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Advanced Coal Gasification System for Electric Power Generation

WESTINGHOUSE ELECTRIC CORPORATION
ADVANCED COAL CONVERSION DEPARTMENT
PROJECTS GROUP
MADISON, PENNSYLVANIA 15663

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WESTINGHOUSE
ADVANCED COAL GASIFICATION SYSTEM
FOR ELECTRIC POWER GENERATION

Sixty-Fifth Monthly Progress Report

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2.1.1 Gasifier Tests

TP-013-3 was conducted this month to evaluate gasifier operability with various coal feedstocks. The primary goal of this test was to explore the feasibility of feeding coal directly to the gasifier without the benefit of pretreatment or devolatilization. The candidate coals chosen were a non-caking Wyoming sub-bituminous coal, a mildly-caking Indiana No. 7 coal from the Minnehaha mines and a highly-caking Pittsburgh seam coal from Consolidation Coal's Champion facility. The free-swelling indices of these three coals were 0, 2 and 8, respectively. The Pittsburgh coal had a Gieseler plasticity of 28,000 ddm.

A minor equipment change was implemented prior to TP-013-3 startup. The 2-3/4 inch recess of the coaxial fines feedline in the air tube was eliminated. The axial location of the air tube was left unchanged at the elevation of the bottom of the grid plate. The operating philosophy for the two caking coals was to feed caking coals coaxially with the air jet and recycle the fines through the radial port. Wyoming coal, being non-caking in character, was fed radially into the reactor.

A total of 75 hours of gasifier operation was logged in this test. The breakdown of run time among the various materials is shown below. Coke breeze and FMC char were used as startup materials and for periods when materials were being changed in the coal handling and storage systems.

Radial Feed	Axial Feed	Run Time, Hours
Coke Breeze	Coke Breeze	9
Recycled Coal/Char Fines	Minnehaha Coal	27
Coke Breeze	FMC (COED)Char	1
Wyoming Coal	FMC (COED)Char	6
Wyoming Coal	Recycled Coal/Char Fines	16
Coke Breeze	Champion Coal	7
Recycled Coal/Char Fines	Champion Coal	9
		75 Total

During this test, 15 tons of Minnehaha coal, 5 tons of Champion coal and 16.8 tons of Wyoming coal were processed. In addition, 11 tons of coke breeze and 3 tons of FMC Utah char were used as substitute feed material during periods of inventory changeover. Reactor temperatures were held between 1720°F and 1770°F. The heating value of the product gas fell in the range of 69-129 Btu/scf. The ash particles discharged from the agglomerator were angular in shape with ash contents of 37% to 69%.

At the conclusion of the test, an emergency shutdown was initiated as a consequence of a fire on the PDU structure. This was the outcome of a procedural failure when a sampling valve was opened in the wrong sequence during the final sample gathering and allowed hot solids and gas to escape from the reactor. Post-test inspection revealed no damage to the refractory, and fire damage to the process structure consisted of minor wiring and instrumentation overheating.

The chronology of the main events during the course of the test is shown in Table 2.1-1. Run data are shown in Table 2.1-2. As Table 2.1-3 shows, product gas heating values produced during the test were 69, 129 and 112 Btu/scf for the three coals. Ash agglomerates were angular and not spherical because of the relatively low temperatures of 1720°F to 1770°F. Ash particle sizes were similar to the larger coal sizes (∿ 1500μm) but were separated from the char bed effectively. Ash concentration in the agglomerate phase was kept at conservatively low levels of 37% to 69%. No caking of the coals took place in the reactor or feed lines, and there was no foreign material deposited in the reactor.

Substantial gasification of the coal was achieved in spite of the small amounts of steam used during the test as shown in the summary below.

	Moisture Content, Wt %	Steam To Dry Coal, Lb/Lb	Total Water to Coal, Lb/Lb	HHV of Gas, Btu/scf
Indiana	6.4	0.20	0.26	69
Wyoming	12.6	0.00	0.13	129
Pittsburgh	1.8	0.24	0.26	112

Although no firm conclusions can be drawn from these preliminary trials with coals, the results are encouraging and show that it is feasible to feed and process a variety of coals in the gasifier without pretreatment or devolatlization. The results encourage future tests in which a greater range of operating parameters are explored. Specifically, runs to achieve steady-state with caking coal at repeatable carbon utilization efficiencies of over 90% and with acceptable product gas quality should be made. These initial evaluations achieved the following accomplishments:

- Demonstrated gasifier operability with coals having a range of caking properties.
- Demonstrated the coaxial coal feed arrangement as an effective means of decaking coal in a lean phase oxidizing air jet.
- Confirmed the absence of coal agglomeration and the ease of operation with a highly-caking coal as no material buildup was noted on the gasifier walls nor on the internals.

