OPERATING A PRESURE-GASIFICATION PILOT PLANT USING PULVERIZED COAL AND OXYGEN:

Effect of Heat Loss on Economy[1]

by

J. H. Holden,[2] K. D. Plants,[2] G. R. Strimbeck,[3] and L. F. Willmott[2]

SUMMARY

Operations involving the processing of coal, oxygen, and steam into synthesis gas by means of two pressure-type gasifiers have demonstrated the effect of heat loss and operating variables on carbon gasified and oxygen and coal requirements. Carbon gasified is the fraction of carbon in the coal that is converted to gas. Oxygen and coal requirement is the quantity of each that is needed to produce a unit volume (M std. c.f.) of carbon monoxide and hydrogen. Operating pressure of the gasifiers ranged from 150 to 300 p.s.i.g. and coal was fed at 200 to 500 lb./hr./cu.ft. of reaction-zone space. Oxygen-to-coal ratios were 8.5 to 10.5 std. c.f./lb.

Heat loss and residence time have opposite effects on carbon gasified; increasing the heat loss decreases the carbon gasified, but increasing the residence time (by raising the operating pressure or reducing the coal-feed rate) increases the carbon gasified. The effects of these two factors are difficult to separate because they usually change simultaneously. A comparison of the results obtained from the operation of two gasifiers with different levels of heat loss, however, permitted the effect of heat loss to be separated from that of pressure and coal-feed rate. When the results were determined on the basis of constant heat loss, increase of the residence time increased the carbon gasified until the reaction virtually had come to completion. For example, at 150 p.s.i.g., decreasing the coal-feed ratio from 500 lb./hr./cu.ft. to 200 lb./hr./cu.ft. substantially increased the carbon gasified. At 300 p.s.i.g., however, changing the coal-feed rate had little effect on the carbon gasified because the reaction had almost reached completion and further increase in residence time resulted only in a negligible change.

The oxygen requirement, which increased with increase in oxygen-to-coal ratio when the effects of heat loss were not taken into account, showed little change in this respect when the effect of heat loss was included. On the

---

[1] Work on manuscript completed May 1961.

[2] Supervisory chemical engineer, Morgantown Coal Research Center, Bureau of Mines, Morgantown, W. Va.

[3] Project coordinator (Acting), Morgantown Coal Research Center, Bureau of Mines, Morgantown, W. Va.

other hand, when heat loss effects were included, the coal requirement declined more rapidly with increase in oxygen-to-coal ratio.

For the operating range investigated, the optimum gasifier capacity, which is the CO + H_2 output at operating conditions that keep the overall cost of coal and oxygen requirements at a minimum, was about 13,000 std. c.f./hr./cu. ft. of reaction zone. Approximate operating conditions giving this optimum capacity were coal-feed rate 460 lb./hr./cu.ft.; oxygen-to-coal ratio, 9.5 std. c.f./lb.; pressure, 300 p.s.i.g.; and heat loss, 415 B.t.u./lb. of coal. Extrapolation to a lower heat loss indicated that coal and oxygen requirements of 36 pounds and 340 std. c.f. per M std. c.f., respectively, were reduced to 34 and 320 when the heat loss was reduced from 415 to 100 B.t.u./lb. of coal.

The temperature of the gas from the gasifier, calculated from a heat balance over the system at optimum gasifier capacity, ranged from 2,200° F. at an oxygen-to-coal ratio of 8.5 std. c.f./lb. of coal to 2,700° F. at an oxygen-to-coal ratio of 10.5 std. c.f./lb. of coal. An increase in heat loss of 1 B.t.u./lb. of coal decreased the exit-gas temperature by about 0.9° F.

This investigation showed the direction and magnitude of the changes to be expected in the dependent variables of the pressure-gasification process when pressure, coal-feed rate, oxygen-to-coal ratio, steam-to-coal ratio and heat loss are varied. As a result, a better approach may be found to the development of a design of an entrainment-type pressure gasifier.

INTRODUCTION

The Bureau of Mines is conducting research and development on a process for producing synthesis gas directly from coal, steam, and oxygen. Synthesis gas, which contains carbon monoxide and hydrogen, can be converted by well-established processes into gasoline, oil, pipeline gas, ammonia, alcohol, and other products. Because the pressure of the synthesis gas entering the first step of most of these processes usually is 400 p.s.i.g. or higher, only oxygen has to be compressed if the gas is generated at pressure; and process costs can be significantly reduced.

