B. Stage 2 Process and Equipment Development Unit--100 lb/hr (R. J. Grace, E. E. Donath, and R. L. Zahradnik)

During the month, the major portion of time was devoted to checking process descriptions and piping and instrumentation drawings from the Koppers Company, preparatory to finalizing compilation of the engineering bid package for the multipurpose research pilot plant facility (MPRF).

Assembly of data and evaluation of overall results from the complete series of 58 tests in the 100 lb/hr PEDU are progressing. In this regard, dispersed tests relative to nitrogen distribution in the products from several PEDU tests and one 5 lb/hr CFR test were assembled. The data and tentative conclusions are presented in this report.

1. Nitrogen Distribution in Products from PEDU Tests: Table 48 shows the distribution of nitrogen in the products from several PEDU tests and one test from the 5 lb/hr CFR unit. Although the data are very meager, certain tentative conclusions can be drawn: (a) For the various coals tested, the nitrogen retention in the char averaged about 30 percent of the nitrogen in the coal; (b) Nitrogen retained in the water (black liquor), which was recovered as ammonia, in most cases was greater than that retained by the char and ranged from about 25 to about 70 percent; (c) Considering only CFR Test 76 and PEDU Tests 34, 35, and 37, the unaccounted for nitrogen, which is considered to be free nitrogen, increased with increased carbon conversion. PEDU Tests 19 and 20 were not considered since the analytical evaluation for nitrogen in the water may have been in error. PEDU Test 52 was not considered because of the very low operating pressure and the fact that with lignite a large percentage of carbon is evolved as carbon oxides ($CO + CO_2$) with the volatile matter components. Low pressure operation would also tend to diminish ammonia formation.

2. Linde Oxygen and Nitrogen Installation: Arrangements were made with the Linde Co. to place the oxygen-nitrogen installation in standby condition. The procedure was completed during the week of November 1, 1971. At this time, the immersion pump in the liquid nitrogen sphere was removed and the opening capped. The unit may be placed back in service for future PEDU work on very short notice.

3. Carbon 14 (C-14) Cleanup: All liquids containing C-14 were disposed of by combustion in the PEDU. All C-14 containers were triple-rinsed with cyclohexane and the liquid was disposed of through combustion. As a consequence of the above operations, the containers were well below the required AEC specifications for minimum radioactivity.

4. Disposition of Surplus Concentrated Carbon 14 (C-14): During the visit of Mr. Neal Cochran on October 1, 1971, it was verbally agreed that any surplus of concentrated C-14 tagged materials would be placed on an OCR disposition list. The present surplus of C-14 materials, amounting to 14 millicuries, is as follows:

4 vials, tagged benzene x 3 mc ea. =	12 mc
8 vials, tagged Xylene x 0.25 mc ea. =	2 mc
TOTAL	14 mc

TABLE 48. NITROGEN DISTRIBUTION IN PRODUCTS FROM PEDU TESTS

Test No.	Coal: Type	Coal: Rate lb/hr (dry)	Coal: Nitrogen Percent	Reactor: Outlet °F	Reactor: Press psig	Nitrogen as % of Nitrogen in Coal: Char	Water	Total	Unaccounted for	Coal: % Carbon Connected Total
19	Elkol	35	1.1	1,500	1,000	31	68	99	1	43
20	Elkol	41	1.1	1,560	1,000	34	72	106	-	43
CFR-76*	Elkol	15 g/min	0.7	1,810	1,000	27	58	85	15	26
34	Pittsburgh Seam	76	1.6	1,800	1,000	28	25	53	47	51
35	Pittsburgh Seam	63	1.6	1,810	525	29	30	59	41	46
37 (1000)	Lower Kittanning Seam	65	1.1	1,730	1,000	34	35	69	31	34
52	Lignite	78	0.9	1,600	220	31	36	67	33	59

* 5 lb/hr Continuous Flow Reactor (CFR)

5. Inspection of Reactor Internal Metal Surfaces in PEDU: During dismantling operations of the PEDU, an opportunity will be provided for inspection of the condition of the internal metal surfaces of the reactor. The operation will include an inspection of the cooling coil surfaces as well as the internal surface of the reactor shell. Initial inspections will be made in the Stage 1 section where maximum temperatures were developed.

Such an inspection will provide information as to how well the particular metals withstood their environment.

6. Future Work: Future work will include:

a. Evaluation and consolidation of the results for the complete series of 58 PEDU tests.

b. Preparation of a summary report.

c. Necessary work to expedite dismantling of the 100 lb/hr PEDU.

d. Completion of the design of the 5 ton/hr pilot plant gasifier and of equipment for the integrated gasification system.

e. Development of appropriate patent disclosures and preparation of technical papers.

C. Cold Flow Model Experiments--5 ton/hr Two-stage Gasifier (R. J. Grace, J. E. Noll, R. D. Harris, R. L. Zahradnik, and E. E. Donath)

Work continued during the month on the cold flow model studies in accordance with the schedule presented in Progress Report No. 92, page 3912. The model studies are expected to indicate both the location and size of nozzles and the shape of the reactor which will avoid excessive localizing of temperatures near the reactor walls. Stages 1 and 2 of the gasifier are to be studied independently at first, followed by tests of the two stages together.

The Stage 1 studies have been divided into three phases, now underway: (1) single-burner tests, (2) multiple-burner tests, and (3) multiple-burner tests plus simulated slag. The experimental requirements for the third phase are considered to be more difficult than those for the other phases. Provisional Phase III work is therefore being undertaken to solve some of the experimental problems so that Phase III data can be obtained immediately following Phase II tests.

1. Phase I Model Tests: The initial work planned for Phase I has been completed and the results are presented as follows:

a. Summary: The model tests so far conducted confirm that the burner designed for Stage 1 of the 5 ton/hr two-stage gasifier should perform as expected. The steam-char and oxygen emitted from each burner was projected in a narrow stream traveling in the direction of the steam flow. This stream mixed rapidly, but expanded and lost velocity gradually as it traveled from the burner. The burners can be directed at relatively wide angles from the center line of Stage 1 without risking high oxygen concentration near the reactor walls, either at points near the burner inlets or at the points at which the burners are directed.

From the test results it was also concluded that, despite the rapid mixing of the two streams from the burner, oxygen would also readily mix and react with the hydrogen, carbon monoxide, or char in the ambient gas. It was concluded, therefore, that most of the char recycled from Stage 2 will have to react with steam and carbon dioxide in the ambient gas rather than directly with the oxygen.

The test results showed that there was no significantly improved mixing of the outer and inner nozzle gases by angling the outer nozzle jets 15 degrees or 30 degrees inwards. Mixing of the outer nozzle gas with air from the center nozzle was possibly enhanced by removing the diffuser ring to simulate a low momentum outer nozzle jet. It was, however, felt that a low momentum oxygen nozzle would have the inherent disadvantage of producing high reaction rates near the reactor wall at the nozzle outlet in case the entraining steam-char jet became blocked. It is therefore recommended that a 15-degree jet be used with the pilot plant burners on the basis of satisfactory PEDU operation with this jet angle.

b. Description of Equipment:

(1) Prototype Burner: Approximately 1/2 mol of oxygen is provided for each mol of carbon in the char residue from the coal reacted in Stage 2. It is desirable to react as much of the oxygen as possible directly with the char. A burner with an annular char nozzle around a central oxygen nozzle, such as with Koppers' Totzec unit, would probably promote a high rate of oxygen-char reaction.

However, for practical considerations, it was decided that the burner should be comprised of a simple central steam-char nozzle surrounded by a ring of smaller oxygen ports. Practical considerations also prescribed relatively high steam and oxygen velocities. High steam velocities are required to entrain the recycled char, and high oxygen velocities to minimize the blockage of the nozzle ports by slag droplets.

The prototype burner was shown in Figure 840, p. 3914 of Progress Report No. 92. It was designed to satisfy the conditions for modeling the burners proposed for Stage 1 using tests at room temperature and atmospheric pressure. The oxygen distribution was simulated by having 12 x 5/32-inch ports arranged around a 5/8-inch diameter port simulating the steam and char nozzle. The oxygen ports were drilled in removable nozzle rings with ports parallel to the steam flow and facing 15 degrees and 30 degrees inward. The rings are shown in Figure 44, p. 141 of Progress Report No. 2.

A blower was set up to provide a separate air supply to the simulated steam and char inlet and to the simulated oxygen inlet. A carbon dioxide cylinder was also provided to supply carbon dioxide to the simulated oxygen stream.

(2) Test Vessel: The prototype burner was mounted in the center of the bottom of an open 55-gallon drum. The drum was extended by the addition of a second bottomless drum, and a conical end piece with a 4-inch diameter outlet was also added.

Holes at 4-inch intervals were provided along the drum for sampling. The drum was set horizontally with guides provided to fix the location of the sampling probe. The set up was shown in Figure 43, page 141 of Progress Report No. 2.

(3) Sampling and Analysis: Air velocity measurements were made with a standard pitot tube[1] connected to a variable-slope manometer.

Carbon dioxide measurements were made using a Gow-Mac gas chromatograph coupled to a Vidar integrator. The analytical procedures were described in more detail in Progress Report No. 2, p. 140.

Conditions were set with respect to air flow, carbon dioxide flow, and type of outlet. Analyses were made in duplicate at each position outward from the source towards the outer surface and towards the end of the unit. In later tests, when constant values were obtained at successive positions, that series of analyses was terminated. Duplicate readings agreed within three percent.

The gas chromatograph was operated with a helium flow of 50 milliliters per minute rather than the 500 milliliters per minute reported last month.

c. Test Procedure: All the tests consisted of successive measurements made under steady state conditions. Before each test, the air rate to the center nozzle and the air, or air and carbon dioxide, rate to the outer nozzle ring were set. The air velocity or the carbon dioxide concentrations were then measured at selected points. The points selected were modified as the test program progressed.

Air velocity determinations were made with 100 percent air fed at 13.9 cfm to the inner nozzle and at 5.6 cfm to the outer nozzle ring. The tests were repeated with all three outer nozzle rings and with no ring.

Carbon dioxide measurements were initially made over widely separated points using the parallel and the 30-degree outer nozzle ring. Further carbon dioxide measurements were than made at locations close to the burner to determine possible differences in the initial mixing between the inner and outer nozzle gases. Finally, tests were made to include the points close to the burner and additional points further out. This arrangement of test points was used in tests to characterize operation with the outer nozzle ring removed and operation at a variety of flow rates with the 15-degree nozzle ring.