(continued)

TABLE 2.1-1 TP-013-3 CHRONOLOGY

Date	Time	Events
NOV 26	2000	Started pressurization.
NOV 27	1600	Ramped reactor temperatures to 500°F to heat up refractories.
NOV 29	0545	Hot air dryout completed.
	0545	Initiated -6 mesh coke breeze feed to build the bed to 25-foot elevation.
	1610	Achieved autogenous combustion of coke breeze.
NOV 30	0100	Began feeding Minnehaha coal through the coaxial feed system. Replaced CO_2 with recycle gas in the booster sparger. Also switched over to steam flow in the grid plate sparger ring.
	0230	Achieved Test Point #1 at a freeboard temperature of 1720°F.
	1700	Failure of fines starwheel feeder shear pin.
	1815	Coal feed interruption caused a drop in the reactor bed height. Air flow was decreased and the radial fines feed rate was increased while repairs were made on the fines feeder.
	2300	Terminated Test Point #1 after running through 15 tons of Minnehaha coal. For the following 7 hours, FMC (COED) char was fed to the gasifier through the coaxial feed system. Storage bin D-104 was charged with 16.8 tons of sub-bituminous, Wyoming coal.
DEC 1	0600	Began Wyoming coal feed through the radial feed port.
	0820	Recycle gas flow to the sparger ring was increased to 1200 lb/hr in order to increase the agitation in the annulus.
	0850	Changed to air as transport gas for the coaxial feedline.
	1200	Achieved Test Point #2 conditions at a freeboard temperature of 1720°F.
	1800	Ash withdrawal capability was lost due to a blockage in the solids discharge leg of the gasifier.
	2000	Dislodged the restriction by pulsing the bottom of the reactor with CO_2 from the ash lockhoppers.

TABLE 2.1-1 TP-013-3 CHRONOLOGY
(continued)

Date	Time	Events
DEC 2	0230	Terminated Test Point #2 after consuming the entire inventory of sub-C Wyoming coal. Coke breeze was fed through the radial feed port for the next 9 hours.
	0515	Switched from air to recycle gas on the coaxial feedline.
	0600	Initiated Champion coal feed through the coaxial feedline.
	1300	Achieved Test Point #3 conditions at a freeboard temperature of 1770°F.
	1700	Experienced difficulty in withdrawing solids through the T129 ash feeder.
	2000	Pulsed the gasifier boot with CO_2 from the ash lockhoppers. Withdrawal was regained.
	2300	Terminated Test Point #3 after consuming 5.0 tons of Champion coal. Coke breeze was fed to the reactor for the remainder of the test.
DEC 2	2330	Normal shutdown was in progress when a procedural failure resulted in a fire on the structure. Emergency actions were taken to rapidly quench char combustion.

