GASIFICATION OF BITUMINOUS COAL WITH OXYGEN IN A PILOT PLANT EQUIPPED FOR STEAM-PICKUP FEEDING

By K. D. Plants, J. H. Holden, and L. F. Willmott

* * * * * * * * * * * report of investigations 6364

UNITED STATES DEPARTMENT OF THE INTERIOR
Stewart L. Udall, Secretary

BUREAU OF MINES
Marling J. Ankeny, Director

This publication has been cataloged as follows:

Plants, Kenneth D

Gasification of bituminous coal with oxygen in a pilot plant equipped for steam-pickup feeding, by K. D. Plants, J. H. Holden, and L. F. Willmott. [Washington] U. S. Dept. of the Interior, Bureau of Mines [1964]

9 p. illus., table. 27 cm. (U. S. Bureau of Mines. Report of investigations 6364)

Includes bibliography.

1. Bituminous coal. 2. Coal gasification. I. Title. II. Title: Steam-pickup feeding (Series)

TN23.U7 no. 6364 622.06173

U. S. Dept. of the Int. Library

CONTENTS

ILLUSTRATIONS

TABLE

GASIFICATION OF BITUMINOUS COAL WITH OXYGEN IN A PILOT PLANT EQUIPPED FOR STEAM-PICKUP FEEDING

by

K. D. Plants,[1] J. H. Holden,[1] and L. F. Willmott[2]

ABSTRACT

Pulverized high-volatile A bituminous coal was gasified with oxygen and superheated steam in a pressure-gasification pilot plant equipped for steam-pickup feeding. The pilot plant operated satisfactorily at relatively high steam-to-coal ratios, but steam-to-coal ratios could not be reduced much below 0.5 lb/lb without condensation of steam or softening of the coal. Carbon gasified, gas composition, and coal and oxygen requirements were essentially the same as for a pilot plant equipped with a fluidized coal feeder. Average results from the pilot plant equipped for steam-pickup feeding were coal requirement, 37.3 lb/M (1,000) scf of $CO + H_2$ produced; oxygen requirement, 358 scf/M scf $CO + H_2$ produced; and carbon gasified, 87.7 percent.

INTRODUCTION

The Bureau of Mines has done extensive research and development at the Morgantown (W. Va.) Coal Research Center on the pressure gasification of bituminous coal with oxygen and steam to produce synthesis gas. Methods of feeding coal to the pressure gasifier have been an important part of this work.

In the first coal-feeding method developed--the fluidized or pneumatic-feeding method--coal entered the gasifier as finely divided particles suspended in air or inert gas. Details of the fluidized coal-feeding method and performance of pilot-scale gasifiers fed with fluidized coal were reported (1-4, 6-8).[3]

---

[1] Chemical engineer.
[2] Chemical research engineer.
All authors are with the Morgantown Coal Research Center, Bureau of Mines, U.S. Department of the Interior, Morgantown, W. Va.
[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Work on manuscript completed June 1963.

A second coal-feeding method involved mixing pulverized coal with water to make a slurry that was heated to produce a superheated steam-coal mixture to be fed to the gasifier (5, 9).

In a third coal-feeding technique, known as the steam-pickup method, volumetrically metered quantities of pulverized coal were dropped into a stream of superheated steam and the resultant mixture piped to the gasifier. This publication presents performance results from a pressure gasifier fed by the steam-pickup method and compares them with results from the same gasifier fed by the fluidized method.

PRESSURE-GASIFICATION PILOT PLANT EQUIPPED FOR STEAM-PICKUP COAL FEEDING

Figure 1 is a flowsheet of the pressure-gasification pilot plant equipped for steam-pickup feeding. Coal ground to about 70-percent-through-200-mesh is pneumatically conveyed by inert gas to the lock hopper of the steam-pickup system. The lock hopper is equipped with a capacitance-type level indicator