---

[1] Bulletin No. 110, Standard Test Code for Centrifugal and Axial Fans, 1938, NAFM.

Operation with all 3 rings and with no ring was characterized with an air feed rate of 13.9 cfm to the center nozzle and air with 10 to 12 percent carbon dioxide fed to the outer nozzle. Three additional tests were also made with the 15-degree nozzle: a test at a reduced rating with both gas streams, a test at an increased rating with both gas streams, and a test with the air rating to the outer nozzle decreased.

d. Test Results: The pitot tube data are given in Table 49 for the parallel port nozzle ring, in Table 50 for the nozzle ring with 15-degree ports, in Table 51 for the 30-degree port ring, and in Table 52 with the nozzle ring removed.

The data on the carbon dioxide measurements, taken over widely separated points, are given in Table 53 for operation with the 30-degree port nozzle ring and no cone at the end of the drum, in Table 54 for the same arrangement with the cone in position, and in Table 55 for operation with parallel ports in the nozzle ring.

The data on carbon dioxide measurements taken close to the burner are given in Table 56 for operation with the 30-degree port nozzle ring and Table 57 for the parallel port ring. The data for carbon dioxide measurements taken with the outer nozzle ring removed are given in Table 58.

The data on carbon dioxide measurements taken with the 15-degree port outer nozzle ring are given in Tables 59 to 62. The data in Table 59 were obtained at normal air and carbon dioxide settings. The data in Table 60 were obtained at 50 percent of the normal air and carbon dioxide settings. The data in Table 61 were obtained at the normal center nozzle air setting but with reduced air supplied to the outer nozzle. The data in Table 62 were obtained with the maximum center nozzle air rate possible with the available blower and a proportionate outer nozzle setting.

e. Interpretation of Results: The data in Tables 49, 50, and 51 were plotted in Figure 45, p. 142 of Progress Report No. 2. The data and curves show that the downstream velocity patterns are not significantly influenced by the outer nozzle ring. The data in Table 52 are similar to the data in Tables 49, 50, and 51.

The curves indicate that the burner nozzles form a gradually widening and decelerating cone-shaped jet propelled in the direction of the center nozzle. At 12 inches from the nozzle, where the jets from the three Stage 1 burners could combine at the center of the 2-foot reactor, the velocities would be approximately 45 ft/sec at the center line, 32 ft/sec 1 inch away, and 9 ft/sec 2 inches away. If it is assumed that most of the reactants are confined in the cone-shaped jets emitted at 100 ft/sec initial velocity, the residence time for the reactants to reach the vortex at the center will be about 0.02 sec.

Even if it could be shown that the mixing between the inner and outer nozzle gases could be significantly modified by using different outer nozzle rings, the overall effects of the mixing in jets converging on the central

TABLE 49. PITOT TUBE DATA. PROTOTYPE STAGE 1 BURNER
WITH PARALLEL PORTS IN OUTER NOZZLE RING

Distance from Burner, in.	Center Line velocity,		1 in. from Center Line velocity,		2 in. from Center Line velocity,	
	in. water	fps	in. water	fps	in. water	fps
2.5	4.25	140	-	-	-	-
6.5	2.25	100	0.04	13	-	-
10.5	0.63	53	0.38	42	0.02	9
14.5	0.38	42	0.22	27	0.02	9
18.5	0.19	28	0.12	24	0.03	11
22.5	0.11	22	0.07	18	0.02	9

Inner Nozzle 13.9 cfm
Outer Nozzle Ring 5.6 cfm

TABLE 50. PITOT TUBE DATA. PROTOTYPE STAGE 1 BURNER
WITH 15° PORTS IN OUTER NOZZLE RING

Distance from Burner, in.	Center Line velocity,		1 in. from Center Line velocity,		2 in. from Center Line velocity,	
	in. water	fps	in. water	fps	in. water	fps
2.5	4.25	141	-	-	-	-
6.5	2.45	105	0.03	11	-	-
10.5	0.73	58	0.17	28	0.01	7
14.5	0.29	34	0.11	23	0.01	7
18.5	0.13	24	0.11	23	0.03	11
22.5	0.10	20	0.08	19	0.04	13

Inner Nozzle 13.9 cfm
Outer Nozzle Ring 5.6 cfm

TABLE 51. PITOT TUBE DATA. PROTOTYPE STAGE 1 BURNER WITH 30° PORTS IN OUTER NOZZLE RING

Distance from Burner, in.	Center Tube Differential, in.	Line Velocity fps	1 in. from Center Line Tube Differential in.	1 in. from Center Line Velocity fps	2 in. from Center Line Tube Differential in.	2 in. from Center Line Velocity fps
2.5	4.50	142	--	--	--	--
6.5	2.50	106	0.01	7	--	--
10.5	0.88	63	0.08	19	--	--
14.5	0.38	42	0.22	32	0.04	14
18.5	0.17	28	0.17	28	0.05	15
22.5	0.13	24	0.09	20	0.05	15

Inner Nozzle 13.9 cfm
Outer Nozzle Ring 5.6 cfm

TABLE 52. PITOT TUBE DATA. PROTOTYPE STAGE 1 BURNER WITH OUTER NOZZLE RING REMOVED

Distance from Burner, in.	Center Tube Differential, in.	Line Velocity fps	1 in. from Center Line Tube Differential in.	1 in. from Center Line Velocity fps	2 in. from Center Line Tube Differential in.	2 in. from Center Line Velocity fps
2.5	4.40	141	--	--	--	--
6.5	2.60	108	0.16	27	--	--
10.5	0.76	58	0.22	32	--	--
14.5	0.36	40	0.21	30	0.02	9
18.5	0.19	29	0.17	28	0.04	13
22.5	0.11	22	0.09	20	0.04	13

Inner Nozzle 13.9 cfm
Outer Nozzle Ring 5.6 cfm

TABLE 53. CARBON DIOXIDE MEASUREMENTS. PROTOTYPE STAGE 1 BURNER WITH 30° PORTS IN OUTER NOZZLE RING, NO CONE.

Distance from Burner, in.	5/8 in. from Center Line		4 in. from Center Line		8 in. from Center Line	
	CO_2, %	Mixing Factor	CO_2, %	Mixing Factor	CO_2, %	Mixing Factor
2	3.52	3.11	1.12	0.99	0.92	0.81
14	1.64	1.44	1.14	1.00	1.01	0.89
30	1.33	1.17	1.24	1.09	1.17	1.13

Center Nozzle 13.9 cfm, 100 percent air
Outer Nozzle 5.9 cfm, 11.50 percent CO_2
Fully Mixed CO_2 1.13 percent

TABLE 54. CARBON DIOXIDE MEASUREMENTS. PROTOTYPE STAGE 1 BURNER WITH 30° PORTS IN OUTER NOZZLE RING

Distance from Burner, in.	5/8 in. from Center Line		4 in. from Center Line		8 in. from Center Line	
	CO_2, %	Mixing Factor	CO_2, %	Mixing Factor	CO_2, %	Mixing Factor
2	4.20	1.36	3.08	1.00	3.12	1.01
14	3.02	0.98	-	-	1.11	1.01
30	3.04	0.99	3.10	1.01	3.08	1.00

Center Nozzle 13.9 cfm 100 percent air
Outer Nozzle 5.9 cfm 11.50 percent CO_2
Fully Mixed CO_2 3.08 percent

TABLE 55. CARBON DIOXIDE MEASUREMENTS. PROTOTYPE STAGE 1 BURNER WITH PARALLEL PORTS IN OUTER NOZZLE RING

Distance from Burner, in.	5/8 in. from Center Line CO_2, percent	5/8 in. from Center Line Mixing Factor	4 in. from Center Line CO_2, percent	4 in. from Center Line Mixing Factor	8 in. from Center Line CO_2, percent	8 in. from Center Line Mixing Factor
2	4.96	1.70	2.96	1.01	2.83	0.97
14	2.97	1.02	2.92	1.00	2.87	0.99
30	2.90	0.99	2.94	1.00	2.90	1.00

Center Nozzle 13.9 cfm 100 percent Air
Outer Nozzle 5.9 cfm 10.60 percent CO_2
Fully Mixed CO_2 2.91 percent

TABLE 56. CARBON DIOXIDE MEASUREMENTS. PROTOTYPE STAGE 1 BURNER WITH 30° PORTS IN OUTER NOZZLE

Distance from Burner, in.	Center Line CO_2, percent	Center Line Mixing Factor	5/8 in. from Center Line CO_2, percent	5/8 in. from Center Line Mixing Factor	1-1/4 in. from Center Line CO_2, percent	1-1/4 in. from Center Line Mixing Factor
2	0.04*	0.01	3.31**	1.06	3.00**	0.96
6	1.92*	0.69	3.32**	1.06	2.99**	0.96
10	2.74*	0.99	2.81**	1.01	2.97**	0.95

Center Nozzle 13.9 cfm 100 percent Air
Outer Nozzle 5.9 cfm 10.80 percent CO_2* 11.66 percent CO_2**
Fully Mixed CO_2 2.78 percent* and 3.12 percent **

TABLE 57. CARBON DIOXIDE MEASUREMENTS. PROTOTYPE STAGE 1
BURNER WITH PARALLEL PORTS IN OUTER NOZZLE

Distance from Burner, in.	Center Line CO_2, percent	Center Line Mixing Factor	5/8 in. from Center Line CO_2, percent	5/8 in. from Center Line Mixing Factor	1-1/4 in. from Center Line CO_2, percent	1-1/4 in. from Center Line Mixing Factor
2	0.05	0.02	5.65	1.92	2.96	1.01
6	1.99	0.68	3.06	1.04	2.99	1.02
10	2.74	0.93	2.89	0.98	2.98	1.02

Center Nozzle 13.9 cfm 100 percent Air
Outer Nozzle 5.9 cfm 11.67 percent CO_2
Fully Mixed CO_2 2.94 percent