TABLE 2.1-2 SUMMARY OF OPERATING DATA FOR GASIFIER TEST TP-013-3

TEST RUN TIME AND DATE		Point #1 0600-1300 Hr Nov 30	Point #2 1230-1815 Hr Dec 1	Point #3 1330-1930 Hr Dec 2
GASIFIER TEMPERATURES (Temperatures As Indicated)	**UNIT**			
TE-504-5 Exit Gas	°F	1720	1720	1770
TE-504-6 24' Bed	°F	1707	1697	1761
TE-504-7 19' Bed	°F	1757	1751	1824
TE-504-8 17' Bed	°F	1779	1767	1847
TE-505-12 15' Bed	°F	1460	1561	1671
TE-504-9 12' Bed	°F	1364	1386	1437
TE-502-11 11' Bed	°F	1502	1455	1515
TE-504-10 5' Bed	°F	399	533	498
TE-501-7 2' Bed	°F	397	532	503
FLUIDIZED BED PARAMETERS				
Average Bed Height	Feet	24.5	25.2	25.8
System Pressure	Psig	230.4	230.5	230.5
PDT-22 Bed Density, 28'-37'	Lb/Ft^3	0.00	0.00	0.00
PDT-23 Bed Density, 24'-28'	Lb/Ft^3	2.52	5.19	6.61
PDT-24 Bed Density, 19'-24'	Lb/Ft^3	9.24	13.54	12.44
PDT-25 Bed Density, 17'-19'	Lb/Ft^3	19.37	26.79	19.84
PDT-26 Bed Density, 12'-17'	Lb/Ft^3	15.26	16.07	14.96
PDT-121 Bed Density, 10'-12'	Lb/Ft^3	3.92	13.88	12.18
PDT-120 Bed Density, 5'-10'	Lb/Ft^3	28.89	35.91	26.99
PDT-119 Bed Density, 4'- 5'	Lb/Ft^3	28.80	29.55	20.87
Annulus Gas Velocity	Fps	1.25	1.16	1.56
Freeboard Gas Velocity	Fps	3.05	2.43	3.03
GAS INLET CONDITIONS				
Steam-Grid FE-34 Flow	Lb/Hr	169	0	245
TE-506-10 Temp	°F	485	0	469
Steam-Annulus FE-36 Flow	Lb/Hr	0	0	0
TE-506-12 Temp	°F	0	0	0
Recycle Gas FT-12 Flow	Lb/Hr	0	349	0
- Grid TE-67 Temp	°F	0	150	0
Recyle Gas FT-11 Flow	Lb/Hr	334	238	215
- Booster TE-67 Temp	°F	135	150	138
Recyle Gas FE-48 Flow	Lb/Hr	895	821	1223
- Sparger TE-503-11 Temp	°F	600	822	680
Air Tube Air FE-37 Flow	Lb/Hr	3558	2840	3301
TE-503-9 Temp	°F	786	1056	1014
Radial Char FE-60 Flow	Lb/Hr	463	415	385
Trans. Gas TE-505-1 Temp	°F	180	100	214
Coaxial Char FE-21 Flow	Lb/Hr	764	692	582
Trans. Gas TE-505-2 Temp	°F	127	158	146
(Char Trans. Gas)		Recycle Gas	Air	Recycle Gas
SOLIDS INPUTS AND OUTPUTS				
Radial Feed Rate, WR-27	Lb/Hr	539**	999*	284**
Coaxial Feed Rate, WR-14	Lb/Hr	902†	698**	850††
Overhead(Cyclone)Char, WR-19	Lb/Hr	606	897	515
Ash Withdrawal	Lb/Hr	78	25	55
PRODUCT GAS ANALYSIS				
Carbon Monoxide CO	%	10.25	21.74	14.19
Carbon Dioxide CO_2	%	21.23	10.86	12.55
Methane CH_4	%	0.88	1.07	1.99
Nitrogen N_2	%	53.44	52.11	55.24
Oxygen O_2	%	0.00	0.00	0.00
Hydrogen H_2	%	5.99	10.32	10.34
Water H_2O	%	8.21	3.91	5.68
SOLIDS ANALYSIS				
Ash Content - Radial Feed	%	15.96	2.55	15.36
Ash Content - Coaxial Feed	%	11.05	14.76	7.02
Ash Content - Bed	%	22.00	20.00	16.00
Ash Content - Agglomerate	%	31.78	41.67	28.97
Ash Content - Cyclone Fines	%	17.68	14.67	15.36

Materials: * = Sub-C Wyoming Coal, ** = Recycled Fines,
† = Minnehaha Coal, †† = Champion Coal

TABLE 2.1-3 PRODUCT GAS CHARACTERISTICS

	Point #1 Indiana Coal	Point #2 Sub-C Coal	Point #3 Pittsburgh Coal
Gas Composition, %			
CO	10.25	21.74	14.19
CO_2	21.23	10.86	12.55
H_2	5.99	10.32	10.34
CH_4	0.88	1.07	1.99
N_2	53.44	52.11	55.24
O_2	0.00	0.00	0.00
H_2O	8.21	3.91	5.68
Higher Heating Value Wet Basis, Btu/Scf	69	129	112
Molecular Weight Ash Discharge	28.9	26.5	26.5
Average Particle Size, Microns	1300	1200	1600
Particle Shape	Angular	Angular	Angular
Ash Content in Discharge, %	43.4	68.6	36.6

- Achieved substantial gasification with minimal steam input to the reactor.
- Fly ash formation was shown to be small.
- Tar and oils production was insignificant.
- Operation was smooth with no process or equipment malfunctions.

2.1.2 PDU Modifications for Integrated Operation

Design, procurement and construction activities were directed toward a March, 1978, startup of the integrated devolatilizer-gasifier system. This work is described in the following paragraphs.

