiments were carried out by increasing the gas flow slowly to determine the minimum fluidization point and the maximum slugging bed height at each flow rate. Both the slugging bed heights in the bottom section and in the expanded section were recorded.

The maximum slugging bed heights in the bottom section could be successfully correlated with the equation for slugging bed heights in a bed of uniform cross-sectional area (Eq.9), if the bubble velocity was taken to be $0.35\sqrt{2gD_1}$, the bubble velocity corresponds to a wall slug rather than an ideal slug. The gas bubbles rising against the wall (wall slug) rather than in the middle of the column (ideal slug) were experimentally observed.

$$H_{max} = H_{mf} + \left(\frac{U_1 - U_{mf}}{0.35\sqrt{2gD_1}}\right) H_{mf} \tag{9}$$

The data are shown in Figure 3.3-2. The maximum slugging bed heights in the expanded section were also successfully correlated with Eq.(1) as shown in Figure 3.3-3. Here, the bubble velocity (U_{B1}) is taken to be the ideal slug velocity $0.35\sqrt{gD_1}$. Based on experimental observation, the bed in the expanded section tends to bridge at the conical transition between the bottom section and the expanded section, especially at high bed heights. The gas slugs rising up in the bottom section tend to be trapped under the bridge and are periodically released as big ideal bubbles.

Further studies are needed varying the distance between the distributor plate and the expanded section. Based on the initial experimental evidence, the expanded section will be effective in reducing slugging, however, care must be exercised in locating the expanded section at a proper distance from the gas distributor plate to reduce the bridging tendency at the conical transition.