TABLE 58. CARBON DIOXIDE MEASUREMENT. PROTOTYPE STAGE 1
BURNER WITH OUTER NOZZLE RING REMOVED

Distance from Burner, in.	Center Line CO_2, percent	Center Line Mixing Factor	5/8 in. from Center Line CO_2, percent	5/8 in. from Center Line Mixing Factor	1-1/4 in. from Center Line CO_2, percent	1-1/4 in. from Center Line Mixing Factor	2-1/2 in. from Center Line CO_2, percent	2-1/2 in. from Center Line Mixing Factor	5 in. from Center Line CO_2, percent	5 in. from Center Line Mixing Factor
2	0.08*	0.03	6.78*	2.25	3.18*	1.05	2.85**	0.99	2.86**	1.00
6	2.18*	0.72	3.45*	1.14	3.04*	1.01	2.88**	1.01	--	--
14	2.97*	0.98	2.96*	1.03	2.97*	0.99	--	--	--	--
22	2.98*	0.99	3.00*	1.00	--	--	--	--	--	--

Center Nozzle 13.9 cfm 100 percent Air
Outer Nozzle 5.9 cfm 12.25 percent CO_2* 11.10 percent CO_2**
Fully Mixed CO_2 3.01 percent* and 2.86 percent**

TABLE 59. CARBON DIOXIDE MEASUREMENTS. PROTOTYPE STAGE 1 BURNER WITH 15° PORTS IN OUTER NOZZLE

Distance from Burner, in.	Center Line CO_2, percent	Center Line Mixing Factor	5/8 in. from Center Line CO_2, percent	5/8 in. from Center Line Mixing Factor	1-1/4 in. from Center Line CO_2, percent	1-1/4 in. from Center Line Mixing Factor	2-1/2 in. from Center Line CO_2, percent	2-1/2 in. from Center Line Mixing Factor	5 in. from Center Line CO_2, percent	5 in. from Center Line Mixing Factor
2	0.06*	0.02	3.98*	1.60	2.41*	1.00	2.39*	0.99	2.39*	0.9[illegible]
6	1.21**	0.54	2.57**	1.16	2.30**	1.03	2.25**	1.01	2.24**	1.0[illegible]
14	2.16**	0.98	2.16**	0.98	--	--	--	--	--	--

Center Nozzle 13.9 cfm 100 percent Air
Outer Nozzle 5.9 cfm 9.28 percent CO_2
Fully Mixed CO_2 2.40* percent and 2.22** percent

TABLE 60. CARBON DIOXIDE MEASUREMENTS. PROTOTYPE STAGE 1 BURNER WITH 15° PORTS IN OUTER NOZZLE

Distance from Burner, in.	Center Line CO_2, percent	Center Line Mixing Factor	5/8 in. from Center Line CO_2, percent	5/8 in. from Center Line Mixing Factor	1-1/4 in. from Center Line CO_2, percent	1-1/4 in. from Center Line Mixing Factor	2-1/2 in. from Center Line CO_2, percent	2-1/2 in. from Center Line Mixing Factor	5 in. from Center Line CO_2, percent	5 in. from Center Line Mixing Factor
2	0.03*	0.02	2.60*	1.50	1.72*	0.99	1.76*	1.01	1.82**	0.99
6	1.19**	0.65	2.02**	1.11	1.88**	1.03	1.84**	1.01	1.83**	1.00
14	1.79**	0.98	1.79**	0.98	--	--	--	--	--	--

Center Nozzle 6.9 cfm 100 percent Air
Outer Nozzle 2.8 cfm 6.58 percent CO_2* and 6.80 percent CO_2**
Fully Mixed CO_2 1.74 percent* and 1.82 percent**

TABLE 61. CARBON DIOXIDE MEASUREMENTS. PROTOTYPE STAGE 1 BURNER WITH 15° IN OUTER NOZZLE

Distance from Burner, in.	Center Line		5/8 in. from Center Line		1-1/4 in. from Center Line		2-1/2 in. from Center Line		5 in. from Center Line	
	CO_2, percent	Mixing Factor	CO_2, percent	Mixing Factor	CO_2, percent	Mixing Factor	CO_2, percent	Mixing Factor	CO_2, percent	Mixing Factor
2	0.06	0.03	3.68	1.40	2.65*	1.00	2.62*	0.99	2.62*	0.99
6	1.97*	0.73	2.71*	1.01	2.70*	1.01	2.67*	1.00	2.66*	1.0[illegible]
14	2.56**	1.00	2.55	1.00	2.56	1.00	--	--	--	--

Center Nozzle 13.9 cfm 100 percent Air
Outer Nozzle 2.8 cfm 15.38 percent CO_2, 14.54 percent CO_2* and 13.61 percent CO_2**
Fully Mixed CO_2 2.64 percent, 2.67 percent* and 2.55 percent**

TABLE 62. CARBON DIOXIDE MEASUREMENTS. PROTOTYPE STAGE 1 BURNER WITH 15° PORTS IN OUTER NOZZLE

Distance from Burner, in.	Center Line		5/8 in. from Center Line		1-1/4 in. from Center Line		2-1/2 in. from Center Line		5 in. from Center Line	
	CO_2, percent	Mixing Factor	CO_2, percent	Mixing Factor	CO_3, percent	Mixing Factor	CO_2, percent	Mixing Factor	CC_2, percent	Mixing Factor
2	0.12	0.05	3.96	1.68	2.28	1.04	2.15	0.98	2.18	0.99
6	1.26**	0.61	2.17**	1.05	2.09**	1.01	2.09**	1.01	2.07**	1.00
14	2.04**	0.99	2.05**	0.99	--	--	--	--	--	--

Center Nozzle 16.5 cfm 100 percent Air
Outer Nozzle 6.4 cfm 7.65 percent CO_2* and 7.38 percent CO_2**
Fully Mixed CO_2 2.20 percent* and 2.07 percent**

vortex would not be significant compared to the effects obtained in 2 to 4 seconds total residence time in the 2-ft diameter, 4-ft high reactor.

The carbon dioxide data taken over widely separated points in the drum show that the air and carbon dioxide are uniformly mixed except in the immediate vicinity of the burner. The data in Table 53, taken near the end of a 6-ft long open drum show that the secondary mixing is sufficient to insufflate approximately twice as much air from the open end of the drum as is injected by the burner.

The addition of the cone eliminated the insufflation of secondary air. The data in Tables 54 and 55 are plotted in Figure 58. This figure shows that the air and carbon dioxide are not completely mixed in the 4-inch radius cylinder which extends 14 inches from the burner.

There is merit in trying to optimize the mixing of the outer nozzle gas with that of the inner nozzle instead of with the ambient gas so as to optimize the reaction of the recycled char with the oxygen. The mixing factors determined at the center line with three different outer nozzle rings and with the ring removed as plotted in Figure 59.

From Figure 59 it would appear that the design of the nozzle ring does not influence the rate of mixing between the inner and outer nozzle gases.

The data in Tables 59 to 62, all taken with the 15-degree port nozzle ring, indicate the effects of changing flow rates. The mixing ratios at the center line for the four conditions tested are plotted in Figure 60, which shows a slight improvement in center line mixing with lower flow rates through the outer nozzle.

2. Phase II Model Tests: Assembly of equipment has been completed.

3. Phase III Model Tests: The equipment for preliminary Phase III tests has been assembled and tested.

Figure 61 shows the installation below the inlet to the oil mist separator described in Progress Report No. 2. The large blower in the foreground can supply six metered air streams to two inlets on three prototype burners. The burner to the left of the picture is connected to an air injector for powder injection. The prototype reactor consists of two 2-ft diameter, 2-ft high plastic cylinders connected to steel conical end pieces.

The cylinders, end pieces, and burners comprise a full-scale mock-up of the current design of Stage 1 of the 5 ton/hr two-stage gasifier.

Figure 62 shows a close-up of the three-burner installation. As shown, the burners are set horizontally and are aimed at the center line of the model. The burners are swivel-mounted to allow testing of a variety of burner angles.

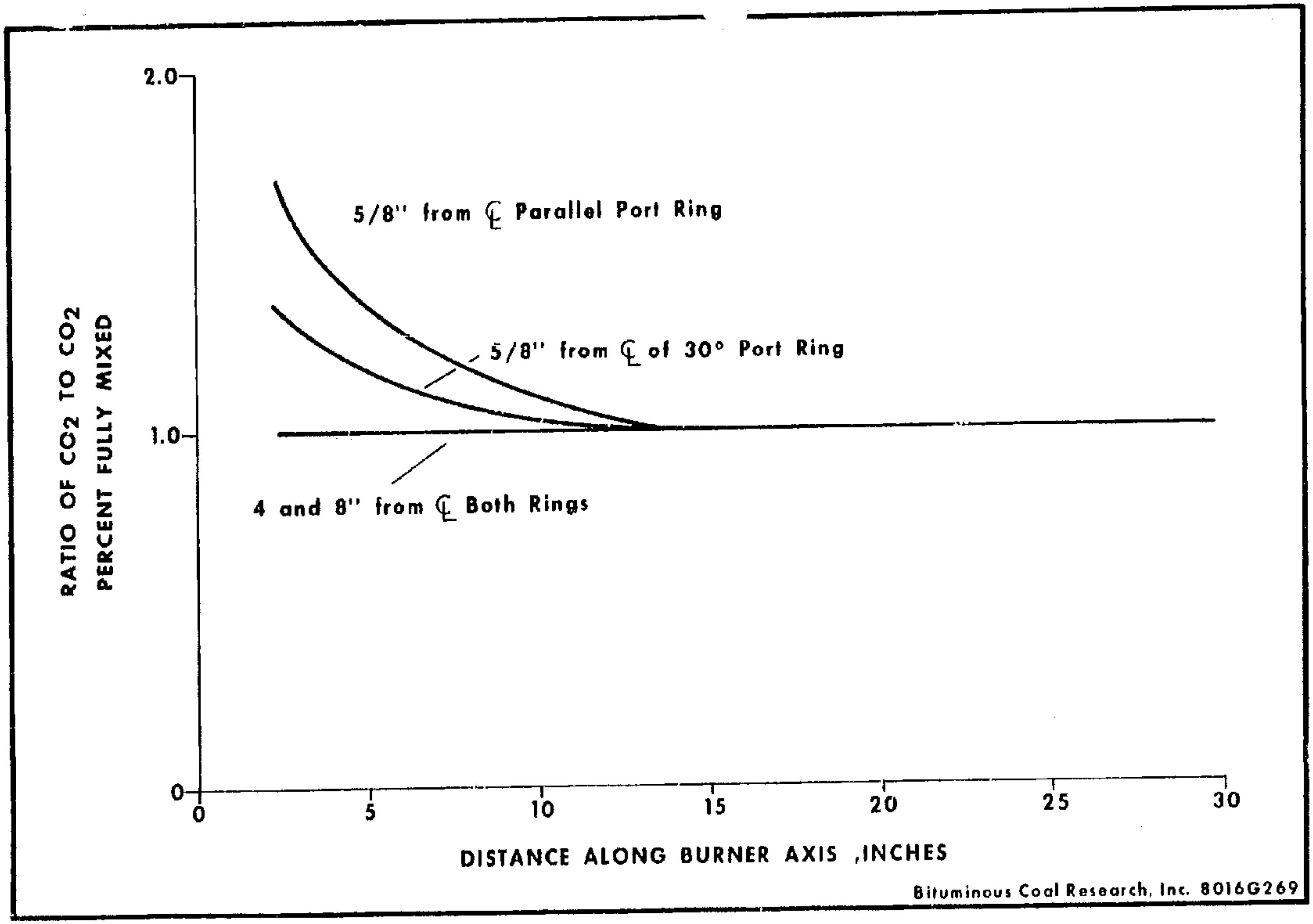


Figure 58. Mixing of Carbon Dioxide Supplied from Outer Nozzle of Prototype Stage 1 Burner with Air from Inner Nozzle

