OPERATION OF PRESSURE-GASIFICATION PILOT PLANT UTILIZING PULVERIZED COAL AND OXYGEN

A PROGRESS REPORT[1]

by

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SUMMARY AND CONCLUSIONS

The Federal Bureau of Mines is doing research and development work on a pressure-gasification pilot plant for producing synthesis gas directly from pulverized coal, oxygen, and steam. A pressure-gasification pilot plant has been constructed, and an investigation was made with the following basic objectives:

1. Determining the effect of varying pressure (75, 100, 150, and 300 p.s.i.g.), coal rate (400, 700, and 1,000 pounds per hour), and oxygen-to-coal ratio (8 to 11 std. c.f. per pound), on percentage of carbon gasified, oxygen and coal requirements per unit of $CO + H_2$ produced, exit-gas temperature, and heat loss. The steam-to-coal ratio was maintained at approximately 0.3 pound per pound.

2. Development of a stabilized gasification zone or reaction space.

3. Improvement in operability of the pilot plant.

In the first several tests of this report the reaction chamber was lined with refractory brick. Then the gasifier was modified by lining the reaction chamber with a water-cooled coil supporting a relatively thin refractory layer, and a series of tests was conducted at three oxygen-to-coal ratios, three coal rates, and four pressures, multiple regression analyses being used to evaluate the data.

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The effect of varying operating conditions was as follows:

1. Carbon gasified (percent) was mainly a function of oxygen-to-coal ratio; effects of changes in pressure and coal rate were small by comparison. At the lowest pressure, residence time (interval during which the reactants are in the reaction zone of the gasifier) appeared to be the limiting factor; however, at the highest pressure, heat loss appeared to be the limiting factor.

2. Oxygen requirement (std. c.f. per M std. c.f. of $CO + H_2$ produced), which was principally a function of oxygen-to-coal ratio, was minimum near the lower end of the oxygen-to-coal ratio range. At the highest pressure, 300 p.s.i.g., the oxygen requirement was lowest at the highest coal rate, whereas at the lower pressures the oxygen requirement was lowest at the lower coal rates. This change probably was caused by the opposing effects of residence time and heat loss.

3. Coal requirement (pounds per M std. c.f. of $CO + H_2$ produced) was mainly a function of oxygen-to-coal ratios, a minimum being reached at approximately 11. Coal requirement showed the same opposing effects of residence time and heat loss.

4. Exit-gas temperature, ° F. (calculated), which decreased with a decrease in oxygen-to-coal ratio, decreased with a decrease in coal rate or with an increase in pressure.

5. Heat loss (B.t.u. per pound of coal), which was essentially independent of pressure, decreased with a decrease in oxygen-to-coal ratio and an increase in coal rate.

All of the dependent variables affecting process economy--oxygen requirement, coal requirement, carbon gasified (percent), exit-gas temperature, and heat loss--were influenced favorably by an increase in gasifier pressure between 75 and 300 p.s.i.g. At 300 p.s.i.g. operating pressure, an advantage was indicated for gasification at the higher coal rates. Oxygen-to-coal ratio was the only independent variable giving opposing effects on the material requirements of the process; that is, oxygen required per unit product was a minimum at low oxygen-to-coal ratios, whereas coal required per unit product was a minimum at high oxygen-to-coal ratios.

Progressive erosion of the refractory brick lining of the gasifier used in the first test series increased the reaction-chamber volume 43 percent. The lining eroded when high oxygen-to-coal ratios were used and gasifier temperatures were high, and slag built up on the lining when oxygen-to-coal ratios and gasifier temperatures were relatively low. When the gasifier was equipped with the water-cooled liner, the volume of the gasification space remained relatively constant after an initial increase of 15 percent.

In general, operation of the pilot plant was satisfactory. Throughout the experimental work alterations were made on many items of equipment to improve operability. Results of these changes are reported in some detail in the body of this report.

There were indications of higher heat loss through the walls of the gasifier equipped with the water-cooled liner, but the results were inconclusive. Further work is in progress to determine the comparative heat loss of gasifier liners and the effect on process economy.

INTRODUCTION

The Bureau of Mines, at its Morgantown Coal Research Center, Morgantown, W. Va., is conducting research and process development work on methods of producing synthesis gas directly from coal. The synthesis gas, comprising essentially carbon monoxide and hydrogen, can be converted by well-known processes into various products, such as gasoline, oil, pipeline gas, ammonia, and alcohol.

Previous publications [7 8] discussed the design and operation of a pilot plant for the pressure gasification of pulverized coal with oxygen and steam and gave the results of test runs through P-22. Later, with only minor changes to the pilot plant, additional tests were made (P-23 to P-35). At the end of run P-35, the gasifier was modified to incorporate, as a reaction-zone liner, a thin refractory layer supported by a water-cooled coil. Experiments were then conducted to determine the effect of varying pressure, coal rate, and reactants ratio on materials requirement per unit of $CO + H_2$ produced, carbon gasified (percent), exit-gas temperature, and heat loss. Results of these tests (runs P-36 to P-68) were used for a statistical analysis of the effect of process variables. This report discusses the operating performance of the pilot plant during runs P-23 to P-35 but does not include all data on these runs. Sewickley, a high-volatile bituminous coal from the Bunker mine, Morgantown, W. Va., was gasified.