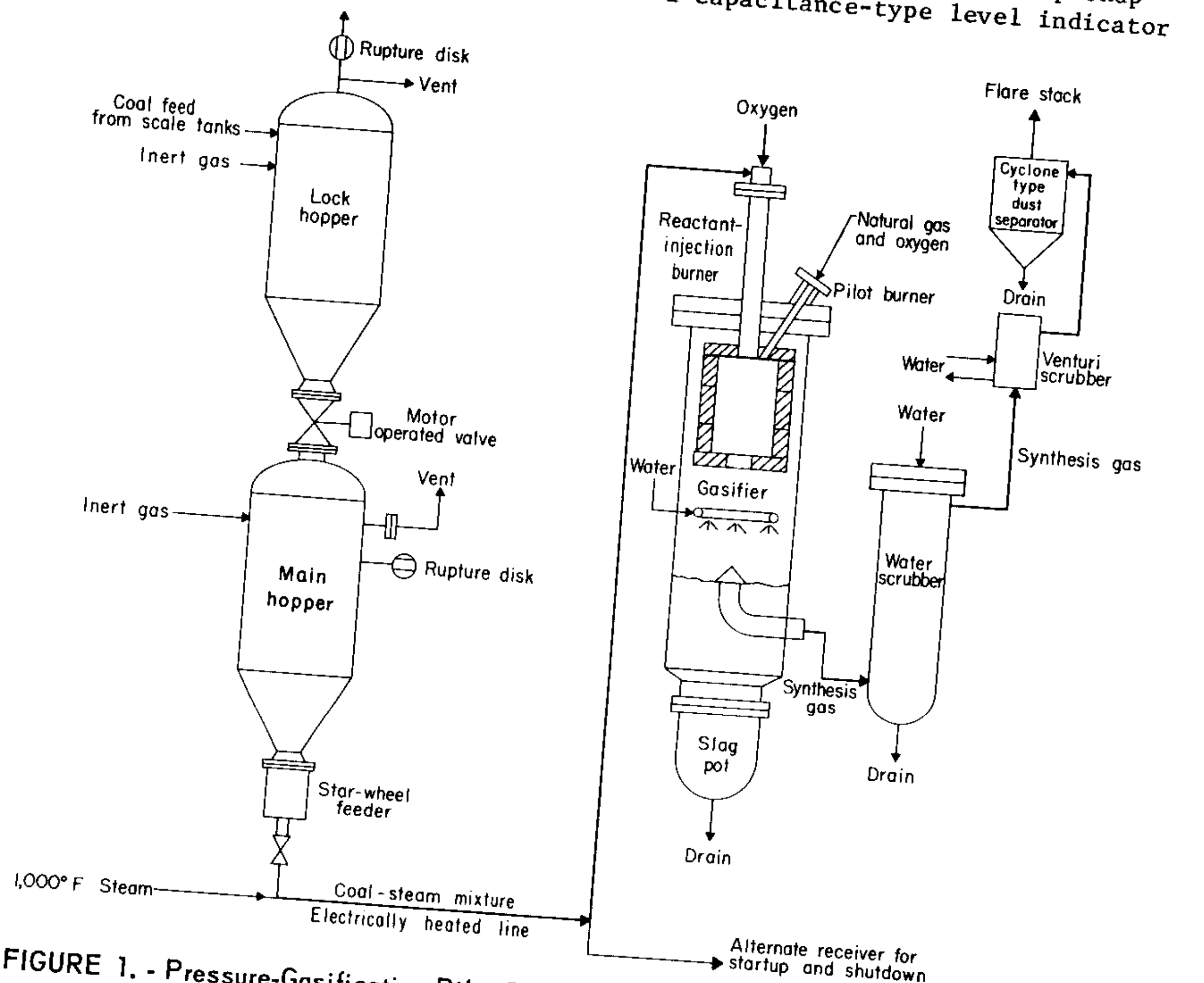


FIGURE 1. - Pressure-Gasification Pilot Plant Equipped for Steam-Pickup Feeding of Coal.