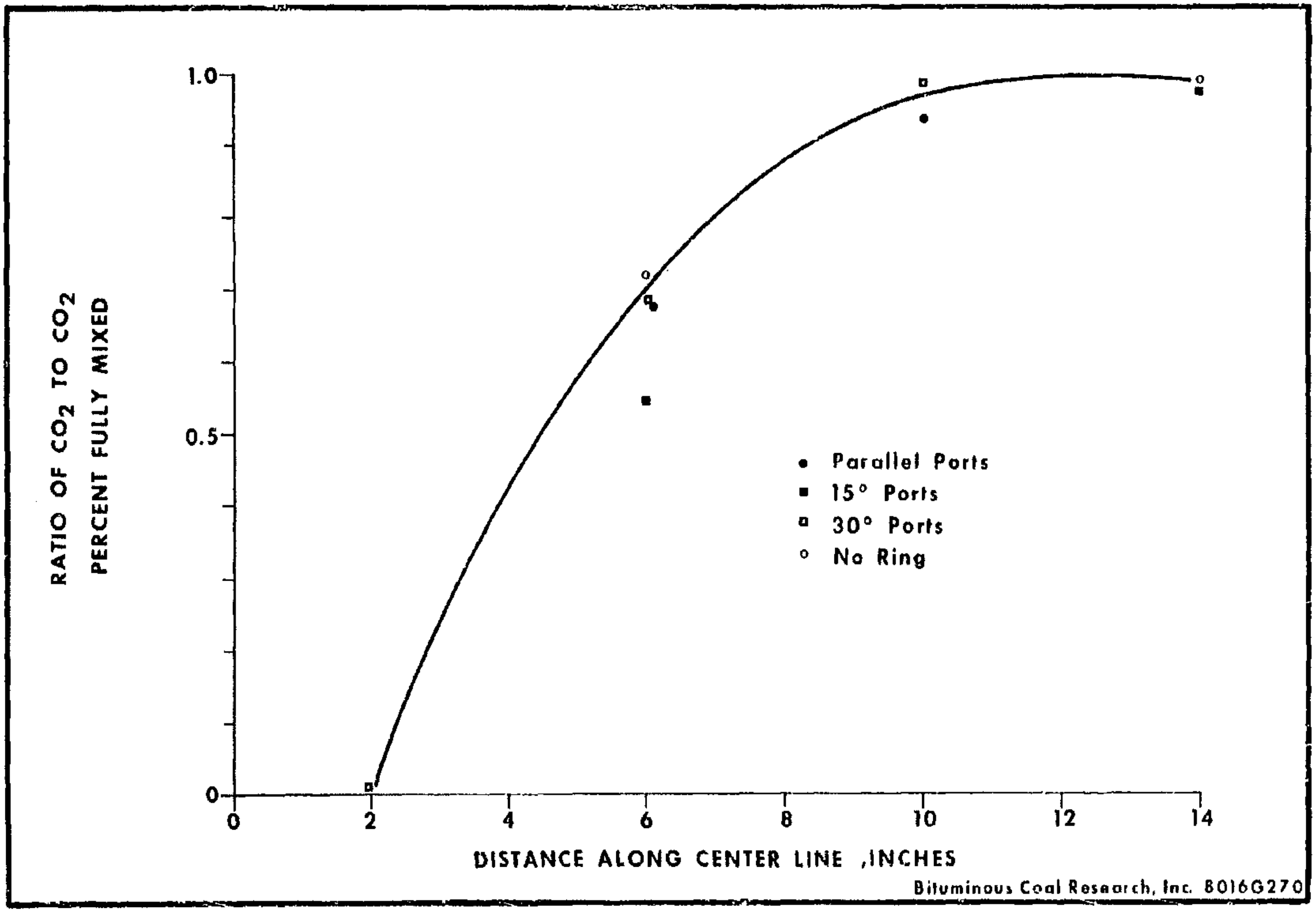


Figure 59. Center Line Mixing of Carbon Dioxide and Air from Prototype Stage 1 Burner (Varying Outer Nozzle Rings)

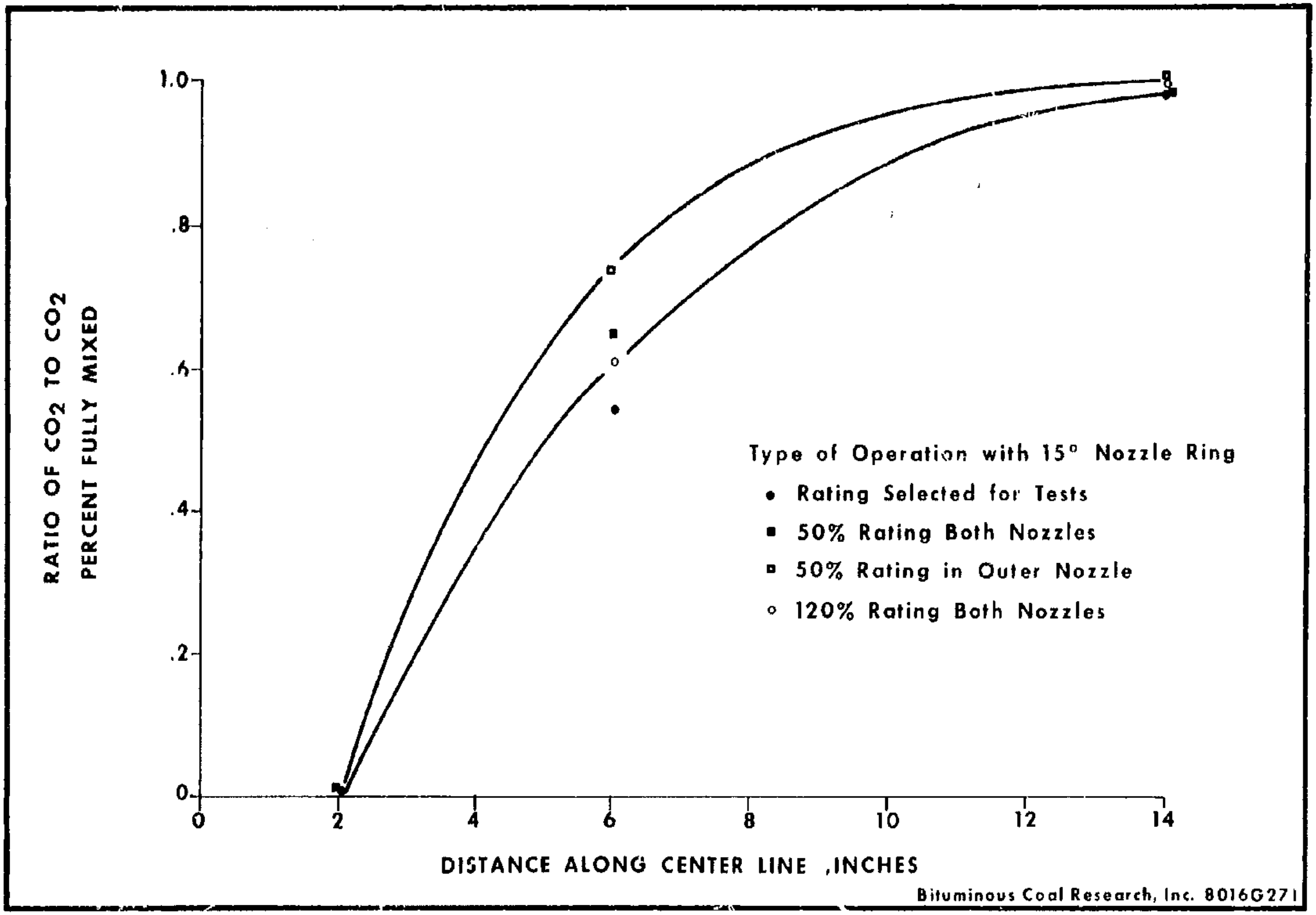


Figure 60. Center Line Mixing of Carbon Dioxide and Air from Prototype Stage 1 Burner - 15° Port Outer Nozzle Varying Gas Rates