Gasifiers with different reaction zones were used. It was anticipated that the heat loss (expressed as B.t.u. per pound of coal fed) through the reaction-zone wall would be higher when the gasifier had a water-cooled reaction-zone liner; however, although there were indications of higher heat loss through the water-cooled liner, the experimental results were quantitatively inconclusive. Further work is in progress to determine the comparative heat loss of gasifier liners and the effect on process economy.

This report presents a brief description of the pilot plant and process and describes alterations to the basic pilot plant (previously reported[9]) in some detail.

7/ McGee, J. P., Schmidt, L. D., Danko, J. A., and Pears, C. D., Pressure-Gasification Pilot Plant Designed for Pulverized Coal and Oxygen at 30 Atmospheres: Symposium for Annual Meeting, AIME, New York, N. Y., Feb. 20-21, 1952, pp. 80-108.

8/ Strimbeck, G. R., Cordiner, J. B., Jr., Taylor, H. G., Plants, K. D., and Schmidt, L. D., Progress Report on Operation of Pressure-Gasification Pilot Plant Utilizing Pulverized Coal and Oxygen: Bureau of Mines Rept. of Investigations 4971, 1953, 27 pp.

9/ Work cited in footnote 8.

ACKNOWLEDGMENTS

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GENERAL REVIEW OF PILOT PLANT AND COAL-GASIFICATION PROCESS

Figure 1 shows the flowsheet of the pilot plant. Coal ground so that about 70 percent passes a 200-mesh screen is fluidized in the continuous coal feeder in an inert gas consisting of CO_2 and N_2. As it enters the gasifier, the fluidized coal stream is broken up by a high-velocity mixture of steam and oxygen preheated to more than 600° F. The gasification reaction takes place in the upper chamber of the gasifier, and the gases produced (along with ash, slag, and unreacted carbon) leave the bottom of the upper chamber in the gasifier and are sprayed with water. Ash, slag, carbon, and water drop into the space at the bottom of the gasifier and are purged from the system. Product gases and water are piped from the gasifier to a water scrubber to remove fine ash and carbon.

OPERATING PERFORMANCE OF PILOT PLANT

Gasifier

During the first 13 gasification runs reported herein, P-23 to P-35, the gasifier, shown in figure 2, was lined with two layers of silicon carbide firebrick. (See fig. 3 for refractory details.) This refractory lining had been in operation about 27 hours before the runs, and approximately 89 additional hours of operation were logged during the 13 runs. The initial inside diameter of the reaction chamber was 8 inches, and the initial volume of the reaction chamber was 1.53 cubic feet. A decrease in volume resulted from replacing the top silicon carbide casting which eroded during the eighth run; otherwise, the volume increased owing to progressive erosion of the refractory lining of the reaction chamber. Table 1 shows the variation in the interior volume. Further indications of the extent of refractory erosion or build-up of slag are shown in figures 4 and 5. Apparently, the resulting changes in flame area and volume of gasification space coincided with changes in gasification performance.

After the 13th run, P-35, the design of the gasifier was changed to incorporate, as a reaction-zone liner, a thin refractory layer supported by a water-cooled coil. (See fig. 6.) The water-cooled liner was installed in an effort to maintain a relatively constant reaction space. Figure 7 shows the heavily studded inner coil before a thin coating of chrome-ore refractory cement had been applied. Refractory material was rammed into the space between the liner and shell coils.