The gasifier expanded section design was modified to provide a larger internal diameter capacity in the area above the grid plate. To accommodate this, the 48-inch section was extended by an additional six feet. Changes were incorporated by Mitternight Boiler Works, and the modified section was delivered December 21. An additional 48-inch instrument ring was placed on order. Other expanded sections were shipped from Mitternight and were received at the PDU site on December 8, 1977. A resizing of the internal refractory configuration was required to be consistent with the change in the gasifier transition section. The internal diameter of the reactor above the grid was changed from 20 to 24 inches. Two 30° transition cones were used between the 20 and 24-inch sections and between the 24 and 30-inch sections. The refractory wall consists of 8 inches of Castable HW-26 and 3 inches of Castolast G.

An alternate spool piece between the gasifier outlet pipe and the cyclone collector was detailed and was ordered. This spool piece will permit the option of testing a single reactor configuration if desired. Based on hardware on hand or on order, several PDU configurations are possible as noted below:

- Gasifier + Cyclone + Quench System
- Gasifier + Cyclone + Devolatilizer + Cyclone + Quench System
- Gasifier + Devolatilizer + Cyclone + Quench System

Purchase orders were issued for two spare draft tube assemblies for the devolatilizer reactor and for Incoloy pipe for nozzle liners in the expanded sections. In addition, a higher capacity impeller for the G101 quench water pump and a nickel-chrome-boron plating of shaft sleeves for all circulation pumps were ordered.

Designs were initiated to modify the devolatilizer product gas outlet pipe and char drawoff transition pipe to be compatible with the expanded sections and to provide an additional gasifier fines drawoff nozzle in the devolatilizer inlet plenum.

Casting molds were designed and fabricated for the 60° conical grid segments for the devolatilizer, and they will be used for making the new grid plate.

The design and procurement work for the sampling and analyzing equipment for product characterization continued. Designs completed this month were: (1) a miniscrubber train for separating and characterizing product gas components and (2) a particulate sampling system including a particulate sampling probe, a minicyclone and a gas conditioning train. System components for the infrared analyzer sampling train and the gas scrubbing train were ordered. Other gas sampling and analysis equipment already on order are being expedited, i.e., two infrared analyzers for CO and CO_2, an additional gas chromatograph and a calorimeter.

General Mechanical's fabrication work continued with the completion of 10-inch and 18-inch pipe fabrication and refractory lining. This subcontractor also completed structural steel fabrication for the supports and work platform for the new piping which connects the two reactors. The shop drawings which detail these piping changes were reviewed and approved for construction. This installation will be delayed until the expanded sections are in place in early February 1978.

With completion of gasifier tests early in the month, a substantial effort could be directed to construction activities related to plant modifications. The following work was performed in December:

1. Removal of refractory from C101 bottom section.
2. Began refractory lining of expanded sections.
3. Repaired fire-damaged equipment.
4. Constructed new waste handling pit.
5. Welded and installed piping for the new waste handling system.
6. Painted process structure and major equipment.
7. Installed new conduits from the control centers to the process structure.

2.1.3 PDU Process and Design Engineering

Design evaluations and computer modeling tasks were conducted in support of the integrated system. The overall arrangements of vessels and piping for integration were reviewed to insure there would be maximum flexibility in permitting operation in various modes as a single or dual reactor system. Also, the process instrumentation and control modes for the integrated system were examined, and, to some extent, modified to simplify the overall instrument requirements. The flexibility noted above was designed into the control system.

An evaluation of the devolatilizer inlet plenum configuration was made for recommending the initial mode of operation for integrated operations. This evaluation showed that the amount of material collected during operation should not be a problem. The material that is collected can be easily removed after the test with the drawoff nozzle port added for this service.

Modeling of the independent reactor systems continued in an effort to develop a heat and material balance computer program for the integrated system. The gasifier heat and material balance program was revised, debugged, verified and installed for use in the computer system. The heat and material balance program for the devolatilizer reactor system is being revised and should be debugged next month.

A conceptual redesign of the existing temperature control for the ash withdrawal systems was completed to provide an electrical method to control operating temperature limits. The new design features an adjustable electrical limiter circuit to automatically control withdrawal speeds by sensing temperature conditions. This control system will be tested during startup operations in March 1978.

2.1.4 Work Planned For January 1978

The installation of refractory in the new expanded sections will be completed and curing operations will begin. Work on the waste system and on instrumentation and controls for integrated operation will continue.

2.2 PHASE I, TASK 3 - LABORATORY SUPPORT STUDIES

Work has been carried out in the following areas: support tasks for the current PDU combustor-gasifier test program, support tasks for the devolatilizer to prepare for integrated plant operation, coal behavior studies, ash behavior studies and reactor analysis. Work accomplished and planned in December 1977 are summarized below.