8016A-P6

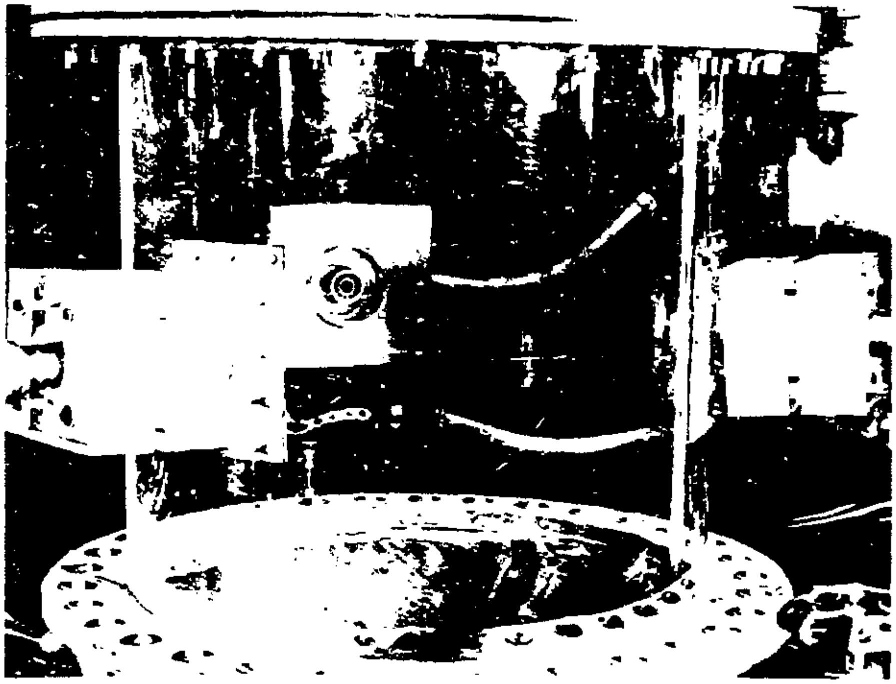


Figure 61. Overall View of Equipment for Testing Full Scale Model of Stage 1 of the Two-stage Gasifier

8016A-P5

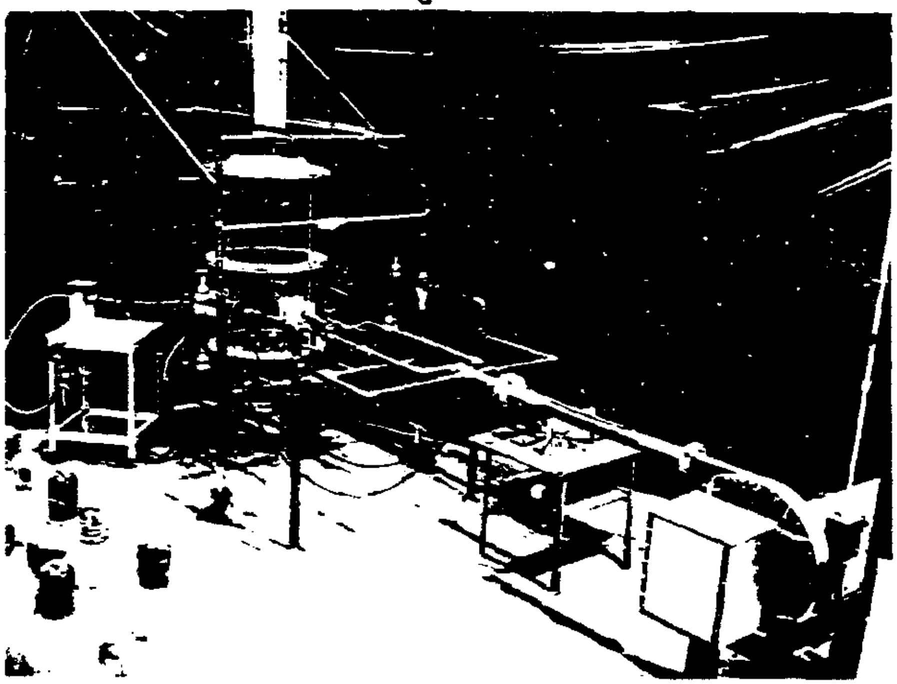


Figure 62. Close-up of the Three-Burner Setup for Stage 1

Details of the swivel mounting are shown in Figure 63, which also shows the prototype burner equipped with an atomizing nozzle that will use glycerol or heavy oil to simulate slag droplets. Figure 64 compares the front view of a stripped gas-only prototype burner with a burner equipped with a center air atomizing nozzle and an annular outer nozzle.

4. Future Work: The preliminary Phase III work should be completed in December, and Phase II should be started. Construction of equipment for Stage 2 tests (Phases IV, V, and VI) will also be started in December.

D. Data Processing (R. K. Young and D. R. Hauck)

1. Commercial Gasifier Modeling: Gas yield expressions which will be incorporated into subroutine GASIFY have not yet been satisfactorily revised. This task should be completed during the next report period.

This computer program has, however, been utilized to generate gasifier simulations by arbitrarily setting various carbon oxide and methane yields (fixed yield mode). Thirty-six sets of data were generated for each of four coals: Pittsburgh seam, Elkol, West Kentucky No. 11, and lignite. These simulations covered a range of 0 to 25 percent char withdrawal, 0.6 to 1.2 steam/coal ratio, 12 to 25 percent methane yield, and 10 to 25 percent carbon dioxide yield. These data will be evaluated during the next report period. Methane yield and carbon oxides yield information for each of the four coals will be presented in a series of graphs.

2. Automated Data Acquisition: Delivery of the PDP8/E computer and peripherals is expected in late December, 1971, or early January, 1972.

As indicated in Progress Report No. 2 (p. 145), two weeks of formal schooling at Digital Equipment Corporation's home office were completed during this report period.

3. Future Work: Plans for the next report period include:

a. Generation of gasification yield expressions to be incorporated in subroutine GASIFY.

b. Generation of gasifier simulation runs as requested.

c. Evaluation of the 36 sets of data for four coals and presentation of methane and carbon oxides yield information.

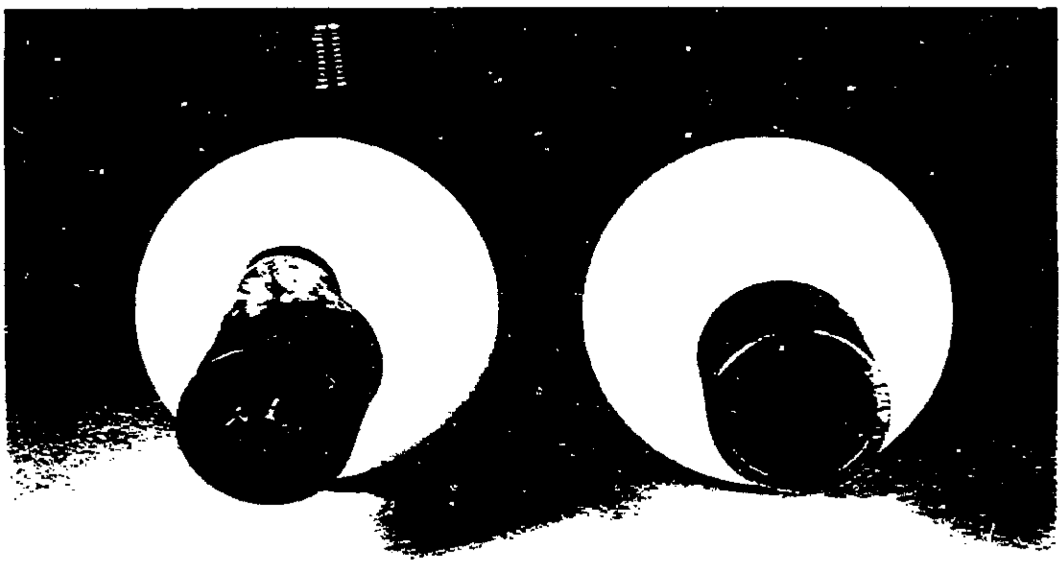
d. Continuing familiarization with operation of the PDP8/E computer and peripherals.

E. Engineering Design and Evaluation

1. BI-GAS Process: The commercial gasifier computer program (sub-routine GASIFY) was used to generate data on four different coals: Pittsburgh seam,

8016A-P4

Figure 63. Exploded View of Swivel Mounting for Gas and Oil Injection Burner



8016A-P3

Figure 64. Front View of Model Test Burners

Elkol, West Kentucky No. 11, and lignite. Yields of carbon oxides and methane were set at various levels. As indicated in section D of this report, the results will be presented in the monthly progress report for December, 1971.

At the request of the Foster Wheeler Corporation, subroutine GASIFY was utilized to generate several sets of data for a char derived from a Pittsburgh seam coal in West Virginia. The objective of this work was to delineate operating conditions for maximum production of hydrogen with minimum methane yield.

2. OCR/BCR Gasification--Power Generation: Discussions continue with industry on this application of the two-stage gasifier. The OCR report (R & D Report No. 20, Supplement No. 1) on the economics of a retrofit system for an existing utility plant has stimulated considerable discussion concerning the practicality of such an application for the air-blown, two-stage gasifier. Use of the gasifier for combined-cycle power generation appears to be of greater potential.

3. Fischer-Tropsch System: No further development occurred in this area this month.

F. Multipurpose Research Pilot Plant Facility (MPRF)

Every assistance is being given to Koppers to ensure that design engineering for the research facility by Koppers Company, Inc., is completed by the end of November, 1971. Progress achieved in preparation of the engineering bid package for the 5 ton/hr oxygen-blown system (BI-GAS Process) and the MPRF general facilities is given in Koppers Progress Report. (See Appendix B.) Koppers plans to submit the first draft of the report December 3, 1971.

The process pilot plant model (1/4 inch = 1 foot) under construction by Visual Industrial Products, Indianola, Pennsylvania, is about 90 percent complete. It is estimated that the process pilot plant model will be completed on or about December 17, 1971. A photograph of the process model taken by BCR during the construction stage will be submitted to OCR. Only a preliminary layout of the overall site model (1 inch = 20 feet) is in progress and this is scheduled for completion by December 31, 1971.

On November 11, 1971, the deed for the land on which the pilot plant will be built was accepted by the United States government.

A list of potential bidders on the MPRF is being developed.

On November 12, 1971, a Task Group on Materials Design Data for Coal Gasification Process Equipment met at the International Nickel Company offices in New York City. The purpose of the meeting was to define task group objectives and to initiate action to meet these objectives. It was agreed that the objectives of the task group would be:

(1) Define potential material problem areas in the various coal gasification processes as related to selection and lack of data.

(2) Formulate and oversee programs directed towards developing useful engineering data as defined by (1) above.

(3) To formulate these programs, a working group, consisting of Frank C. Schora, Jr., R. A. Glenn, and C. Schulz, was appointed to provide a written report by the end of the year defining areas for programs.

A meeting of the work group is scheduled for December 9, 1971, in Pittsburgh, Pa., and the next meeting of the task group is set for January 12, 1972, in Pittsburgh, Pa.