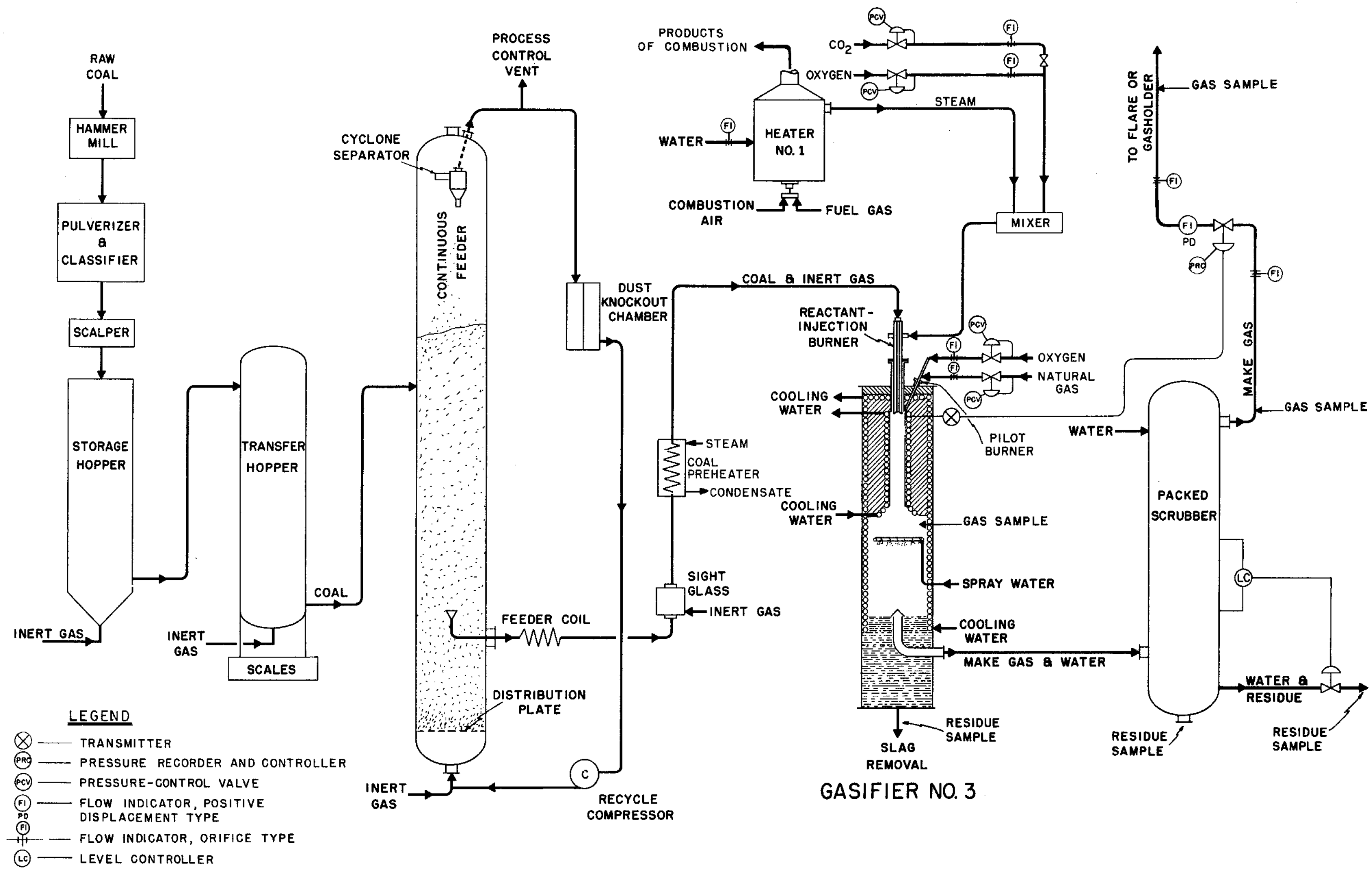

FIGURE 1. - Pilot-Plant Flowsheet for Gasifier 3.