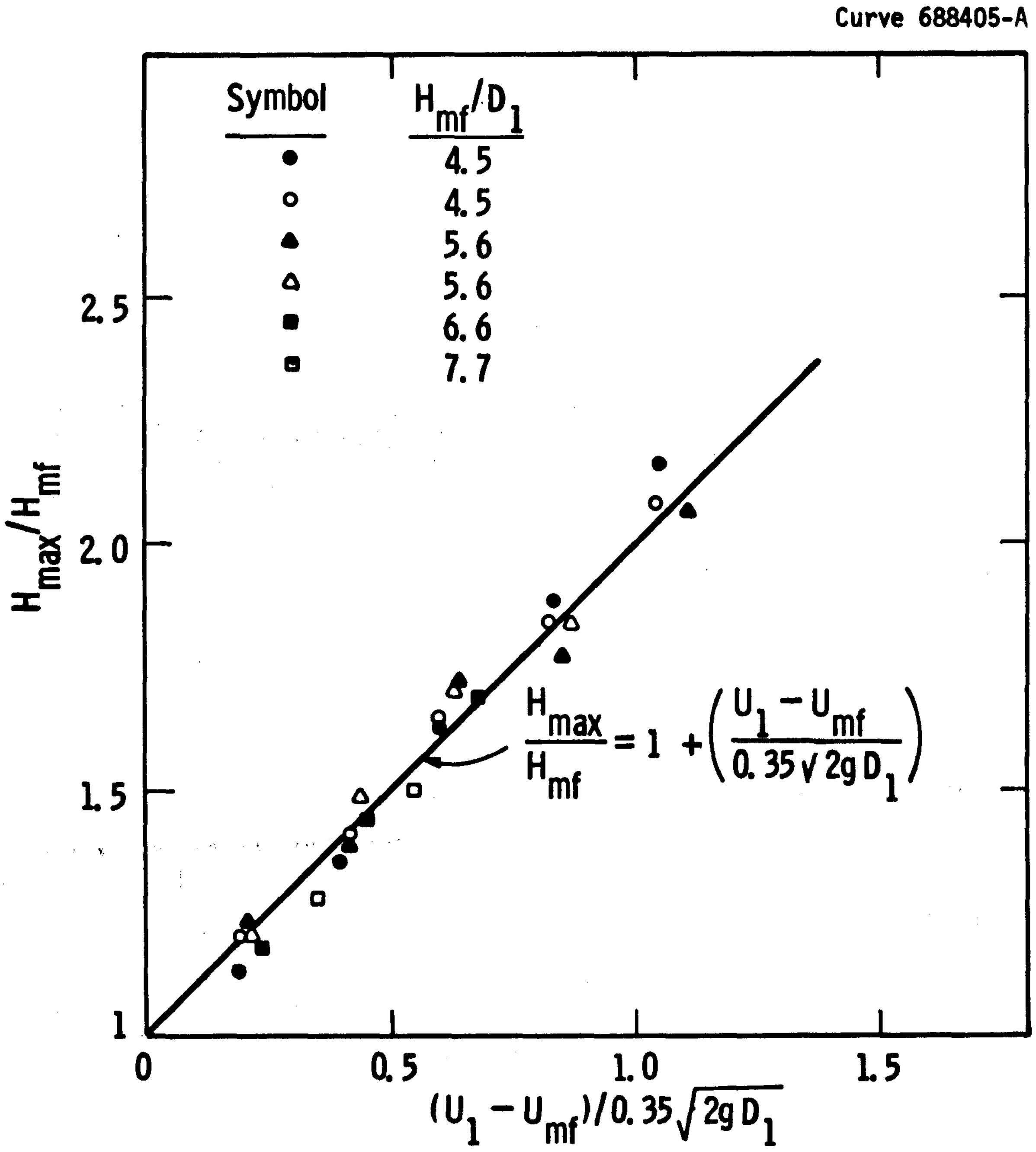


Figure 3.3-2 Maximum Slugging Bed Height In A Semi-Circular Column

Curve 688406-A

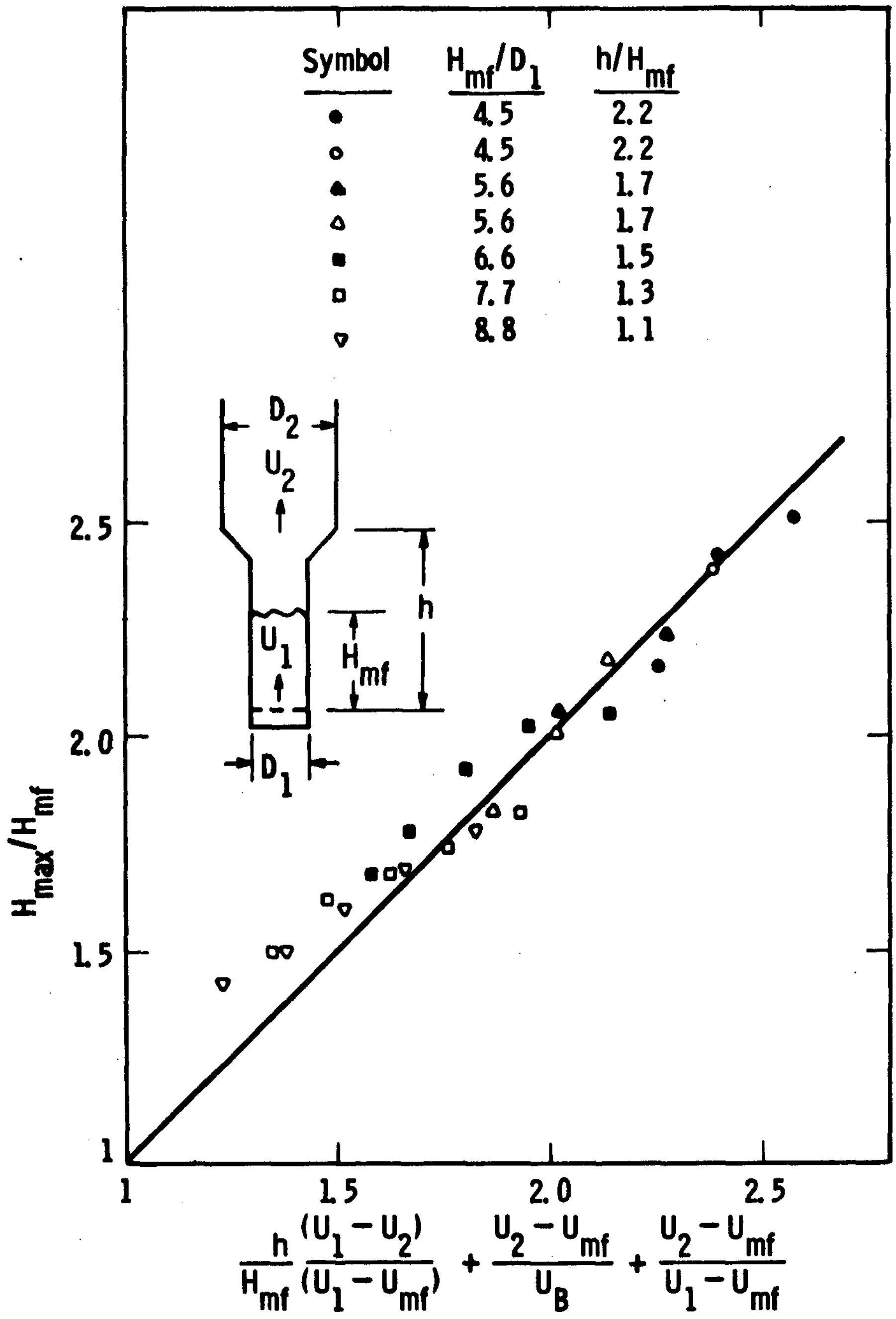


Figure 3.3-3 Effect Of An Expanded Section On Maximum Slugging Bed Height

The semi-circular column was also converted into the gasifier-combustor configuration to study the effect of air tube position on solid exchange rate between the gasifier and the combustor and to study the jet penetration. Initial results are reported here. With sand particles, having an average diameter of 750μm, as the bed material, the jet penetration was studied in two modes: (1) with jet flow alone and (2) with both jet flow and conical flow. The jet nozzle position was fixed at 45.7 cm (18 in.) from the conical transition, and the jet nozzle diameter was 3.8 cm (1.5 in.). The observed jet penetration depths are compared with Merry's, predictions(3) in Fig. 3.3-4. Merry's model is for the penetration of vertical jets into minimally fluidized beds. Thus, the larger jet penetration depths predicted by Merry's model are not surprising. To properly locate the jet nozzle in the gasifier-combustor of the PDU, the discrepancy between Merry's predictions and the experimental results should be taken into account. The experiments are continuing using different bed materials and different air nozzle positions.