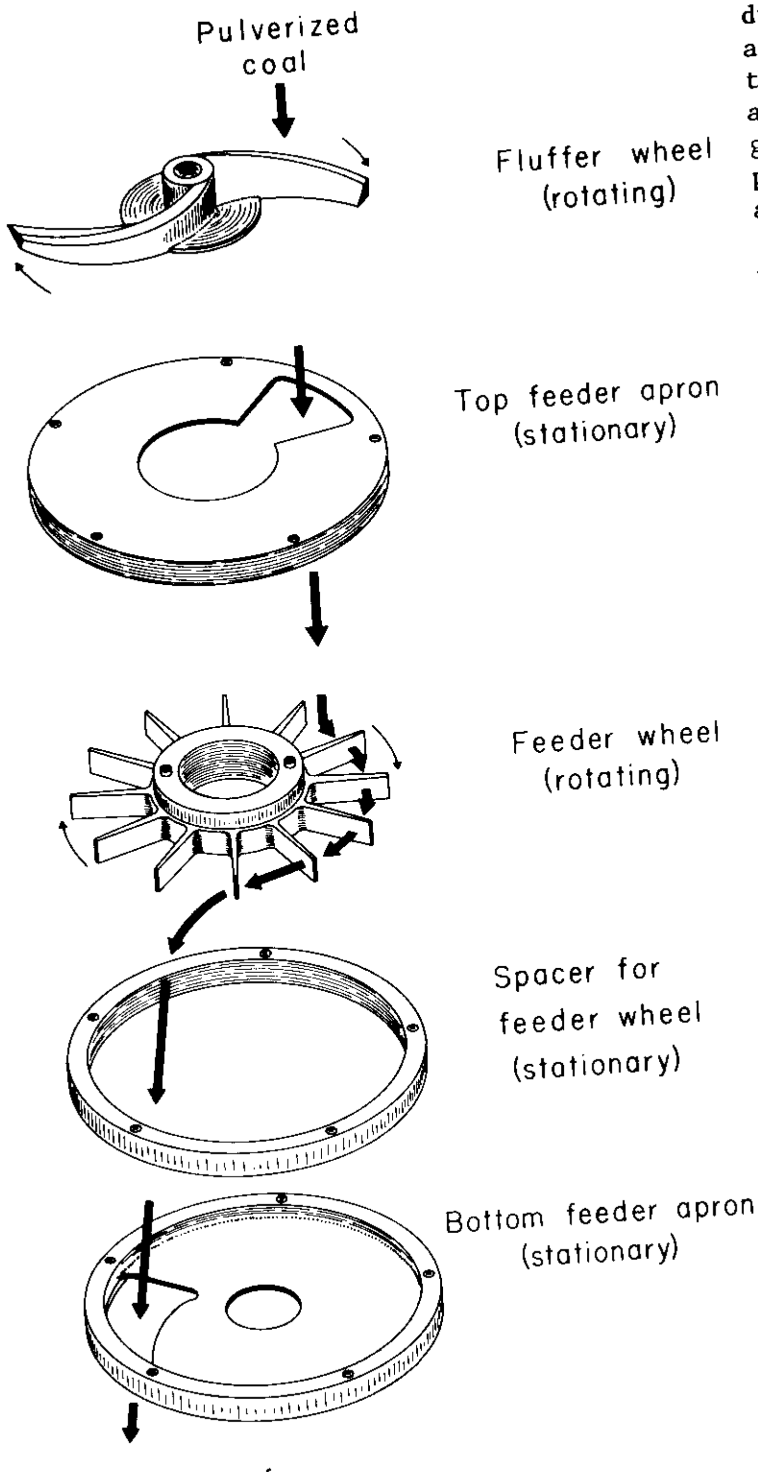


FIGURE 2. - Exploded View of Star-Wheel Feeder.

(not shown), a 4-inch motor-driven valve at the bottom to allow the coal to flow into the main hopper, a line for admitting pressurizing inert gas, a line for equalizing the pressure in the lock hopper and the main hopper (not shown), and an air-operated vent valve for releasing the gas used to transport the pulverized coal from the coal-preparation plant to the lock hopper.

The main hopper also has a pressurizing line, a vent line, and an inert-gas pressure-control line. Mounted on the bottom of the hopper is a motor-driven star-wheel (Bailey) feeder with variable speed control. Figure 2 is an exploded view of the internal elements of the star-wheel feeder. The feeder is calibrated at various gas pressures and speeds for coals of particular rank, ash content, moisture content, and size. Thus the feeder delivers preset metered weight flows of coal to the mixing tee below the feeder. The pulverized coal enters the vertical leg of the tee, superheated steam at 1,000° F and approximately 300 psig passes into one of the horizontal legs, and the steam-coal mixture flows out the other horizontal leg. The mixing tee is water cooled to prevent coal particles from agglomerating and sticking on the hot metal walls. The coal particles will not agglomerate and become sticky if the temperature of the mixture is kept far enough below the softening point of the coal.