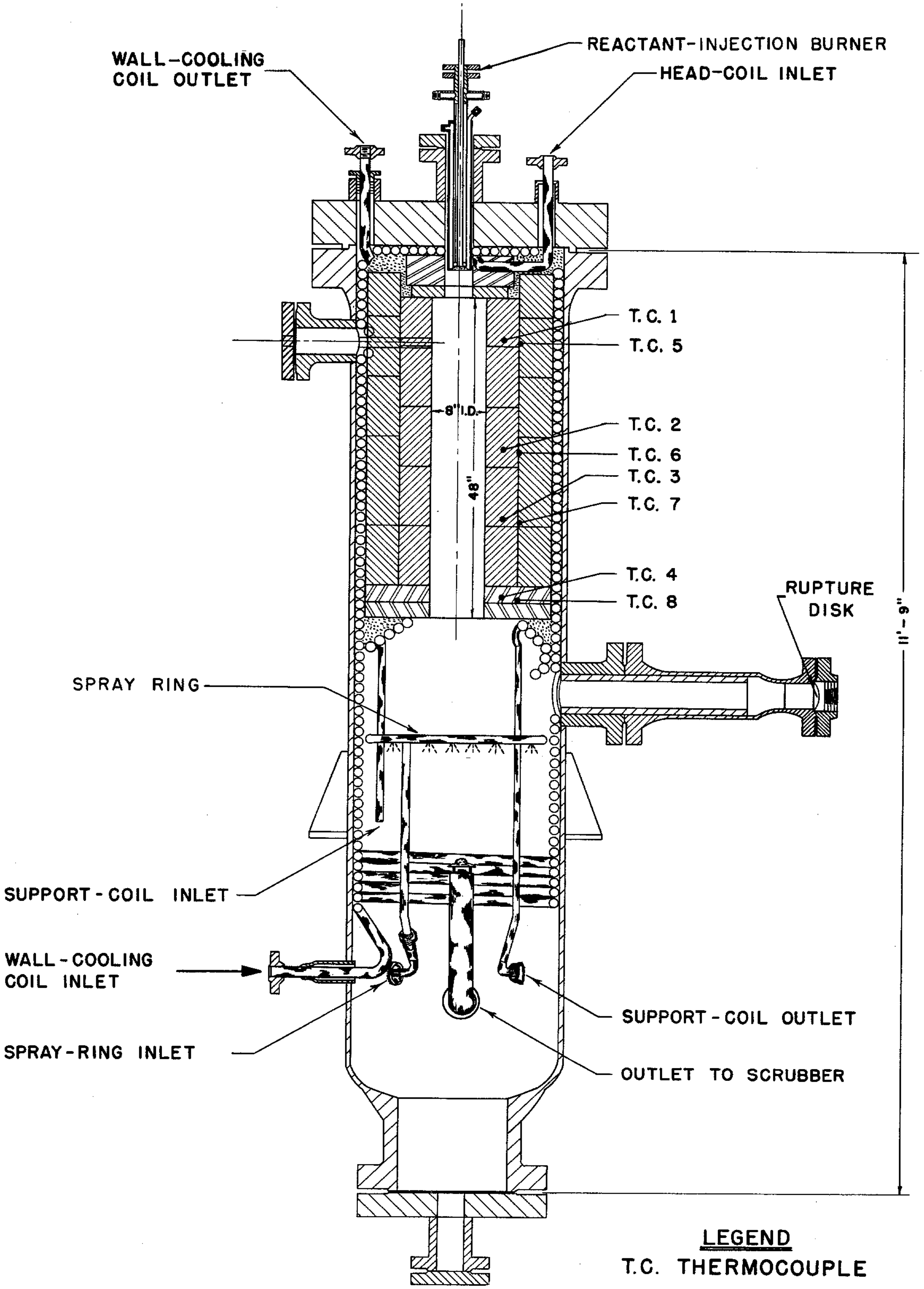

FIGURE 2. - Reactor for Pressure Gasification.