As part of its research program on coal gasification, the Bureau designed and constructed a pressure-gasification pilot plant at Morgantown, W. Va. This pilot plant operated satisfactorily in a series of 68 experiments.[4] [5] [6]

---

[4] 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 Ann. Meet. AIME, New York, N. Y., Feb. 20-21, 1952, pp. 80-108.

[5] 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.

[6] Holden, J. H., Strimbeck, G. R., McGee, J. P., Willmott, L. F., and Hirst, L. L., Operation of Pressure-Gasification Pilot Plant Utilizing Pulverized Coal and Oxygen. A Progress Report: Bureau of Mines Rept. of Investigations 5573, 1960, 56 pp.

The footnoted publications describe the development of process equipment and analyze the effects of variations in operating conditions on coal and oxygen requirements, carbon gasified, and the temperature of the gas from the gasifier. Only limited information was obtained, however, about one of the most important factors in the economy of the process--the amount of heat that is lost through the walls of the gasifier. Therefore, the effects of heat loss on process variables could not be fully evaluated. After several runs were made to attain smooth operation of a new and improved pilot plant at Morgantown, additional experiments were conducted to correlate heat loss with the other process variables. The analysis presented in this report is based on a comparison of these experiments with the results of those published previously.

ACKNOWLEDGMENTS

This investigation was conducted in cooperation with the West Virginia University, Morgantown, W. Va. The authors wish to acknowledge the assistance and cooperation received from P. R. Grossman of the Babcock and Wilcox Company, which designed and fabricated major equipment items purchased for the pilot plant.

DESCRIPTION OF PILOT PLANT AND THE COAL-GASIFICATION PROCESS

Figure 1 is a flowsheet of the pressure-gasification process. Coal ground to 70-percent through 200-mesh is fluidized with carbon dioxide and nitrogen in a continuous feeder. A high-velocity mixture of preheated oxygen and steam breaks up the stream of fluidized coal as it enters the gasifier. Coal, steam, and oxygen react in the upper part of the gasifier. The product gas, containing ash, slag, and unreacted carbon, is sprayed with water in the lower section of the unit. Heavier and larger solids in the gas drop into a pot at the bottom of the gasifier and are removed periodically. Finely divided solids in the gas from the gasifier are removed in an unpacked water scrubber. Gas from the scrubber passes through a pressure letdown valve, a positive displacement meter, and an orifice meter and is flared. Figure 2 is a diagram of the gasifier, the main unit in the process.

COALS GASIFIED

Results in this report are from the gasification of Sewickley-bed, run-of-mine high-volatile A bituminous coal. The coal was crushed in a hammer mill and ground in a Raymond pulverizer to 70 percent through 200-mesh. Table 1 shows a typical analysis of the coal.

SAMPLING OF GASES AND RESIDUES PRODUCED DURING GASIFICATION

Three composite samples of the product gas, for complete analysis, were collected continuously during each data period. Spot samples were collected and analyzed by Orsat for carbon dioxide, oxygen, and carbon monoxide every half hour. Usually, analyses of the composite samples were used in the calculations for each period. Table 2 shows typical analyses of gases produced at various combinations of operating conditions.