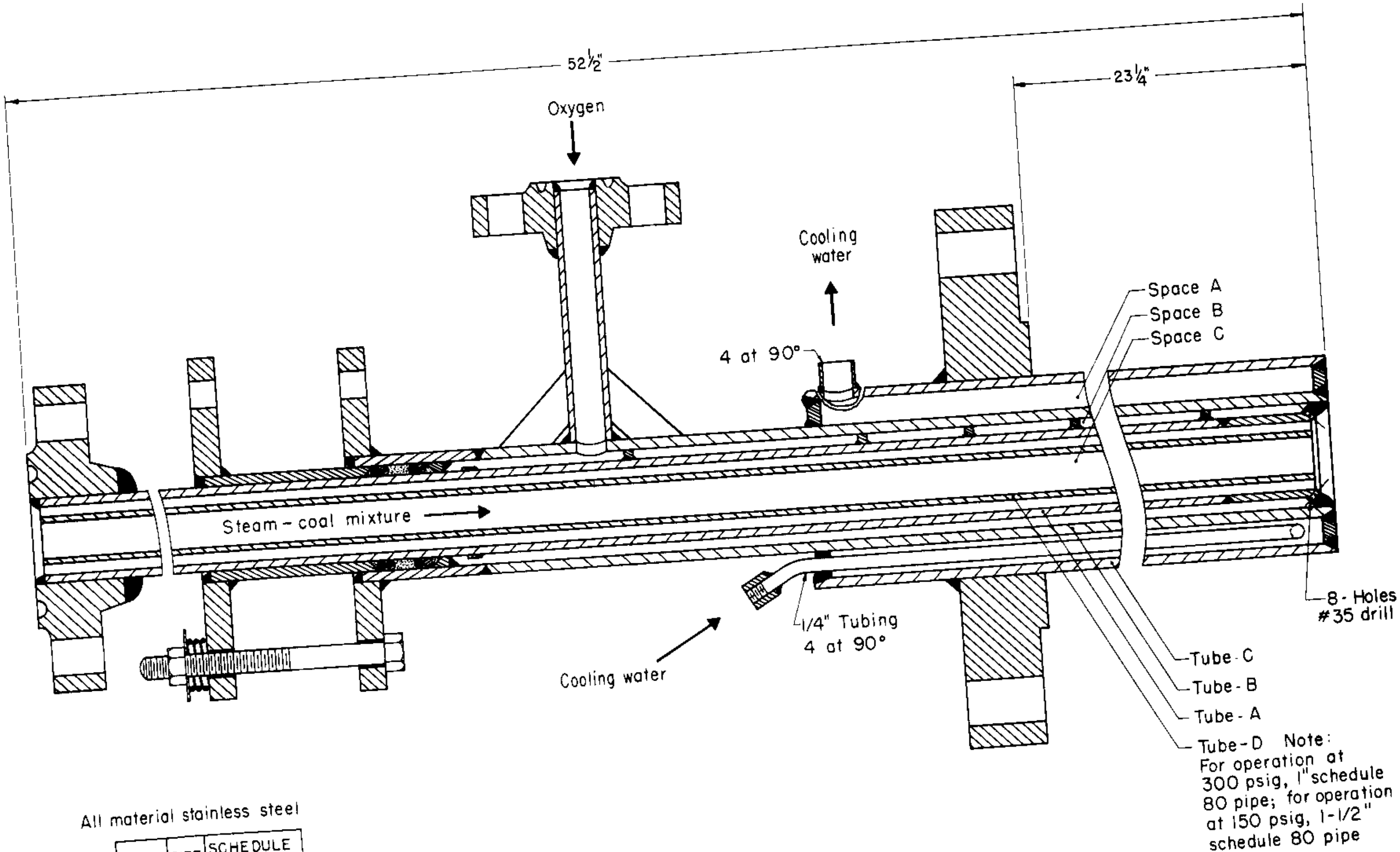
A noncondensable inert gas can be used to transport the finely divided coal at any temperature up to the softening point of the coal. Unlike steam, however, which is one of the gasification reactants, an inert gas would be a diluent and impurity in the product gas. Thus, steam is preferred as a conveying medium if the desired steam rates can be obtained without charring and condensing difficulties. The steam must be superheated so that the temperature of the steam-coal mixture is above the saturation temperature at the operating pressure; otherwise, the steam will condense on the walls of the pipe and interrupt the flow. Also, no part of the fuel can be heated above its softening temperature,or coal (or char) will stick on the walls of the pipe and stop the flow. Local overheating often occurred when very-high-temperature steam was used, even though the average temperature of the coal-steam mixture was well below the softening temperature of the coal. The highest practicable steam temperature (before mixing) to avoid plugging by char was found to be 1,080° F. Since the coal fed to the mixing tee was not preheated, this temperature limitation required the steam-to-coal ratio be approximately 0.5 lb/lb or more to avoid condensation and plugging of the line. Another operating difficulty was the close control required on pressure differential across the star wheel. The pressure in the main hopper had to be kept higher than the pressure in the mixing tee to prevent steam from leaking into the main hopper. Even small amounts of steam would condense and block the flow of coal to the star wheel. However, if the pressure differential across the star wheel exceeded 90 inches of water, the star wheel would bind.