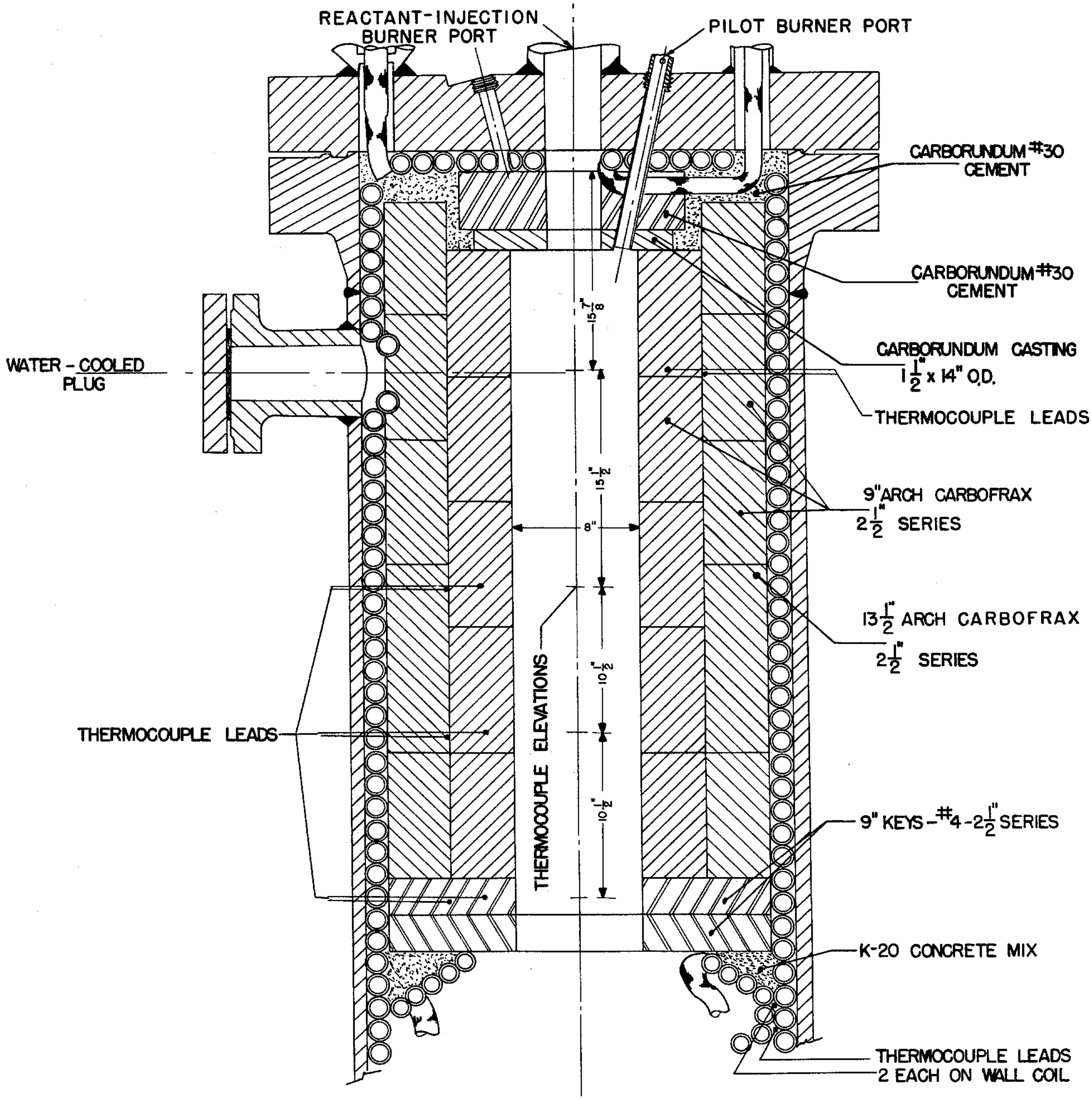

FIGURE 3. - Refractory Detail for Gasifier 3.

Figure 8 shows the dimensional changes in the water-cooled reaction-chamber liner during gasification. At the top of the 10-inch i.d. the refractory was eroded to 11-1/2 inches in diameter. At the bottom, where the slag throat is located, erosion of the refractory was only 1/4 inch, changing the diameter from the original 10 inches to 10-1/2 inches. After the fourth run, P-39, with the redesigned gasifier, the inside dimensions of the chamber changed little. The original volume was 1.95 cu. ft.; at the conclusion of the series the volume was 2.25 cu. ft.

TABLE 1. - Variation in volume of refractory-lined reaction zone, gasifier 3

Run No.	Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	Oxygen, std. c.f./hr.	Steam, lb./hr.	Temperature of refractory 2 inches from original inside surface, °F.			Volume before run, cu.ft.	Volume after run, cu.ft.	Change in volume, percent 1/
					Sight, glass level	16 inches below sight glass	27 inches below sight glass			
P-23	300	869	7,670	244	1,850	1,675	1,530	1.53	1.45	-5.2
P-24	300	960	8,520	285	-	1,640	1,485	1.45	1.44	-.7
P-25	300	974	8,090	285	1,810	1,655	1,490	1.44	1.44	.0
P-26	300	1,099	8,915	300	1,625	1,640	1,410	1.44	1.51	4.9
P-27	300	990	8,670	300	1,645	1,630	1,370	1.51	1.55	2.6
P-28	300	1,035	8,520	270	1,540	1,555	1,410	1.55	1.57	1.3
P-29	450	1,082	10,470	414	-	1,580	1,455	1.57	1.56	-.6
P-30	450	1,120	11,015	368	-	-	1,642	1.56	2/ 1.72	10.3
P-31	-	-	-	-	-	-	-	1.49	3/ 1.75	17.4
P-32	450	1,264	12,070	426	-	-	1,470	1.75	1.74	-.6
P-33	450	1,162	11,865	390	-	-	-	1.74	1.84	5.7
P-34	100, 200, 300	1,287	11,980	390	-	-	-	1.84	1.98	7.6

1/ Gain in volume indicates extent of corrosion.
2/ Top silicon carbide casting eroded; replaced for run P-31.
3/ Fast heat-up after sight-glass failure probably was responsible for erosion.

Detail A, figure 8, shows the slag deposit overlying a layer of coke or char. Probably, the coke or char was deposited in the early stages of run P-39, before the gasification flame had reached the ash-slagging temperature. It should be noted that the condition of the internal surfaces of the gasifier was not revealed until the unit had cooled enough to permit inspection; hence, the conditions shown in figure 8 might not be the exact conditions during operation. While the gasifier is cooling, molten slag may flow downward from the point of original deposition; during a run, however, equilibrium may be reached between the amount of slag adhering to the surface and the amount swept from the surface.

The arrangement of the gasifier-shell cooling coil (often called the wall cooling coil) was changed in an effort to determine the precise location of the gasification reaction space by determining where heat was lost through the wall. In the original design, the shell coil was continuous over the height of the gasifier, and it was impossible to determine how much heat came from the designated reaction space and how much came from the hot gases below the slag throat. In the new design (fig. 6), the shell coil consisted of two coils--an upper- and a lower-shell coil--the division occurring at the level of the slag-throat opening. Moreover, the cooling coil at the top of the gasifier (also known as the head coil) was replaced. This coil protects the top flange of the gasifier. Openings were provided for installing the