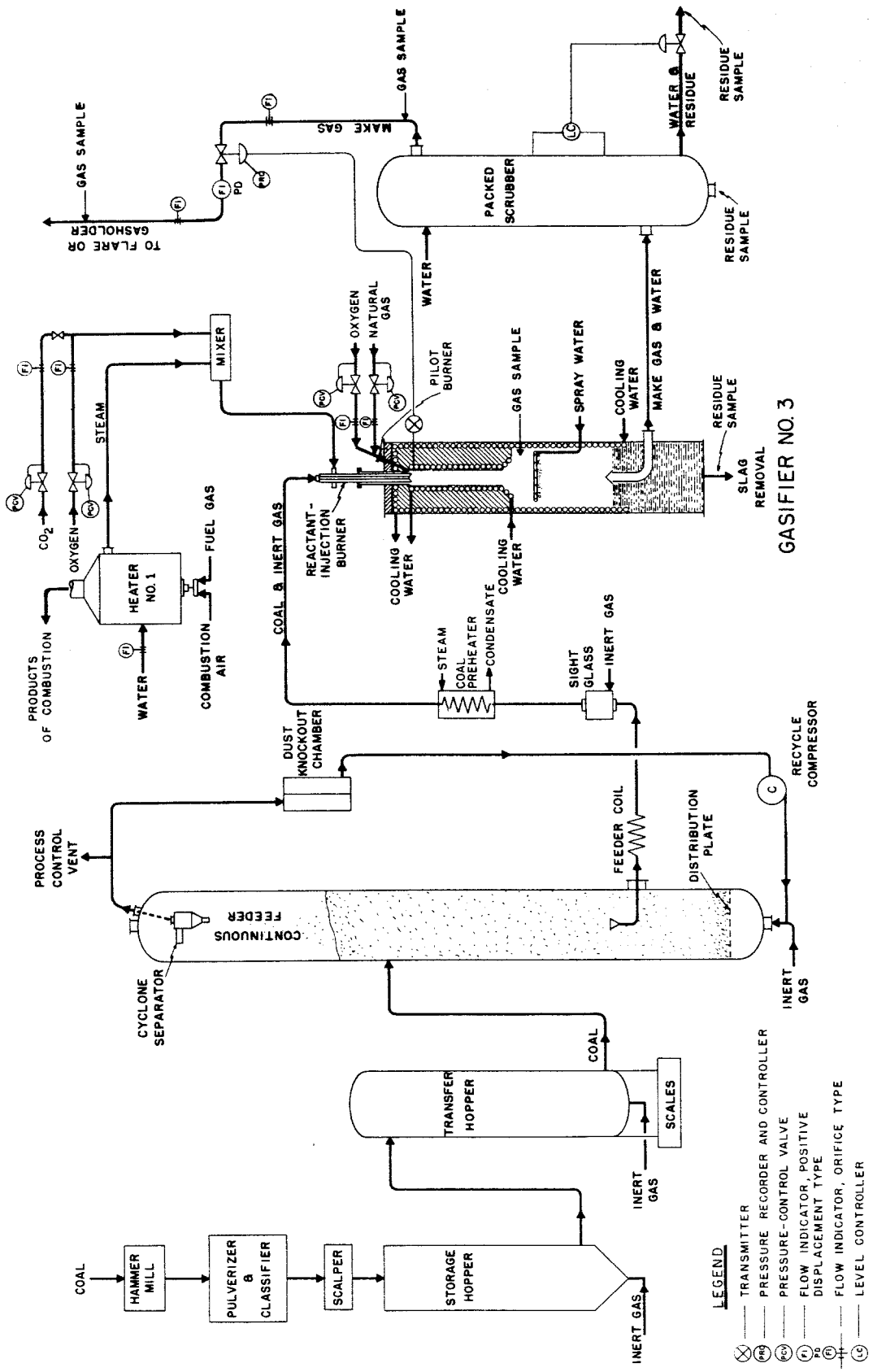

FIGURE 1. - Flowsheet of Pressure-Gasification Process.

TABLE 1. - Analysis of high-volatile A bituminous coal

	Quantity
Ultimate analysis, percent:	
Moisture	2
Hydrogen	5
Carbon	71
Nitrogen	1
Oxygen	6
Sulfur	1
Ash	14
Calorific value, B.t.u.:	
As received	12,750
Moisture and ash free	15,180
Fusibility of ash, °F.:	
Initial deformation	2,090
Softening temperature	2,240
Fluidity	2,460
Screen analysis, percent:	
Minus 20 plus 100 mesh	5
Minus 100 plus 140 mesh	9
Minus 140 plus 200 mesh	15
Minus 200 mesh	71

TABLE 2. - Typical analyses of gases produced by different gasifiers at various combinations of pressure, oxygen-to-coal ratio, and steam-to-coal ratio