G. Literature Search (V. E. Gleason)

Annotated literature references completed during the month are listed in Appendix C.

H. Other

1. Prime Contract Matters: There were no new developments during this report period.

2. Outside Engineering and Services: In addition to working on the bid package for the MPRF, Koppers continues to provide engineering assistance as required and as reported above.

Copies of a proposed Amendment No. 7 to Subcontract No. 2 signed by Koppers were submitted to OCR for approval on October 20, 1971.

3. Brigham Young University: The project entitled "Study of High Rate, High Temperature Pyrolysis of Coal" with joint funding by Brigham Young University and BCR is now in its eighth month. Figure 65, Monthly Progress Chart, Expenditures, shows the current budget status. The letter report of progress by BYU is as follows:

During November, two tests were completed in the reactor using a mixture of coal and fly ash. These tests were made to determine the suitability of using a rather inert solid diluent to prevent caking in the reactor when the unit was operated at low pressure and/or high coal-to-combustion gas ratios. The fly ash was obtained from the University Central Heating Plant, the same source as for the coal. With a mixture containing 50 percent fly ash, continuous operation was obtained with a solids (coal and fly ash) to oxygen feed ratio of 2.4. During previous operation with coal only, the reactor plugged after about two minutes operation.

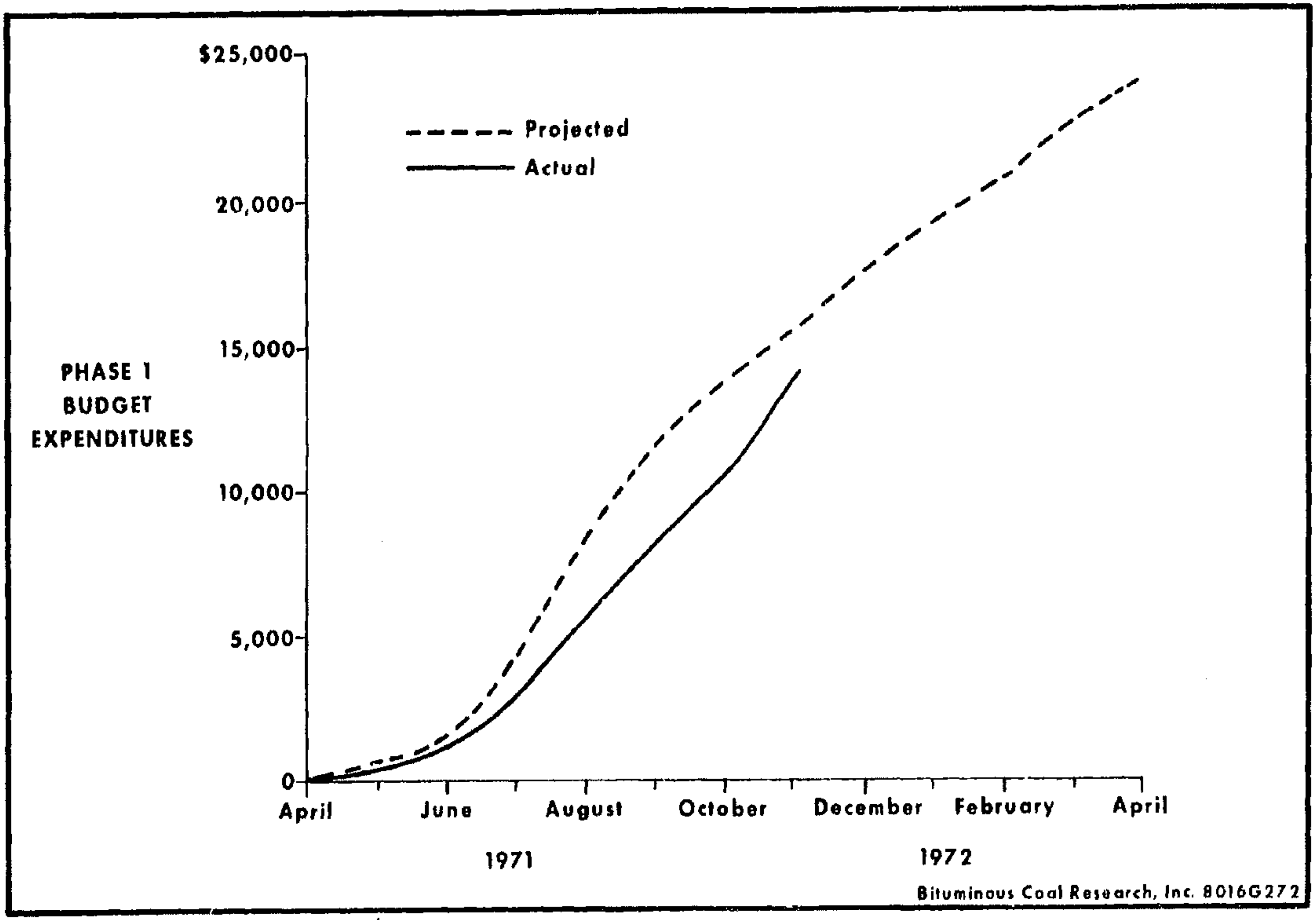


Figure 65. Monthly Progress Chart, Expenditures, Brigham Young University

Some difficulty has been encountered with the present reactor. Shorting of the electrical connections to the heater has occurred on three occasions due to carbon buildup. This difficulty should be eliminated in the 3/4-inch reactor because of better sealing of the view and sampling ports. The fabrication of the new parts for the 3/4-inch reactor is essentially complete.

The quench and char collection is being redesigned such that sampling of the reactor effluent stream can be made during the course of a test. A three-way valve will be installed in the effluent line to permit diversion of the flow long enough to fill a small sample container. This procedure will eliminate the time-consuming operation that has been employed in the past. Quenching and scrubbing of the gas at one point using fresh water rather than using separate quench and scrubbing sprays of recycled water will also be employed. A spray nozzle, gas filters, and containers for this purpose have been ordered.

The Chemical Engineering Department has decided to purchase a new gas chromatograph for use on both this project and air pollution research. Funds for this purchase will be provided entirely by the University. An order has been placed for a Model M-150-G Chromatograph manufactured by Tracor Corporation; delivery is expected by January 15. This equipment will greatly reduce the gas analysis time and will also improve the accuracy of this part of the work.

During December, the 3/4-inch reactor will be assembled along with fabrication and assembly of the new quench system. Check-out tests of this equipment also will be made.

4. Reports and Papers: As reported last month, the revised manuscript of the paper entitled "Gasification of Lignite by the BCR Two-stage Super-pressure Process," by R. J. Grace, R. A. Glenn, and R. L. Zahradnik, was returned to INDUSTRIAL & ENGINEERING CHEMISTRY quarterlies. Early publication is expected.

5. Patent Matters: As reported in Progress Report No. 84, December, 1970, all worthwhile ideas are being written up as invention disclosures for submission to OCR for consideration.

a. OCR-866 and OCR-1078: A U.S. patent application based on the new process concept (E. E. Donath, December 11, 1970) has now been filed and given Serial Number 182,652. The application, entitled "Gasification of Carbonaceous Solids," contains nine claims. The appropriate document assigning rights to the U.S. Government has been prepared.

b. New Invention Disclosures: Formal Invention Disclosures (Form DI 1217) for six individual BCR suggestions were submitted to OCR on May 7, 1971. These were listed in Progress Report No. 1.

Inasmuch as 90 days have elapsed since the submission of these invention disclosures, in accordance with the patent clause under Contract 14-01-0001-324, BCR is proceeding, as reported last month, to develop patent applications for filing in the U.S., first obtaining the approval of the Solicitor's office.

I. Visitors During November 1971

November 2, 1971

Mr. Raymond Dorsey
Koppers Company, Inc.
Koppers Building
Pittsburgh, Pa. 15219

November 10, 1971

Mr. D. M. Mitsak
Mr. A. Kroeber
Koppers Company, Inc.
Koppers Building
Pittsburgh, Pa. 15219

November 11, 1971

Mr. D. M. Mitsak
Koppers Company, Inc.
Koppers Building
Pittsburgh, Pa. 15219

November 17, 1971

Mr. Rudolph Bins
Koppers Company, Inc.
Koppers Building
Pittsburgh, Pa. 15219

November 18, 1971

Mr. D. B. Malcom
Dr. M. C. Chang
Dravo Corporation
Neville Island
Pittsburgh, Pa.

November 19, 1971

Mr. Gene T. Hilton
Mr. F. G. Palcanis
Mr. Frank S. Chalmers
Arthur G. McKee & Company
526 Penn Avenue
Pittsburgh, Pa. 15222

Mr. A. Kroeber
Mr. D. M. Mitsak
Koppers Company, Inc.
Koppers Building
Pittsburgh, Pa. 15219

November 22, 1971

Mr. A. Kroeber
Mr. D. M. Mitsak
Koppers Company, Inc.
Koppers Building
Pittsburgh, Pa. 15219

November 23, 1971

Mr. Paul Towson, Engineer
Mr. Jack E. Ryan
Office of Coal Research
U.S. Department of the Interior
Washington, D. C. 20240

J. Trips, Visits, and Meetings During November

November 12, 1971	Meeting of Task Group on Materials Data for Coal Gasification Equipment, New York, N. Y.	R. A. Glenn

K. Requests for Information

Heinrich Koppers GmbH
P.O.B. 8
43 Essen 1
GERMANY

Stauffer Chemical Co.
New York, New York

Michigan Wisconsin Pipeline Co.
Detroit, Michigan

Mr. Ike Heitlinger
Knob Hill Apartments
Blackwood, New Jersey 08012

Mr. Erwin J. Unger
Economic Planning Department
Columbia Gas System Service Corporation
20 Montchanin Road
Wilmington, Delaware 19807

III. WORK PLANNED FOR DECEMBER, 1971

The work planned for December will basically be a continuation of the on-going program which has been underway for the past few months.

The final summary report on the coal composition and beneficiation studies has been edited and will be completed this month.

The review of the bid package from Koppers for the fluidized-bed gasification PEDU will continue. A list of usable instrumentation and equipment from the Stage 2 PEDU will be compiled with the idea of using as many of these items as possible in the new PEDU installation. Reactivity studies of the Consol char will continue, and a summary report of the procedure and development of the reactivity equations will be drafted.