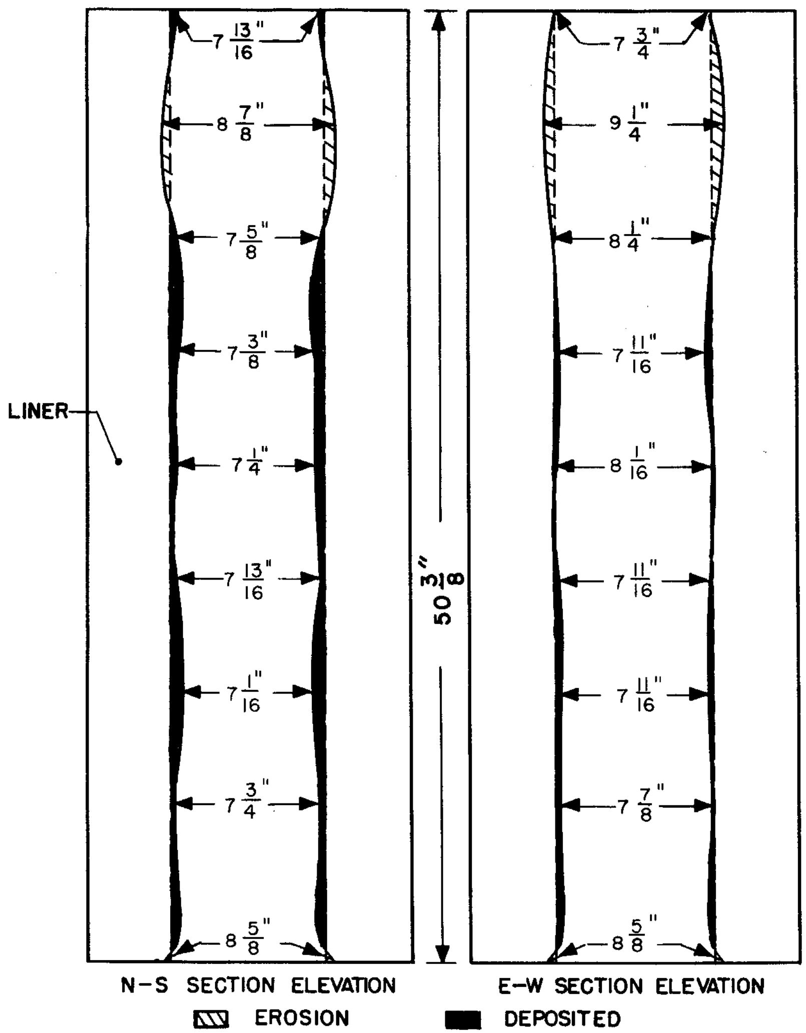

FIGURE 4. - Refractory Condition After Test P-25, Gasifier 3.

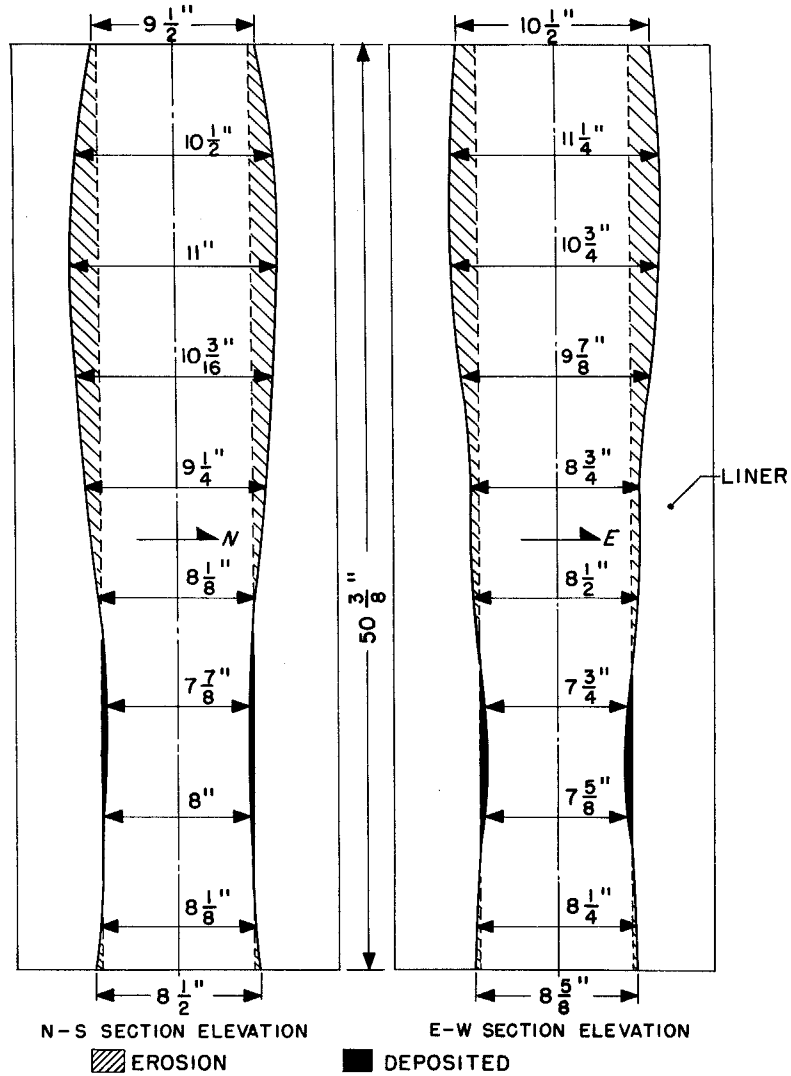

FIGURE 5. - Refractory Condition After Test P-34, Gasifier 3.