2.2.1 Combustor-Gasifier Test Program Support

PDU test program support and the analysis of wall deposits continued. Characterization of ash agglomerates from TP-011-5 was completed.

A comparison between pictures taken under the microscope of ash deposits on the wall of the gasifier (C115), on the outlet pipe (C119), and of ash agglomerates from the boot suggested the presence of a molten or fused bonding ash material under the operating conditions of the combustor-gasifier. Molten or fused ash beads formed during gasification or combustion reactions would coalesce to form ash agglomerates or would wet the walls of the gasifier to form ash deposits.

Particle size was shown to have a small effect on the sintering and melting of ash particles: particles of coke breeze ash (formed by slow oxidation in a Lab furnace) were separated by grinding into three different sizes (-425μ+150μ, -150μ+75μ, and -75μ) and were heated for one hour in a furnace at different temperatures. The samples were observed for signs of sintering or melting. Sintering of particles smaller than 150μ was noticed at 1200°C and complete melting at 1400°C while particles in the -425μ+150μ size range showed signs of sintering and partial melting at 1450°C.

The study of wall deposit formation will be continued in close relation with the study of ash agglomeration to determine the formation and melting (or fusion) of the bonding ash material.

2.2.2 Devolatilizer Test Program Support

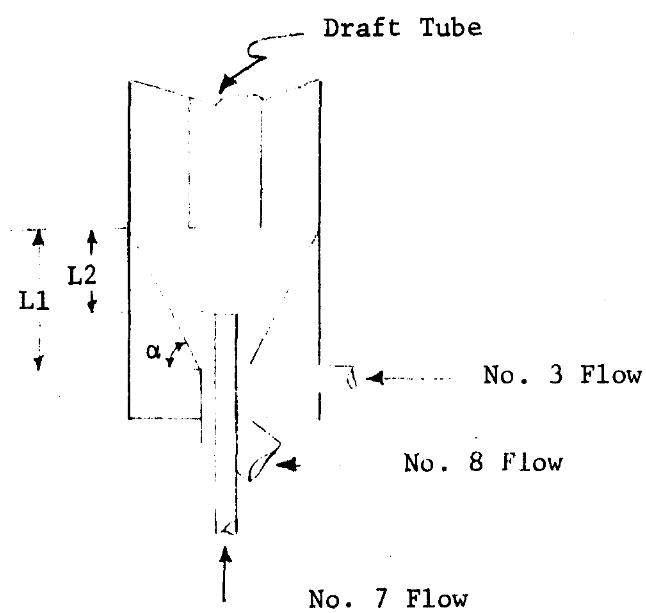
The experimental series for the 60° conical plate at a distance of 27.4cm from the draft tube inlet using Ottawa sand (750μm average particle size) as the bed material were completed. This concluded the first phase of the test program for the distributor plate design studies for integrated operation. Altogether, two distributor plate designs were studied in the test program. The 60° conical plate was located at three different positions, i.e., 14.1cm, 21.7cm and 29.3cm from the draft tube inlet. The 45° conical plate was studied only at one location, 21.7cm from the draft tube inlet. Both polyethylene beads and sand were used as the bed material. Different combinations of flow inlets were also employed. The test series are summarized in Table 2.2-1. Some of the results are presented in the Fourth Quarterly Progress Report (1977).

Several preliminary conclusions are obtained. First, the solid circulation rate depends on the distance of the distributor plate from the draft tube inlet, the greater the distance (over the range tested) the higher the solid circulation rate. Second, the performance of the 60° and the 45° conical plates is essentially similar in terms of solid circulation rate; however, a stagnant region exists on the 45° conical plate but not on the 60° cone. Since the angle of repose of the bed material (polyethylene beads) is about 30° and the angle of internal friction is probably close to that of wheat, 55°, the design angle of the conical plate should be larger than the angle of internal friction of the bed material rather than the angle of repose. Third, the distributor plate location at 29.3cm and the jet nozzle position at 21.7cm gave the best performance at similar operating conditions. This configuration minimizes the startup problem by locating the jet nozzle at the higher position and also takes advantage of higher solid circulation rate by lowering the distributor plate position.

A separate semicircular column, the sections in the old column which were replaced with the expanded sections, is being set up so that both the gasifier-combustor and the devolatilizer configurations can be simulated simultaneously in the future.