Gasifier design	Pressure, p.s.i.g.	Oxygen-to-coal ratio, std. c.f./lb.	Steam-to-coal ratio, lb./lb.	Composition of gas, volume-percent		
				CO_2	H_2	CO
WC	150	8.74	0.3	10.4	34.3	50.9
RL	150	8.54	.3	10.0	34.5	50.3
WC	300	8.74	.3	9.3	34.1	50.3
RL	300	8.48	.3	9.2	35.0	49.9
WC	150	9.80	.3	10.9	32.6	52.2
WC	300	9.86	.3	10.4	32.5	51.3
WC	150	10.64	.3	11.6	31.2	53.1
RL	150	10.55	.3	11.6	32.6	52.0
WC	300	11.18	.3	12.7	30.5	51.2
RL	300	10.51	.3	11.3	32.0	51.5
RL	150	8.42	.6	14.0	37.0	44.4
RL	150	10.74	.6	14.9	35.4	46.5
RL	300	8.55	.6	13.9	37.5	42.7
RL	300	10.77	.6	14.0	35.2	46.3

[1] WC--water-cooled gasifier, volume reaction space, 2 cu. ft.; RL--refractory-lined gasifier, volume reaction space, 3 cu. ft.

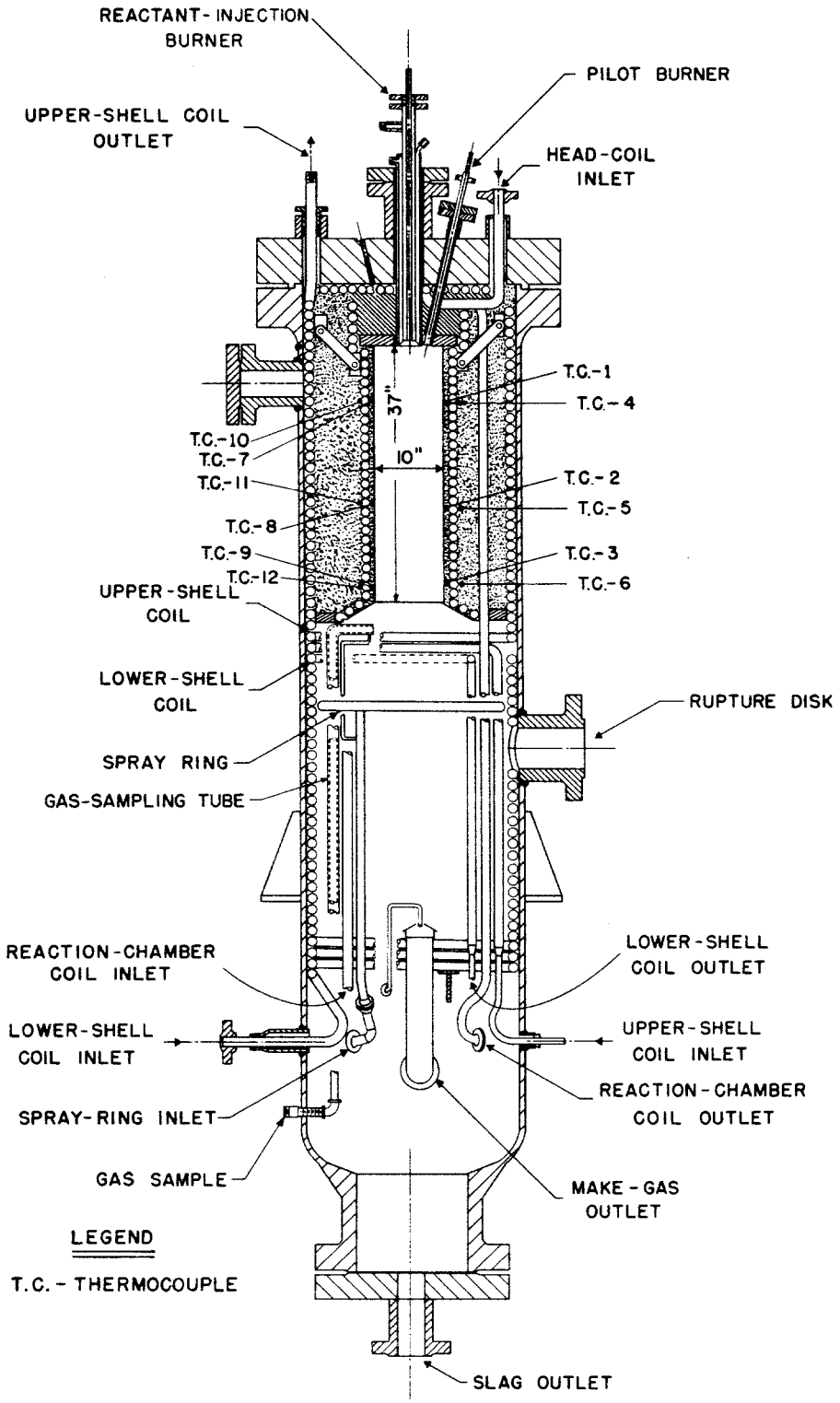

FIGURE 2. - Pressure Gasifier.