Tests will continue in the bench-scale methanator to evaluate suitable catalysts. Emphasis will be placed on non-nickel catalysts as a result of previous experience. Evaluation and review of the bid package from Koppers for the methanation PEDU is planned, as well as continued work on the model studies.

The test work on the Stage 2 PEDU (100 lb/hr) was officially terminated on September 30, 1971. Data are being compiled in preparation for writing a final summary report to cover work completed since September 20, 1970. A schedule is being developed for the dismantling of the Stage 2 PEDU equipment.

Tests in Phases II and III of the cold flow model studies for the 5 ton/hr two-stage gasifier will begin. Construction of equipment for Phases IV, V, and VI (Stage 2 tests) is also planned.

Gas yield expressions will be revised and incorporated into subroutine GASIFY in order to obtain simulation runs for Pittsburgh seam, Elkol, and lignite coals. Operation of the PDP8/E computer will continue to be studied. Data from simulation runs will be evaluated.

A. Trips and Meetings Planned

December 6, 1971	Office of Coal Research Washington, D. C.	R. A. Glenn
December 9, 1971	Meeting of Materials Design Task Group Consolidation Coal Co. Library, Pa.	R. A. Glenn J. P. Tassoney

B. Visitors Expected

None

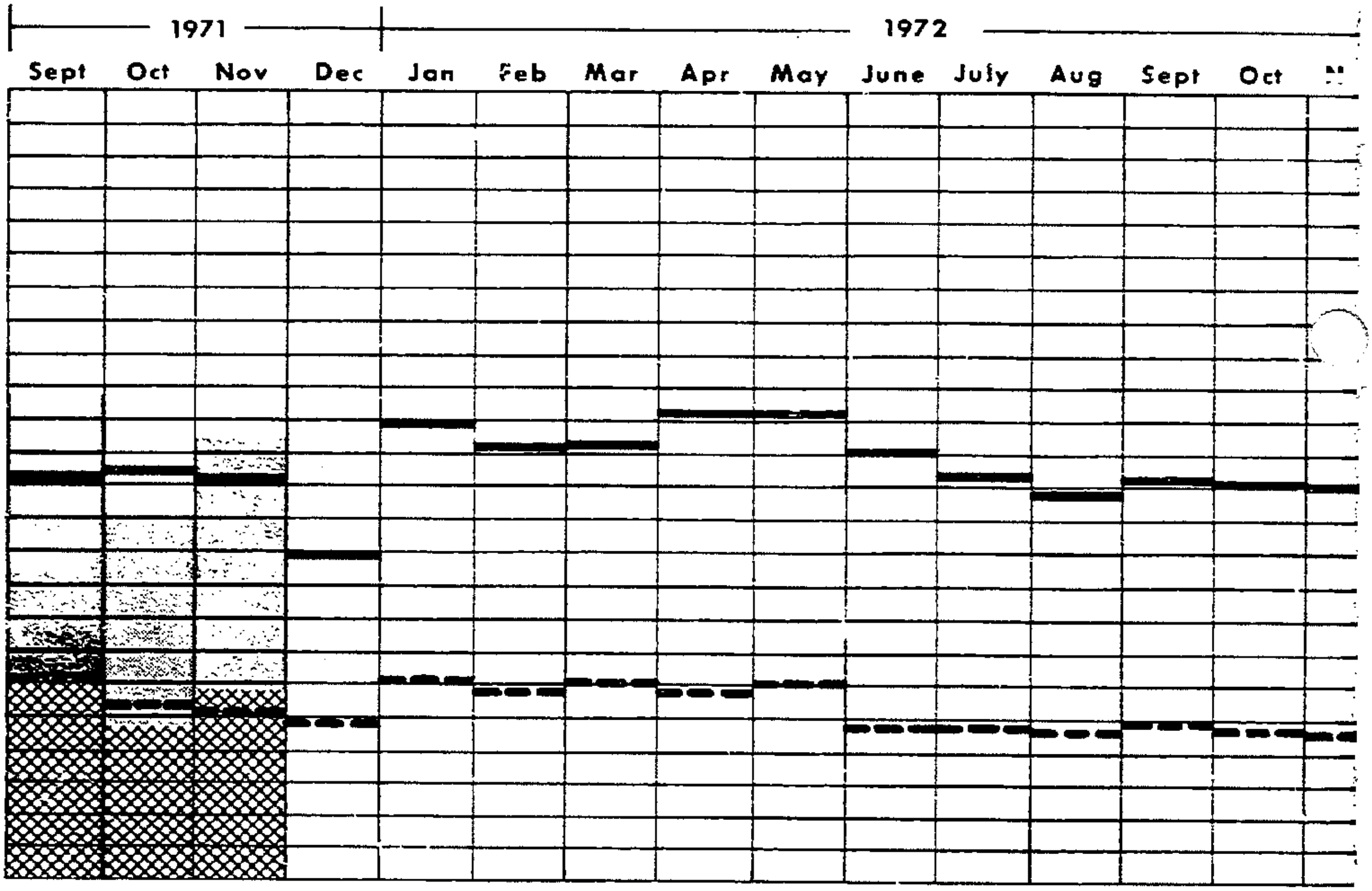
C. Papers to be Presented

None

RAG:v

8006

MANHOURS

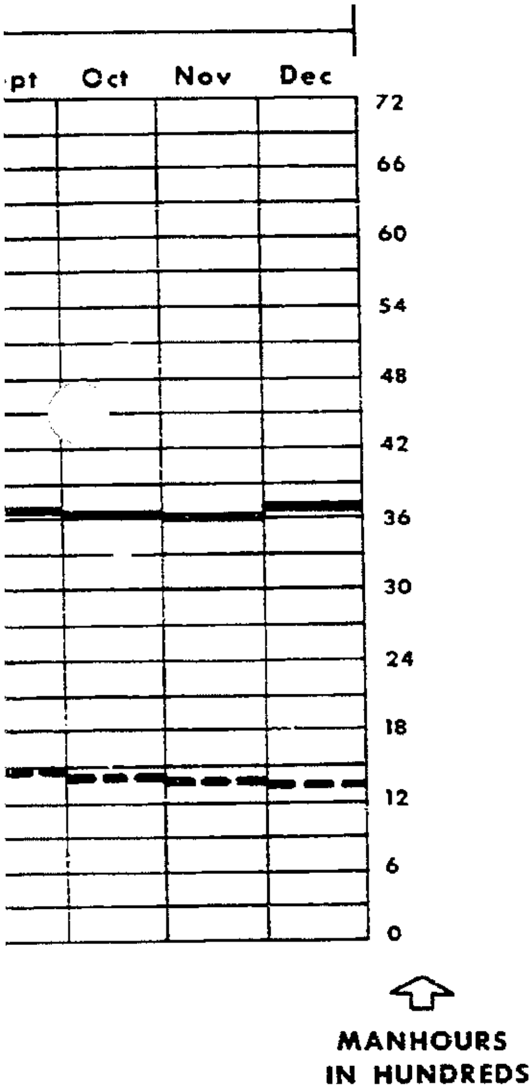

1971
1972
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct

MONTHLY PROGRESS CHART
PART 1 MANHOURS

Bituminous Coal Research, Inc.
350 Hochberg Road Monroeville, Pa.

OFFICE OF COAL RESEARCH
DEPARTMENT OF THE INTERIOR

CONTRACT NO. 14-32-0001-1207



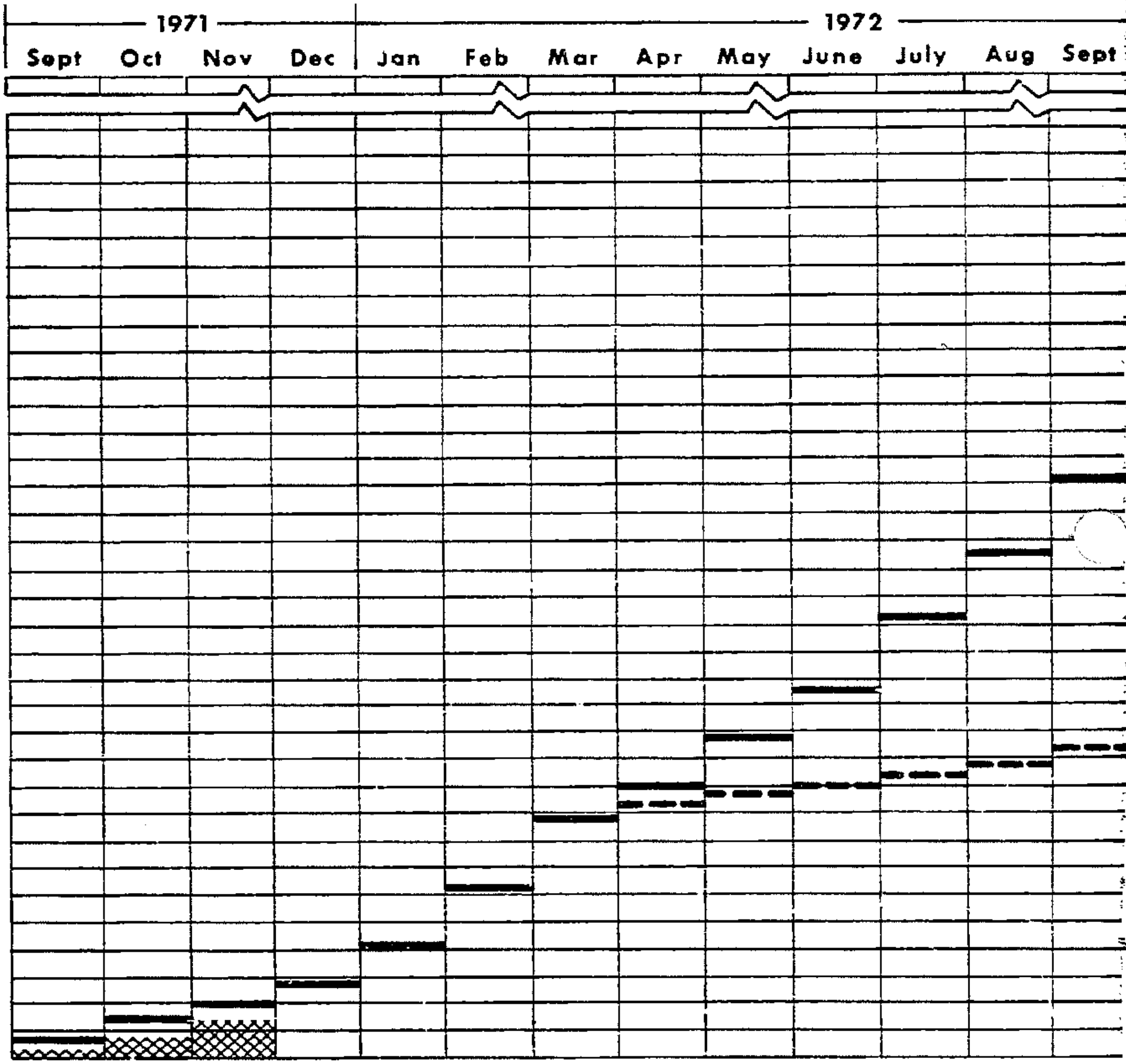
Predicted Professional and Non-professional