Experiments were conducted this quarter using hollow epoxy spheres to study the effect of jet velocity on solid circulation rate by following tracer particles with a stop watch. The initial results are presented in Figure 3.3-5 for a jet nozzle position at 45.7 cm (18 in.) from the conical transition. The particle velocity depends directly on the air nozzle velocity up to about 36.59 m/sec (120 ft/sec). Beyond this gas velocity, the particle velocity increases even at a faster rate. The particle velocity also increased by about 25% when the char-ash separation region (the annular region) was minimally fluidized. Data for the jet nozzle positions at 30.5 cm (12 in.) and 15.2 cm (6 in.) were also collected and are under analysis.

The transparent semi-circular model modified into the gasifier-combustor configuration was used for demonstration of different operating modes to be conducted during PDU operation. This helped train PDU operators to visualize the actual PDU operation. This unit will be available for troubleshooting capacity during PDU operation.

3.3.1.2 Work Forecast For Next Quarter

Continue to operate the semi-circular unit in the gasifier-combustor configuration to study the jet penetration depth, the effect of jet nozzle position and the effect of nozzle sizes on solids exchange between the gasifier and the combustor using different bed materials.

Conduct experiments on simulated continuous char-ash separation in the semi-circular unit under different operating conditions including slugging in the char-ash separation zone.

Support PDU operation.

Curve 688404-A

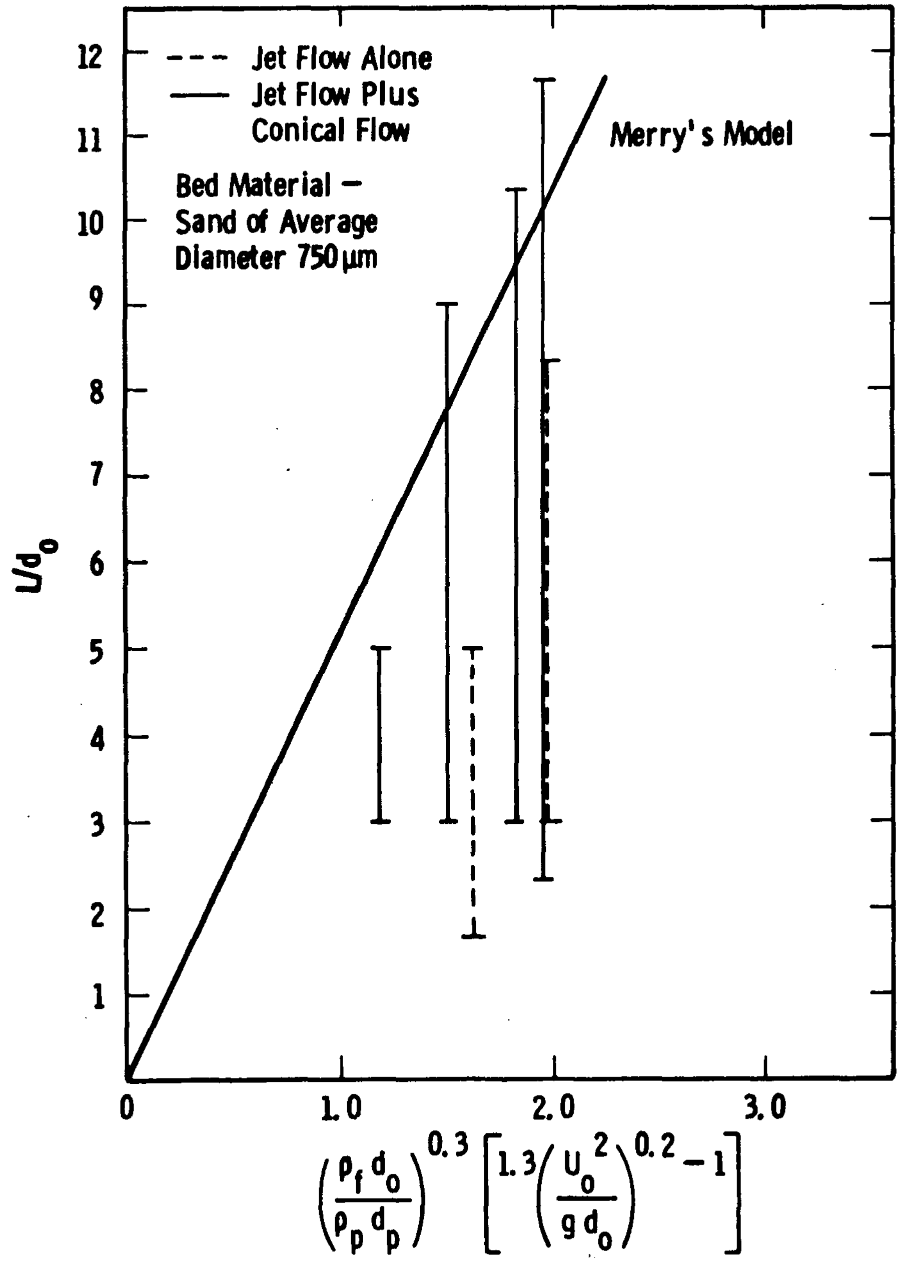


Figure 3.3-4 Comparison Between The Experimental Jet Penetration Depths And The Predictions By Merry's Model