Wraparound electric heaters on the pipe conveying the coal-steam mixture from the mixing tee to the gasifier keep the temperature of the mixture above that at which the steam would condense at the pressure in the line. The line is also equipped with a bypass line to an alternate receiver. An air-motor-driven actuator opens a valve to the gasifier and simultaneously closes a valve to the receiver at startup, or vice versa at shutdown.

The superheated steam is generated from metered deionized water in a gas-fired coil-type heater. Flow control is achieved with a diaphragm-type valve operating in conjunction with an orifice meter. As mentioned above, flow of coal to the mixing tee is controlled by varying the speed of the star-wheel feeder.

The reactant-injection burner for the introduction of coal, oxygen, and steam (fig. 3) is virtually the same as the one used for slurry feeding. The only important change is the reduction in the diameter of the central tube. This change was made to prevent coke from depositing on the burner tip, as happened occasionally at the low entrance velocities associated with the larger tube.

The major change in the gasifier, figure 4, was lengthening the refractory-lined gasification space by 9 inches to compensate for the longer flame produced by the burner modification described above. The synthesis gas produced from the partial combustion of the coal is quenched inside the pressure gasifier, cleaned in a water scrubber, metered, and flared. Slag settles into a vessel attached to the bottom of the gasifier.



All material stainless steel

TUBE	SIZE	SCHEDULE NUMBER
A	2"	80
B	3"	80
C	5"	40
D	See note	

FIGURE 3. - Reactant-Injection Burner Used With Steam-Pickup System.