Residues from the bottom of the gasifier were examined as removed but were not sampled or weighed. Residues from the water scrubber usually were discarded without being inspected, weighed, or sampled.

EXPERIMENTAL PLAN

This report presents an analysis of data obtained from a pilot-scale pressure gasifier equipped with two different types of linings. Results of operating a gasifier equipped with a water-cooled lining (fig. 3) were previously reported,[7] but important operating variables in the process were correlated without taking into account the amount of heat loss from the gasifier. Data more recently obtained from a refractory-lined gasifier (fig. 4) gave another level of heat loss and permitted a correlation that

[7] Work cited in footnote 6, p. 2.

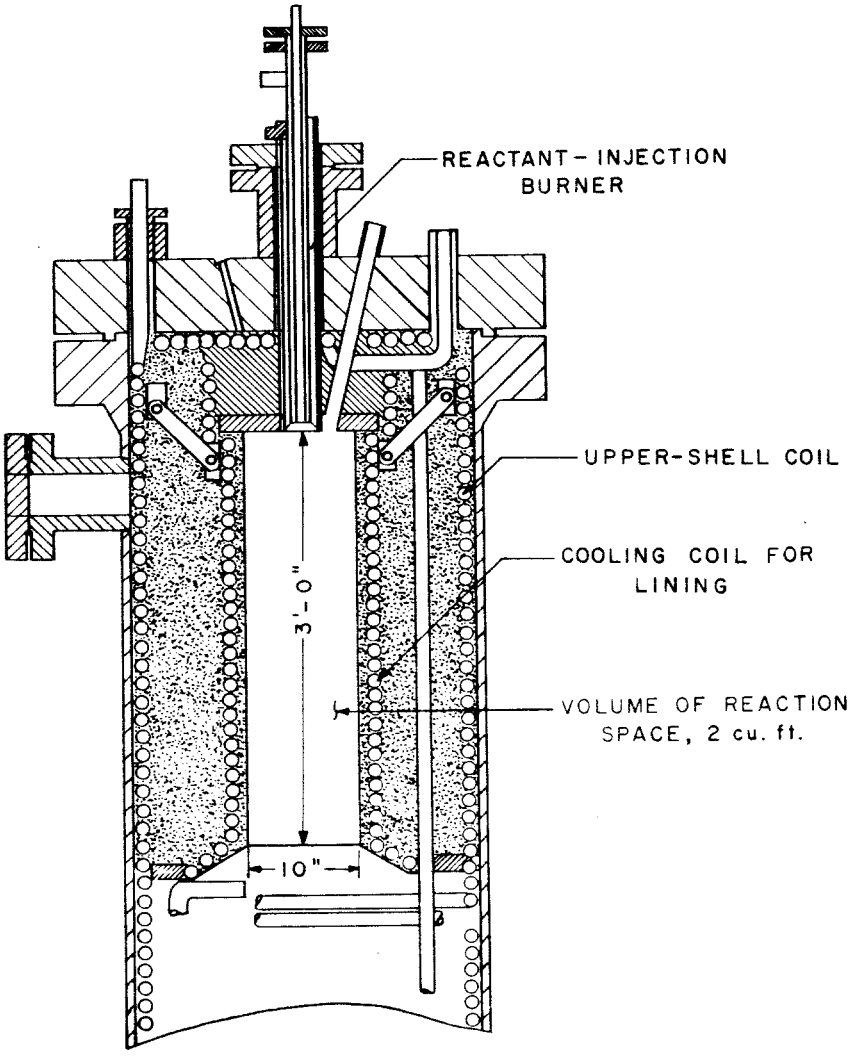

FIGURE 3. - Gasifier With Water-Cooled Lining.

includes the effects of heat loss. Results from the refractory-lined gasifier are given in table 3.

In an attempt to obtain a third level of heat loss, several tests were made with the refractory-lined gasifier modified by adding an upper-support coil (fig. 5). The difference in heat loss, however, was not statistically significant.