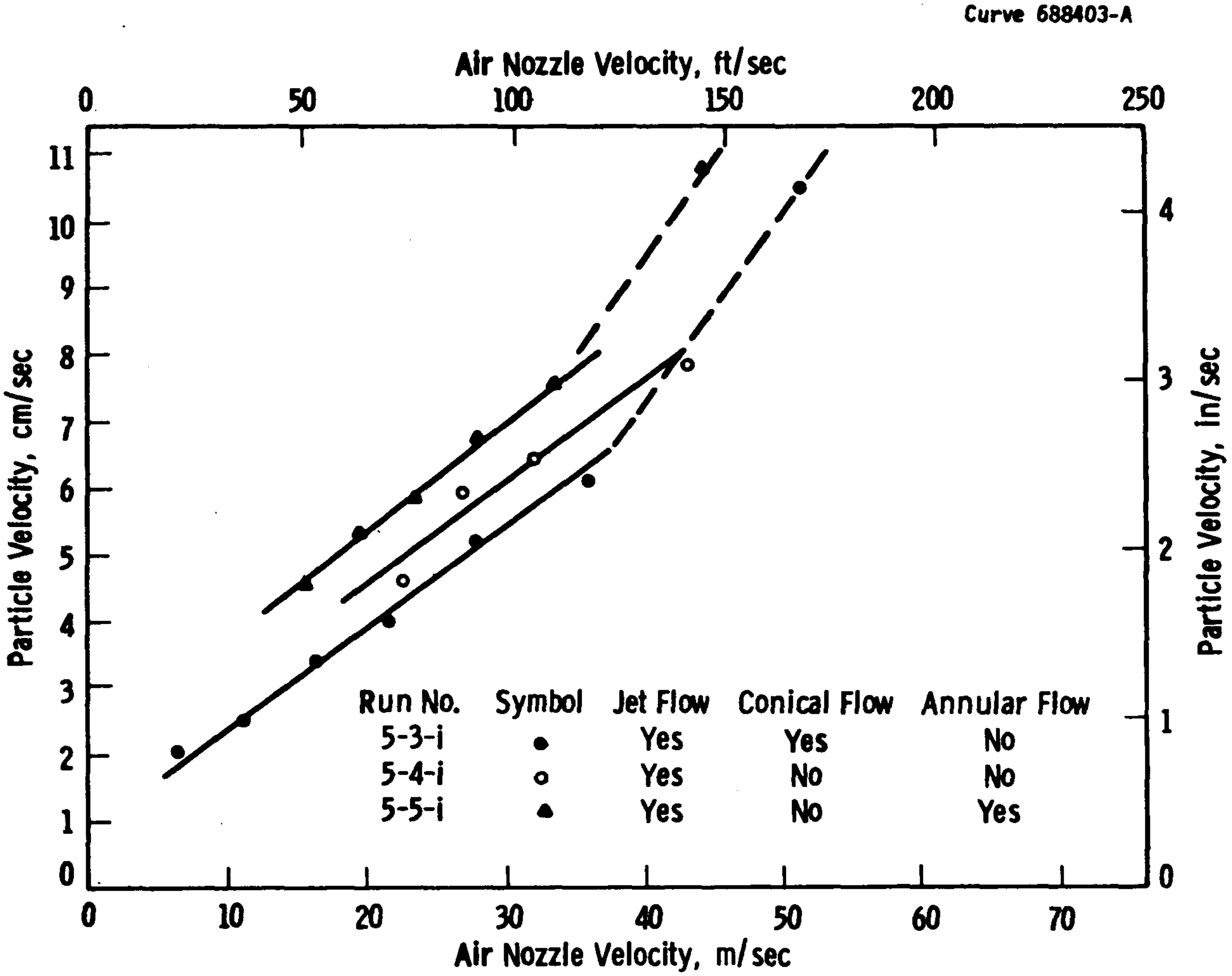


Figure 3.3-5 Solid Particle Velocity Between The Gasifier And Combustor Sections At Different Air Nozzle Velocities & Operating Modes

3.3.2 Coal Behavior

3.3.2.1 Work Accomplished

1. Devolatilization: Auxiliary equipment was ordered to permit the investigation of the effect of char dust on coal agglomeration.

2. Char Gasification: The reaction rate of Minnehaha char with steam was studied at a pressure of 10 atm and temperatures of 1500°F, 1600°F, 1700°F and 1800°F for different inlet concentrations of steam in nitrogen. These results are shown in Figure 3.3-6 along with the results of studies conducted on Montour char and coke breeze at 1700°F. The reaction rate of both Montour char and coke breeze is significantly lower than that of Minnehaha char, possibly because the Montour char and coke breeze are considerably denser than Minnehaha char. The difference in sensitivity to changes in the partial pressure of steam may be attributed to the difference in the change of activity with time. The results obtained in the case of coke breeze are not conclusive and these studies should be repeated.