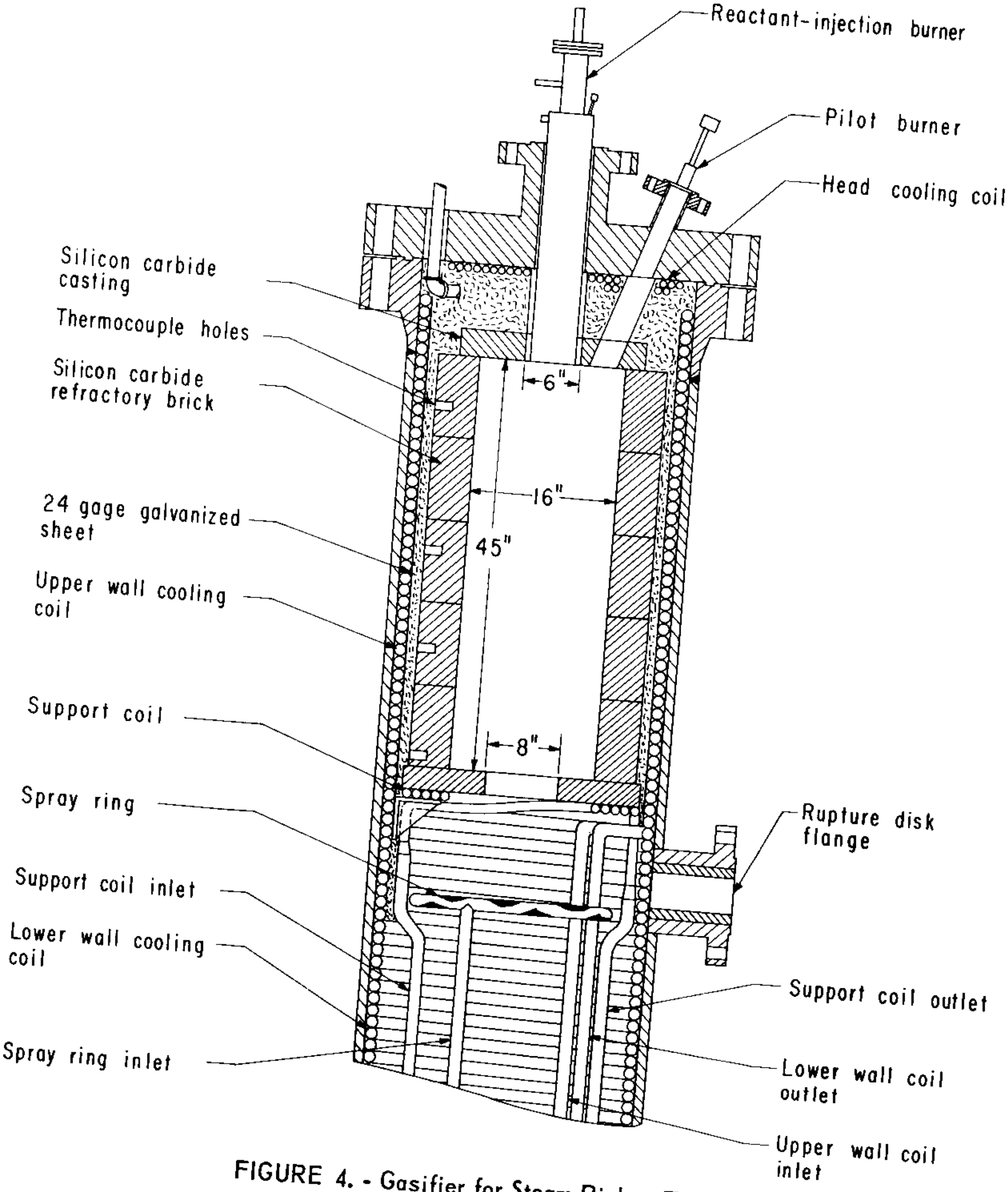


FIGURE 4. - Gasifier for Steam-Pickup Tests.

The integrated plant is equipped with a safety system and with instruments that provide a complete and continuous record of process data--including flowrates, pressures, and temperatures.

EXPERIMENTAL PLAN

The primary purpose of operating the pilot plant equipped for steam-pickup feeding was to determine the operability of the gasifier fed by this method and to compare the results with those obtained when the gasifier was fed with the fluidized-coal feeder. Therefore, the tests with the pilot plant equipped for steam-pickup feeding were made at operating conditions permitting comparison of the results with those from the fluidized feeder operations. Pressures were 150 to 300 psig, oxygen-to-coal ratios 8.0 to 11.0 scf/lb, steam-to-coal ratios 0.45 to 0.85 lb/lb, and coal rate approximately 800 lb/hr.

A complete factorial experiment was not planned because 27 tests for 3 variables, each at 3 levels, were deemed unnecessary. The operating conditions are given later in this report.

COAL GASIFIED

Coal gasified in these runs and in the previous gasification tests with the fluidized feeder was high-volatile A bituminous from the Sewickley bed, near Morgantown, W. Va. A typical analysis is moisture, 1 percent; ash, 13 percent; sulfur, 4 percent; hydrogen, 5 percent; carbon, 71 percent; oxygen, 5 percent; and heating value, 13,000 Btu/lb of coal.

ACCURACY OF REACTANT AND PRODUCT-GAS MEASUREMENT

The average estimated error in the measurement of the oxygen flowrate and the coal-feed rate was about 2 percent. Average error in the steam-feed rate was about 2 percent at the higher steam rates and 3 percent at the lower steam rates. These estimates are based on calculated results after the run, not on the planned values.

Because the product gas contained dust and moisture, its measurement was subject to somewhat larger errors. The standard deviation of the difference in flow as measured by orifice-type and positive-displacement-type meters was 6.0 percent.

Oxygen requirement, coal requirement, and percent of carbon gasified were subject to errors caused by inaccuracies in flow measurement of coal and product gas.

RESULTS

Major dependent variables in the pressure-gasification process include (1) the fraction or percentage of carbon in the fuel that is converted into gas; (2) the amount of oxygen required to produce M scf of $CO + H_2$; and (3) the amount of coal required to produce M scf of $CO + H_2$. These variables influence both equipment design and process economy and serve as a basis of comparison of results from the two feeding methods. Results from the pilot plant equipped for fluidized-coal feeding were calculated values and were determined from mathematical correlations of experimental data (3).

Table 1 gives the results of gasification tests with pilot-size systems equipped with the fluidized and steam-pickup coal-feeding methods. The standard deviation of the tests with the fluidized feeder is compared with the standard deviation of the differences between the two feeding methods. This shows that the difference is not significant at the 5 percent level for any of the dependent variables--coal requirement, oxygen requirement, and carbon gasified. Thus, there is no reason to expect different results from steam-pickup feeding than from fluidized-coal feeding at the same conditions. A similar conclusion had been reached earlier (9) for slurry feeding and fluidized feeding.