Both gasifiers had water-cooled shells, so that in one sense both were water-cooled. Throughout this report, however, the gasifier with the water-cooled lining (fig. 3) is called the water-cooled gasifier. The gasifier lined with refractory (figs. 4 and 5) is called the refractory-lined gasifier. Volume of reaction space in the water-cooled and refractory-lined gasifiers was approximately 2 and 3 cu. ft., respectively. Aside from the gasifier, the rest of the equipment in the pilot plant was virtually the same as in previous tests.

Experiments were carried out according to a factorial design, which comprises a series of tests in which each of the independent variables in a process are set at two or more values. The process is then operated with all possible combinations of these independent variables to find the effect on the dependent variables.

Independent variables in the pressure-gasification process were pressure, coal-feed rate, oxygen-to-coal ratio, and steam-to-coal ratio. Major dependent variables were carbon gasified, oxygen requirement, and coal requirement. In this report, carbon gasified is expressed as the percent of carbon in the coal that is converted to gas; oxygen requirement is given as standard cubic feet of oxygen per thousand standard cubic feet of carbon monoxide and hydrogen

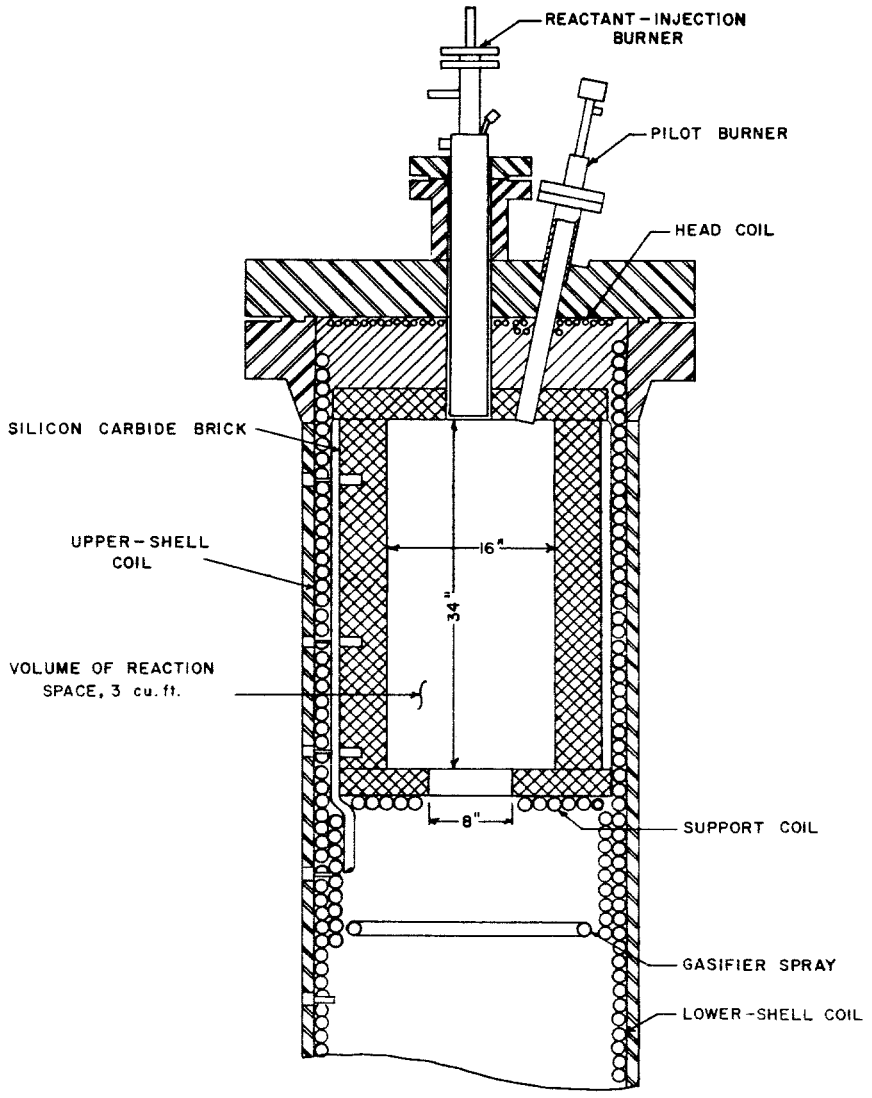

FIGURE 4. - Gasifier With Refractory Lining.