Predicted Professional

Actual Non-professional

Actual Professional

2



MONTHLY EXPENDITURES (All Costs, in Dollar

		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	M...
Monroeville	Predicted	129,991	129,991	129,991	129,991	323,486	382,228	558,454	105,058	86,2
	Actual	63,610	121,696	146,834						
Homer City	Predicted								154,000	215,6
	Actual									
Total	Predicted	129,991	129,991	129,991	129,991	323,486	382,228	558,454	259,058	301,8
	Actual	63,610	121,696	146,834						

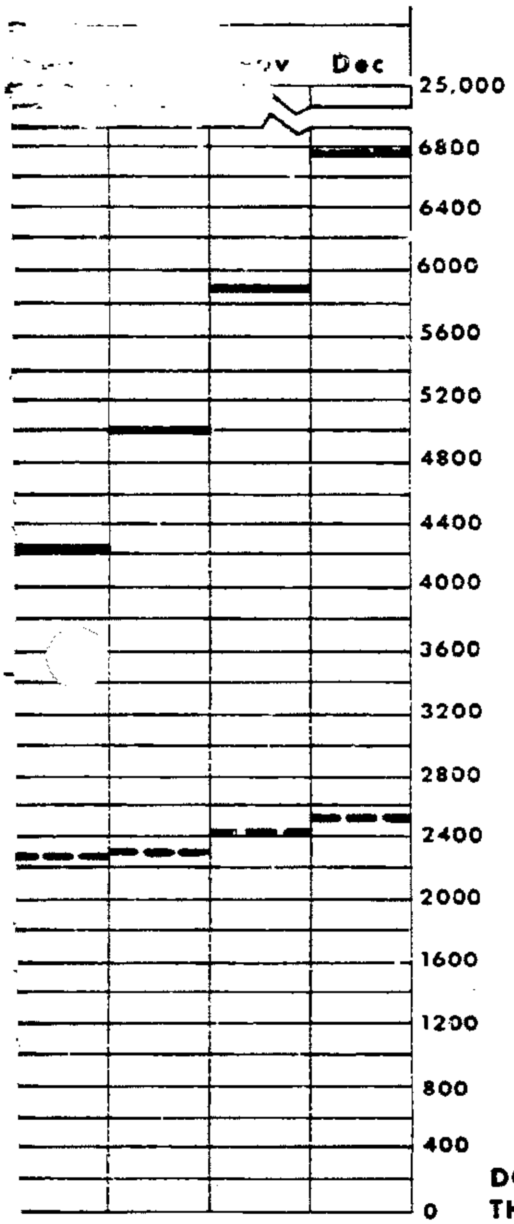
CUMULATIVE EXPENDITURES

MONTHLY PROGRESS CHART
PART 2 EXPENDITURES

Bituminous Coal Research, Inc.
350 Hochberg Road Monroeville, Pa.

OFFICE OF COAL RESEARCH
DEPARTMENT OF THE INTERIOR

CONTRACT NO. 14-32-0001-1207



DOLLARS IN THOUSANDS

Expenditures, Cumulative

Actual, Monroeville

Actual, Homer City

Predicted Expenditures, Cumulative

Total, Monroeville and Homer City

Monroeville

ollars)

May	June	July	Aug	Sept	Oct	Nov	Dec
36,238	86.240	65,813	65,813	74,746	62,273	62,273	62,275
5,600	280,400	444,300	444,300	444,400	760,600	760,600	760,800
3	366,640	510,113	510,113	519,146	822,873	822,873	823,075

2

APPENDIX B

PROGRESS REPORT #28

BITUMINOUS COAL RESEARCH, INC.
COAL GASIFICATION

NOVEMBER 1971

KOPPERS CONTRACT 2415

I. STATUS OF CONTRACT

A. PILOT PLANT ENGINEERING BID PACKAGE

(1) On November 4, 1971, Koppers submitted to BCR (by letter C-203) for their review and appropriate action a memorandum prepared by Mr. J. M. Bialosky of Koppers Metallurgical Laboratory in which he suggested further in-depth studies on materials of construction required for certain problem areas in the coal gasification process.

(2) The proposed contents of the Bid Package were submitted to BCR for their review and approval on November 9, 1971 (letter C-212).

(3) Information received from Ralph M. Parsons Company in their letter dated November 5, 1971 concerning the sulfur recovery plant (Claus) and the secondary clean-up Beavon sulfur removal plant was transmitted to BCR by Koppers letter C-231 dated November 16, 1971.

(4) On November 18, 1971 (letter C-239) Koppers requested BCR's permission to release applicable drawings and specifications of the pilot plant Bid Package to responsible suppliers to obtain the necessary quotes or cost data required for the preparation of definitive cost estimates.

(5) On November 17 and 18, 1971, Mr. C. W. Fisher of Koppers Monroeville Research Center met with OCR and BCR representatives to review and revise certain aspects of the pilot plant effluent treatment plant. Following this meeting Koppers transmitted to BCR additional data on November 23, 1971

(letter C-249) to be incorporated by BCR in the final Environmental Statement. This information was requested by BCR in their letter dated November 5, 1971 and by Mr. Howard Smith of OCR during a meeting at BCR held on November 11, 1971. For details see Conference Report #202 transmitted by Koppers letter C-252 dated November 24, 1971.

(6) By letter C-253 dated November 29, 1971, Koppers questioned the customer's decision to defer the work on the soils investigation. Delaying this work is inconsistent with general practice in the engineering and construction field, and will result in further delay of start of construction and increase in the cost of the pilot plant.

B. ENGINEERING ASSISTANCE AND RECOMMENDATIONS FOR PEDU PROGRAM

(1) Koppers submitted to BCR detailed estimate sheets for construction cost of Methanation and Char Gasification PEDU's. Summary of cost estimates was attached to Conference Report #200, identified as Encls. (1) and (2) and transmitted to BCR in Koppers letter C-209 dated November 8, 1971.

(2) Koppers was requested by BCR to review cost estimates for both PEDU's and to revise the scope of work with particular emphasis to the reduction in cost of instrumentation and piping. The result of this study was reported in Conference Report #201, transmitted to BCR by Koppers letter C-222 dated November 15, 1971.

II. CONTRACT EVALUATION

Four (4) copies of Amendment No. 7 to Amended Subcontract No. 2, including Appendices I through VIII, signed by Mr. J. D. Rice, Vice President, Engineering and Construction Division, Koppers Company, Inc., were transmitted to BCR in our letter C-183 dated October 18, 1971. Receipt of these copies was acknowledged by BCR in their letter dated October 18, 1971.

Koppers is completing the Bid Package in accordance with the scope of work stated in proposed Amendment No. 7 (par. III. A. 5 of Appendix I). Transmittal of the first draft of the Bid Package will be sent to BCR for their approval on December 3, 1971.

J. F. Farnsworth
Project Manager

SMT:jp

APPENDIX C

ADDITIONS TO ABSTRACT FILE, NOVEMBER 1971

Bund, K., Henney, K. A., and Krieb, K. H., "Combined gas/steam-turbine generating plant with bituminous-coal high-pressure gasification plant in the Kellermann power station at Lünen," The Eighth World Energy Conference, Bucharest, Rumania, 1971. Paper 2.3-71. 20 pp. 540.000 621. W927

The combined gas/steam turbine generating plant consists of a gas turbine with a gross capability of 74 Mw, two pressure-fired steam generating units with an aggregate steam rate of 340 tons/hr without intermediate superheat, and one steam turbine with a capacity of 96 Mw. The two pressure-fired steam generators are arranged ahead of the gas turbine. The fuel for the gas turbine is produced by Lurgi coal gasification at a pressure of 20 atm gauge in a mixture of compressed air from the compressor of the gas turbine and of steam. The generator is charged with slightly caking lump coal containing up to 30% mineral matter. Cost advantages are discussed. (Authors' synopsis adapted)

"Economics of generating clean fuel gas from coal using an air-blown two-stage gasifier," Bituminous Coal Research, Inc., Final Report - Supplement No. 1 to U.S. Office of Coal Research, R & D Report 20 (August 5, 1971). 13 pp. 540.000 OCR - B

Estimates are presented from two engineering studies of the capital and operating costs of an air-blown version of the gasifier for in-plant generation of boiler fuel gas. The studies were not intended as process optimizations. Differences in coal feeding, removal and recycle of char, estimation of necessary labor, and in handling steam and electric power requirements lead to a significant overall difference in cost. A modification of one of the systems to improve its economics is presented.

"Manufacture of substitute pipeline gas using the CRG process," Humphreys and Glasgow Limited, London, England, undated. 4 pp. 540.000 71-8

This brochure includes a flow diagram and description of the process which uses Catalytic Rich Gas (CRG) technology of the British Gas Council. Composition and combustion characteristics of gases produced from naphtha, LPG or methanol and subjected to different steps in the process are tabulated. Information is also given on utilities needed for production of substitute pipeline gas.

Strom, A. H. and Eddinger, R. T., "COED plant for coal conversion," Chem. Eng. Progr. 67 (3), 75-80 (1971). 540.000 Journal

A new commercial evaluation incorporating modifications of previous evaluations of the COED process is presented. The design and preliminary cost estimate given in the article are based on processing 25,000 ton/day of dry Colorado Bear coal. Synthetic crude oil, char, and, with a process modification, producer gas will be the chief products of the multistage fluidized-bed pyrolysis of coal.