   The change in the activity of Minnehaha char with time at 1800°F and at a steam partial pressure of 3.14 atm was observed. These results are given in Figure 3.3-7. It can be noted that, initially, there is a twofold increase in the reaction rate followed by a drastic fall. The increase in the reaction rate with time is believed to be due to the increase in the surface area of carbon available for reaction. The reduction in the reaction rate may be attributed to decreasing concentration of carbon in the bed. Results obtained previously with Minnehaha char, at a temperature of 1600°F and steam partial pressures of 1.1 atm and 0.73 atm, indicated no significant change in the reaction rate. The above variation in the activity of char introduces an additional complexity in obtaining rate equations and necessitates a change in the experimental procedure, possibly at high temperatures and high partial pressures of steam.

   The C-CO_2 reaction was studied with Minnehaha char at 1700°F at various partial pressures of CO_2 in nitrogen, and results are shown in Figure 3.3-8 along with results obtained at 1600°F and 1800°F which were presented in the December Monthly Report. The reaction rates at a partial pressure of 1 atm were used to determine the activation energy, the calculation of which is shown in Figure 3.3-9. The value of 101,700 Btu/lb mole for the activation energy should be considered as a preliminary estimate as it was obtained from limited data.

   An additional test was conducted with Minnehaha char to study the effect of heating the char at a high temperature on the reaction rate. These results are given in Table 3.3-1.