0.833 × 3.09 ft
= 1.7 CF

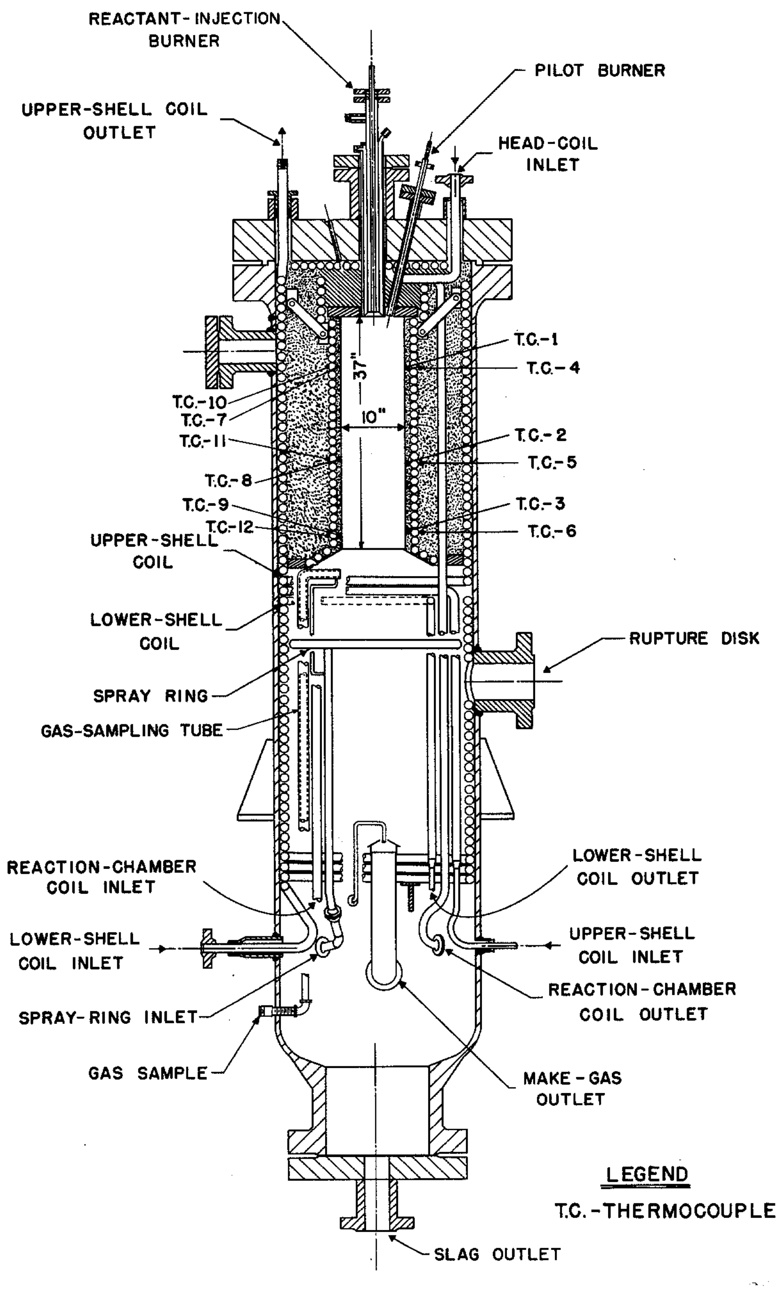

FIGURE 6. - Pressure Gasifier 3.

reactant-injection burner, the pilot burner, and a thermocouple to check the temperature of the top refractory.

There was evidence of pitting of the outside surface of the reaction-chamber liner coils, probably caused principally by exposure to carbon dioxide and sulfur in the product gas. This condition was aggravated because the gasifier was operated intermittently, and corrosive effects of the sulfur constituents on stainless steel are believed to be greatest when the metal is alternately wetted and dried. Moreover, there was evidence that the head coil was too large; it was difficult to adjust the water flow through the coil so as to achieve the degree of cooling desired.

To obtain a reliable indication that there was a flame in the reaction zone and that gasification was taking place, a commercial (Fireye) photoelectric cell was mounted over a window in the outer end of the pilot burner. (A very small flow of inert gas past the window was sufficient to keep it clear.) The cell was connected to a visual alarm mounted on the central control panel. (See fig. 9.)