TABLE 2.2-1 SUMMARY OF TEST SERIES FOR THE DISTRIBUTOR PLATE DESIGN FOR INTEGRATED OPERATION

Run No.	Distributor Plate, α	Distributor Location, L1	Jet Nozzle Location L2	Flow Combination	Bed Material
30i-34i	60°	21.7cm	21.7cm	7 and 8	Polyethylene
35i-36i	60°	21.7cm	21.7cm	3 and 7	Polyethylene
37i-47i	60°	21.7cm	21.7cm	3, 7 and 8	Polyethylene
49i-51i	60°	14.1cm	14.1cm	7 and 8	Polyethylene
52i-61i	60°	14.1cm	14.1cm	3, 7 and 8	Polyethylene
62i-63i	60°	14.1cm	14.1cm	3 and 7	Polyethylene
64i-68i	45°	21.7cm	21.7cm	7 and 8	Polyethylene
69i-70i	45°	21.7cm	21.7cm	3 and 7	Polyethylene
71i-80i	45°	21.7cm	21.7cm	3, 7 and 8	Polyethylene
81i-84i	60°	29.3cm	21.7cm	7 and 8	Polyethylene
85i-86i	60°	29.3cm	21.7cm	3 and 7	Polyethylene
87i-102i	60°	29.3cm	21.7cm	3, 7 and 8	Polyethylene
103i-109i	60°	29.3cm	21.7cm	3, 7 and 8	Sand
110i-112i	60°	29.3cm	21.7cm	7 and 8	Sand
113i-114i	60°	29.3cm	21.7cm	3 and 7	Sand



2.2.3 Coal Behavior

Pore size distributions and internal surface areas of pores from 100 to 0.01μm diameter of several carbonaceous materials were measured by means of a mercury penetration porosimeter. The reactivities of various chars were plotted as a function of the pore surface area and no definite correlation was observed between these two variables. Information from the literature indicates that a correlation can be expected between the reactivities and the surface area of chars provided pores of smaller size (less than about 55 angstroms) are included in the surface area measurement. Measurement of surface areas using carbon-dioxide includes pores of this size range. Attempts will be made to conduct these measurements.

Examination of the pore volume as a function of the pore diameter of several chars indicates that a sharp increase in the pore volume occurs around a pore size of 10μm diameter and the pore volume then remains constant down to about 0.1μm. Pores in the range of 100 to 10μm and 0.1 to 0.01μm diameter contribute to the pore volume.

2.2.4 Ash Behavior

Equipment needed for the ash agglomeration unit for runs involving steam have been ordered. Necessary modifications for introducing steam in the annulus are being performed.

In recent tests, hollow agglomerates with a thin shell (cenospheres) along with some dense agglomerates were obtained. The formation of ash cenospheres was attributed to Raask* to the evolution of CO_2 inside the molten silicate particles due to the reaction of ferric oxide with dispersed carbon. He found a strong correlation between the amount of cenospheres formed and the amount of ferric oxide in fly ash collected at power plants. The study of Raask indicates that a minimum of about 8% of ferric oxide in ash is needed for the formation of appreciable amounts of hollow agglomerates.

It is likely that, in the present experiments, hollow agglomerates were formed during temperature excursions. It should be noted that the iron oxide content in the ash agglomerates is about 15%. If Raask's explanation is valid for the agglomeration phenomenon, hollow agglomerates can be expected during temperature excursions with any char with an appreciable iron oxide content (greater than about 8% in ash).

2.2.5 Sorbent Behavior

No work was scheduled or performed on this task in December 1977.

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*Raask, E., "Cenospheres in Pulverized-Fuel Ash," J. Inst. of Fuel, 339, September, 1968.

2.2.6 Reactor Analysis

Reactor models of the combustor-gasifier continue to be updated. Work is continuing to develop particle profile analysis capability for integrated plant operation.

2.2.7 Work Planned For January 1978

Combustor-Gasifier Test Program Support: The semicircular column will be changed into the gasifier-combustor configuration to study jet entrainment phenomenon and the particle separation in the annular region. Provide consultation for post-test data analysis. Continue analysis to understand deposit formation.

Devolatilizer Test Program Support: Provide consultation on design and operation for integrated operation.

Coal Behavior: Surface area measurements on various chars using carbon dioxide will be initiated.

Ash Behavior: Continue ash agglomeration experiments to support PDU operations.

Sorbent Behavior: No work is planned or scheduled for January.

Reactor Analysis: PDU test data will be compared with predictions of gasification rate for various tests.