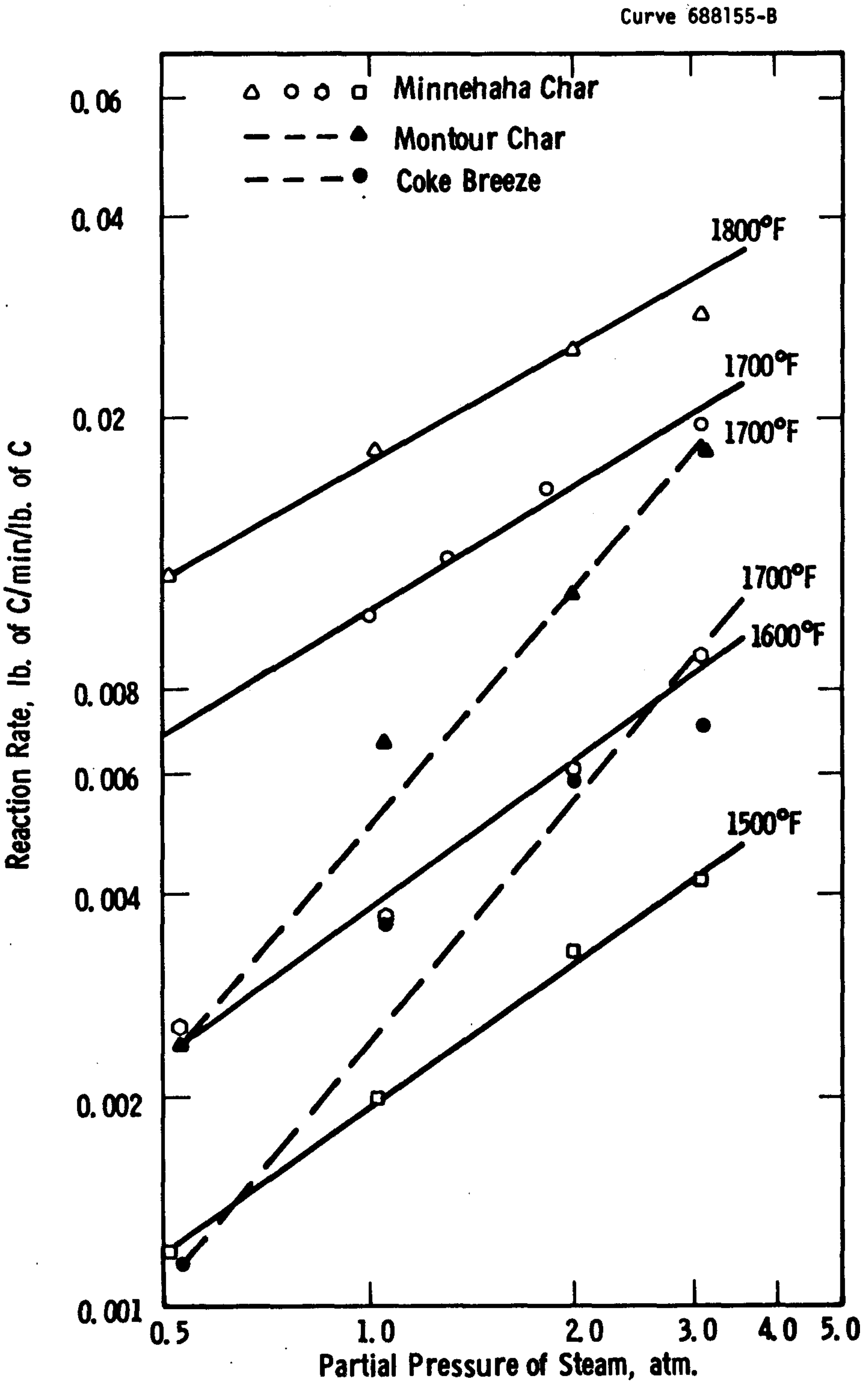


Figure 3.3-6 Carbon-Steam Reaction For Different Chars

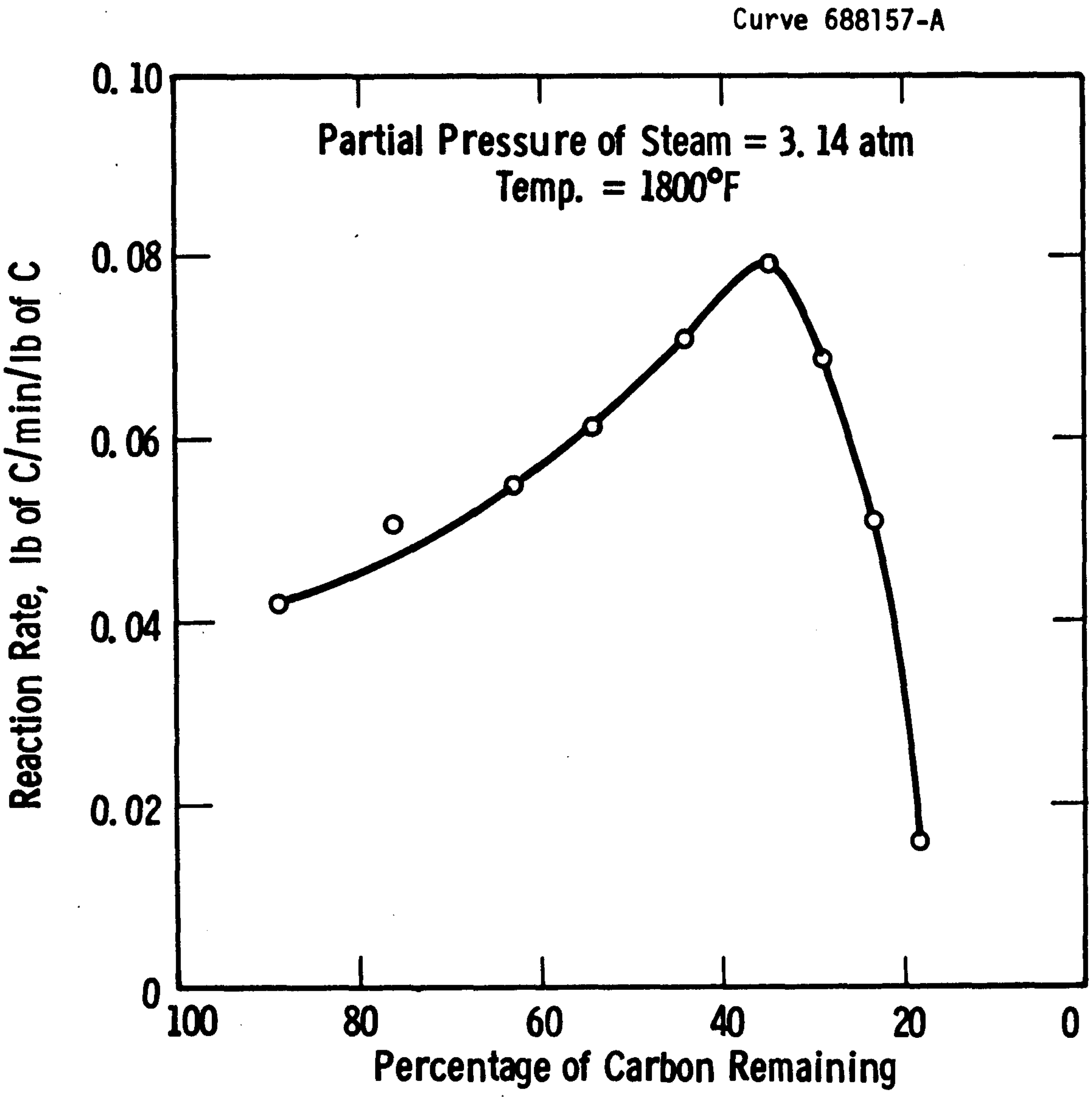


Figure 3.3-7 Minnehaha Char-Steam Reaction At 1800°F

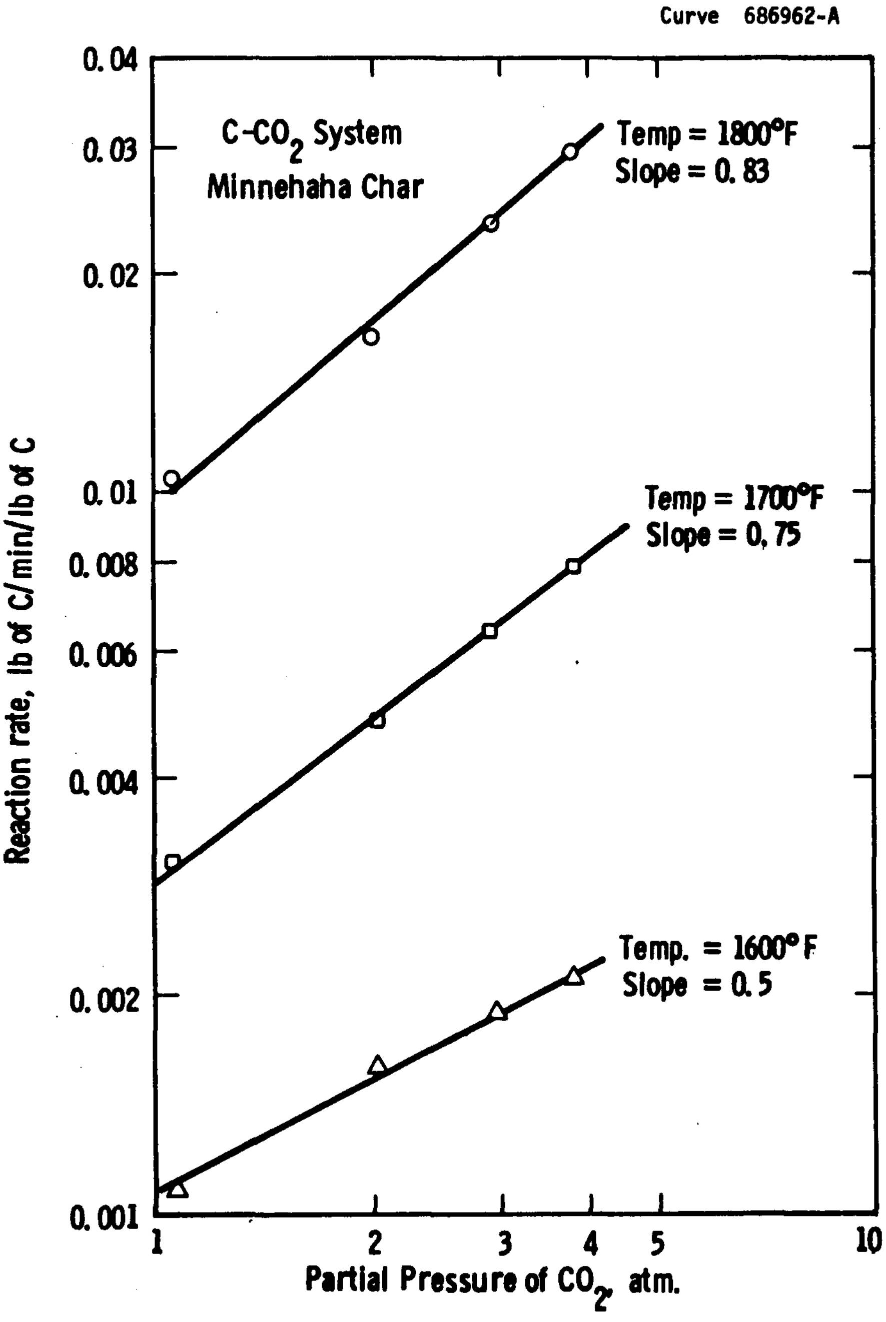


Figure 3.3-8 Reaction Rate Of C - CO_2 Reaction

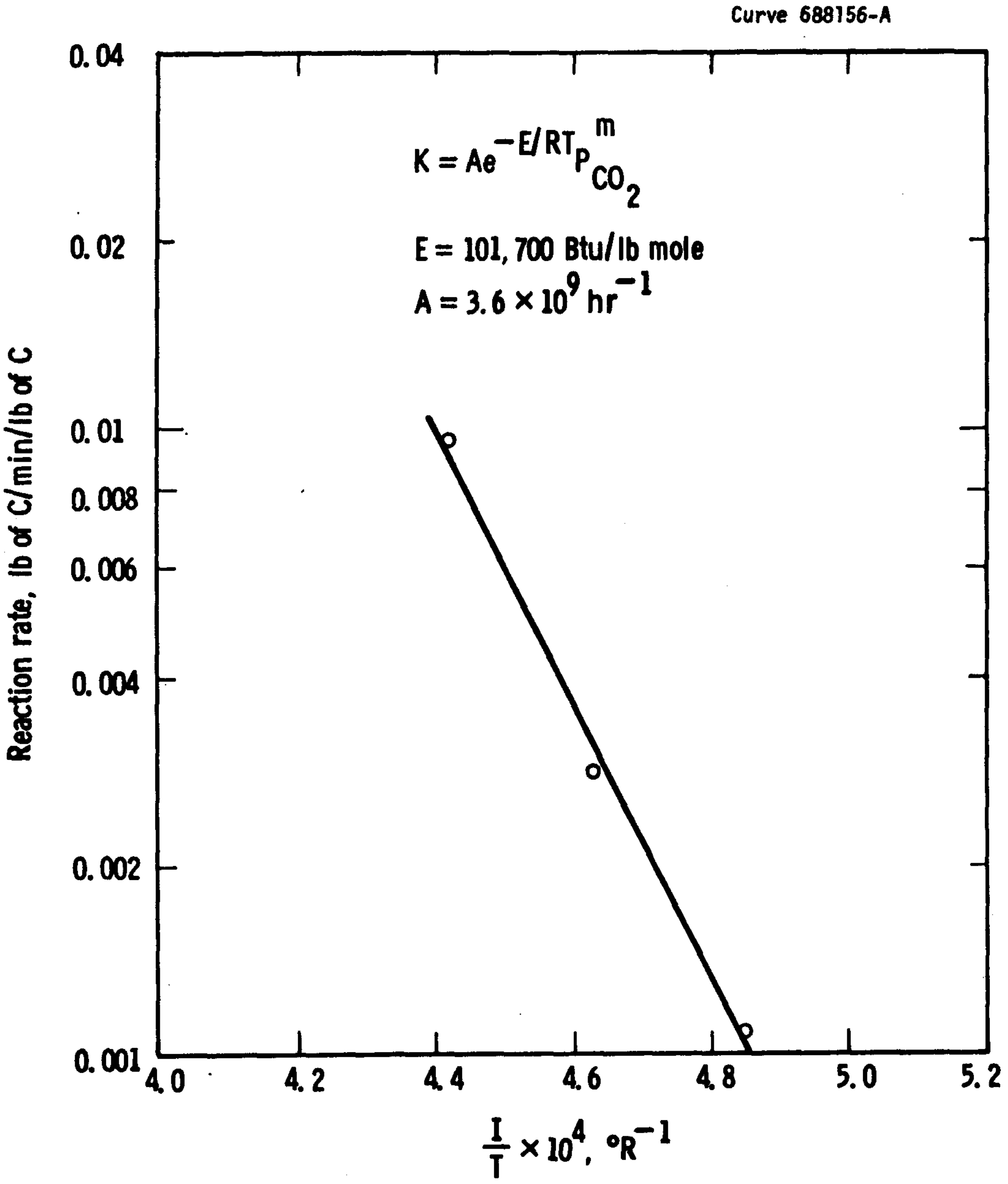


Figure 3.3-9 Minnehaha Char - CO_2 Reaction Activation Energy

TABLE 3.3-1 REACTION RATE DATA ON C-CO_2 WITH MINNEHAHA CHAR

Run Number	Temperature, °F	Partial Pressure of CO_2, Atm	Reaction Rate Lb of C/Min/Lb of C
1	1500	2.88	4.20×10^{-4}
2	1600	2.91	1.68×10^{-3}
3	1600	2.90	1.81×10^{-3}
4	1500	2.86	5.20×10^{-4}

Runs #3 and #4 were conducted after the char was heated in nitrogen to 1800°F and held for about one hour, then cooled to the test temperature. A significant increase in the reaction rate can be noticed in each case.

3.3.2.2 Work Forecast For Next Quarter

Tests will be conducted in the high-temperature, pressure reactor to permit investigation of phenomena in the devolatilizer. The effect of char dust on coal agglomeration will be investigated.

Char gasification studies will continue with coke breeze, Montour char and Minnehaha char to study C-H_2O reaction and C-CO_2 reaction in an effort to obtain rate equations.