The water-spray coil (or ring) in the gasifier was renewed, and an additional spray was provided at the entrance to the crossover--the connection between the gasifier and the scrubber. In one test the water-spray ring was elevated within 6 inches of the slag throat or bottom of the reaction zone. This was done to quench the gasification flame if it extended beyond the slag throat and to determine any variation in gasification performance attributable

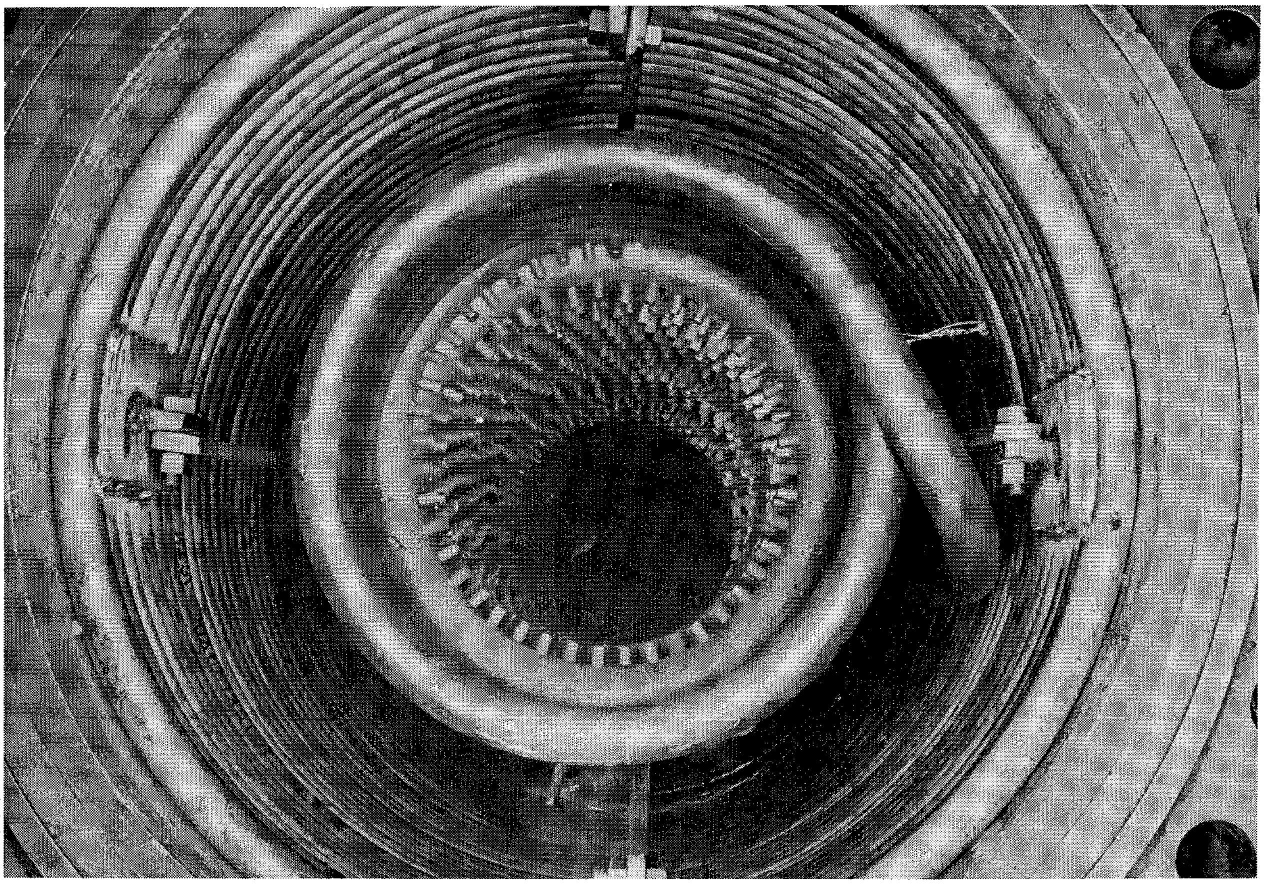

FIGURE 7. - View of Water-Cooled Wall Coil for High-Pressure Reaction Chamber, Looking Down Into Gasifier.

to the change. Figure 10 shows the spray ring in its original and final positions. The view, looking up into the gasifier quench chamber, shows the position of the sprays relative to the slag throat or outlet of the reaction zone. The eight button-shaped spray nozzles are shown on the under side of the spray ring. It was impossible to operate the gasifier for extended periods with the spray ring elevated, because the slag throat became blocked with slag. However, the gasification results were the same with or without slag-throat quenching, and there was no significant reduction in gasifier capacity during 4 hours of operation with the spray ring elevated. (A 4-hour test is sufficient to establish steady-state conditions in the gasifier.) Thus, indications were that the flame did not extend beyond the reaction zone and that the designated reaction space was the actual gasifying volume. Moreover, this experiment demonstrated that if insufficient space is left below the slag throat the slag will not remain fluid enough to flow down the refractory wall; therefore, the spray ring was returned to its original position.

A lock-hopper pressure tank (fig. 11) was added to the bottom of the gasifier to permit removal of slag during the test. During operation, only minor alterations were made to the lock hopper. Generally, its performance was