The steam-pickup system offers a satisfactory method of feeding pulverized coal to a pressure gasifier. Choice of one of these feeding systems can be made solely on the basis of the characteristics of the system, since at similar gasifier operating conditions all three feeding systems were equally effective for gasification. However, the steam-pickup and slurry-feeding methods could not be used with steam-to-coal ratios much below 0.5 lb/lb.

TABLE 1. - Results from gasification of coal in a pilot plant equipped with the different feeding systems

Operating conditions				Performance data[1]								
				Coal requirement, lb/M scf $CO + H_2$			Oxygen requirement, scf/M scf $CO + H_2$			Carbon gasified, percent		
Pressure, psig	Coal rate, lb/hr	Oxygen-to-coal ratio, scf/lb	Steam-to-coal ratio, lb/lb	Steam-pickup feeder	Fluidized feeder	Diff.	Steam-pickup feeder	Fluidized feeder	Diff.	Steam-pickup feeder	Fluidized feeder	Diff.
150	838	10.08	0.716	36.5	35.6	0.9	368	359	9	92.3	92.3	0.0
150	897	9.41	.447	36.8	36.6	.2	346	345	1	87.9	91.4	-3.5
225	787	10.63	.658	32.7	36.7	-4.0	348	389	-41	96.3	94.0	2.3
225	839	9.94	.617	36.7	38.4	-1.7	365	379	-14	88.2	89.7	-1.5
300	815	10.27	.750	36.3	35.4	.9	373	367	6	93.3	91.8	1.5
300	867	7.79	.466	42.0	42.3	-.3	327	337	-10	75.4	76.8	-1.4
300	893	9.44	.479	40.0	38.0	2.0	377	357	20	80.4	88.1	-7.7
Average				37.3	37.6	-0.3	358	362	-4.0	87.7	89.2	-1.5
Standard deviation of differences						1.9			18.9			3.5
Standard deviation of fluidized feeder correlation						1.5			14.5			3.3
Ratio of standard deviations						1.3			1.3			1.1
Significance level, percent						nil			nil			nil

[1] Values for steam-pickup feeding are observed; values for fluidized feeding are calculated.

REFERENCES

1. Albright, C. W., J. H. Holden, H. P. Simons, and L. D. Schmidt. Pneumatic Feeder for Finely-Divided Solids. Chem. Eng., v. 56, June 1949, pp. 108-111.

2. _____. Pressure Drop in Flow of Dense Coal-Air Mixtures. Ind. Eng. Chem., v. 43, No. 8, August 1951, pp. 1837-1840.

3. Holden, J. H., K. D. Plants, G. R. Strimbeck, and L. F. Willmott. Operating a Pressure-Gasification Pilot Plant Using Pulverized Coal and Oxygen: Effect of Heat Loss on Economy. BuMines Rept. of Inv. 5956, 1962, 32 pp.

4. Holden, J. H., G. R. Strimbeck, J. P. McGee, L. F. Willmott, and L. L. Hirst. Operation of Pressure-Gasification Pilot Plant Utilizing Pulverized Coal and Oxygen. A Progress Report. BuMines Rept. of Inv. 5573, 1960, 56 pp.

5. Huff, W. R., and L. F. Willmott. Development and Operation of a Pilot Plant for Feeding Bituminous Coal Slurry to a Pressure Gasifier. BuMines Rept. of Inv. 5719, 1961, 36 pp.

6. Strimbeck, G. R., J. B. Cordiner, Jr., N. L. Baker, J. H. Holden, K. D. Plants, and L. D. Schmidt. Gasification of Pulverized Coal With Steam and Oxygen at Atmospheric Pressure. BuMines Rept. of Inv. 5030, 1954, 37 pp.

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

8. Strimbeck, G. R., J. H. Holden, L. P. Rockenback, J. B. Cordiner, Jr., and L. D. Schmidt. Pilot-Plant Gasification of Pulverized Coal With Oxygen and Highly Superheated Steam. BuMines Rept. of Inv. 4733, 1950, 41 pp.

9. Willmott, L. F., K. D. Plants, W. R. Huff, and J. H. Holden. Gasification of Bituminous Coal With Oxygen in a Pilot Plant Equipped for Slurry Feeding. BuMines Rept. of Inv. 6117, 1962, 10 pp.