3.3.3 Ash Behavior

3.3.3.1 Work Accomplished

The ash agglomeration combustor was completed, and testing of the furnace, instrumentation and char feed system is under way.

3.3.3.2 Work Forecast For Next Quarter

Complete testing and calibration of the equipment and begin ash agglomeration experiments, using coke breeze as the feed material.

3.3.4 Sorbent Behavior

3.3.4.1 Work Accomplished

Work on sorbent behavior was limited to the review of devolatilizer test data in support of analyzing PDU test results.

3.3.4.2 Work Forecast For Next Quarter

Support of PDU operation will be provided as needed.

3.3.5 Reactor Analysis

3.3.5.1 Work Accomplished

Material and energy balances were made on the combustion zone and gasification zone of the agglomerating combustor-gasifier for a wide range of operating conditions in order to generate a map of operating conditions for the PDU. The results of the modeling study on char gasification have been used to conduct these balances. Calculations on material and energy balances consist of first predicting the rate of char gasified for the specified temperature and the steam flow rate. After knowing the amount of char that can be gasified in both the gasifier and the combustor, the amount of char to be burned in each zone can be calculated for specified solid circulation rate and other parameters. The effect of gasifier and combustor temperatures, air temperature and solid circulation rate on the char feed rate, air flow rate, freeboard velocity and the heating value of the gas has been examined from the above calculations.

A document is being prepared to report the details on the char gasification model and material and energy balance calculations.

3.3.5.2 Work Forecast For Next Quarter

Update combustor-gasifier material and energy balance program as new data are available.

Update devolatilizer and combustor-gasifier models based on PDU and support program data.

4.0 REFERENCES

1. Sandstrom, W. A., Rehmat, A. G. and Bair, W. G., "The Gasification of Coal Chars in a Fluidized Bed Ash Agglomeration Gasifier," 69th AIChE Meeting, Chicago, Illinois, November, 1976.

2. Matsen, J.M., Hovmand, S. and Davidson, J. F., "Expansion of Fluidized Beds in Slug Flow," Chem. Eng. Sci., 24, 1743 (1969).

3. Merry, J. M. D., "Penetration of Vertical Jets Into Fluidized Beds," AIChE J., 21 (3), 507 (1975).