($CO + H_2$) in the product gas; coal requirement is expressed as pounds of coal per thousand standard cubic feet of $CO + H_2$ in the product gas. Heat loss from the gasifier is given in B.t.u. per pound of coal fed to the unit.

The water-cooled gasifier was operated at 150 and 300 p.s.i.g., and the refractory-lined unit was operated at 150, 225, and 300 p.s.i.g. Coal-feed rates are expressed as weight-rate per cubic foot of reaction space to account for the difference in volume of the reaction space of the two gasifiers. Coal-feed rates varied from 200 to 530 lb./hr./cu. ft. Oxygen-to-coal ratios were about 8.5, 9.5, and 10.5 std. c.f./lb. Steam-to-coal ratio for the water-cooled gasifier was approximately constant at 0.3 lb./lb.; steam-to-coal ratios for the refractory-lined gasifier were 0.3, 0.45, and 0.6 lb./lb. Different levels of heat loss were obtained by means of the different liners; the average heat loss of the refractory-lined gasifier was about two-thirds that of the water-cooled unit. Heat loss fluctuated somewhat owing to changes of operating variables and erosion of refractory or buildup of slag.

METHOD OF CALCULATING RESULTS

Results of the gasification tests were correlated by fitting empirical equations to the data. The data were processed by standard multiple regression analysis and correlated by means of a general second order equation. Details of the calculations, including an explanation of the mathematical treatment are given in the appendixes.

TABLE 3. - Operating conditions and principal results, gasifier 3 with refractory lining

Run and period	Gasifier pressure, p.s.i.g.	Coal rate, lb./hr.	Oxygen-to-coal ratio, std. c.f./lb.	Steam-to-coal ratio, lb./lb.	Carbon gasified, percent	Requirements per M std. c.f. CO + H_2		Heat loss, B.t.u. per lb. of coal	Calculated exit-gas temp., °F.
						Coal, lb.	Oxygen, std. c.f.		
100D	150	772	8.78	0.311	92.5	37.1	325	446	2,785
94E	150	817	8.23	.291	81.7	40.5	333	542	2,190
92C	150	806	8.33	.608	79.6	39.0	325	516	1,810
101B	150	800	8.49	.601	78.4	42.7	363	565	2,384
102E	150	778	10.87	.312	94.9	36.3	395	739	2,927
93D	150	796	10.47	.299	95.9	37.0	388	863	2,675
95B	150	798	10.51	.612	92.9	35.9	378	682	2,605
99C	150	750	11.20	.643	92.3	37.8	425	760	2,738
93E	150	1,485	8.55	.315	83.9	38.4	328	347	2,520
102A	150	1,475	8.61	.305	88.4	38.9	335	317	2,852
95E	150	1,498	8.54	.599	76.5	43.8	374	356	2,475
100E	150	1,538	8.34	.576	81.4	42.6	356	355	2,478
99E	150	1,522	10.23	.302	91.5	35.4	363	426	2,862
94A	150	1,495	10.64	.316	96.8	36.5	388	579	2,820
92A	150	1,484	10.65	.611	86.1	38.6	412	448	2,440
101D	150	1,484	10.62	.598	94.8	35.7	379	500	2,757
92E	225	1,179	9.30	.455	83.9	37.3	347	442	2,145
93C	225	1,164	9.27	.455	88.8	37.4	347	472	2,480
94B	225	1,155	9.68	.459	92.1	35.9	348	524	2,360
95A	225	1,033	10.00	.481	91.6	36.0	360	536	2,590
96D	225	1,176	9.33	.444	85.1	37.9	354	405	2,560
97C	227	1,155	9.49	.442	89.5	36.4	346	445	2,435
98B	225	1,122	9.72	.463	89.6	37.0	359	544	2,506
99D	225	1,140	9.76	.454	90.4	35.8	349	437	2,701
100B	225	1,173	9.36	.448	93.5	36.2	339	465	2,552
101C	225	1,153	9.53	.442	93.9	34.6	329	476	2,603
102B	225	1,097	9.86	.474	100.0	34.9	344	466	2,838
103A	225	1,054	8.78	.491	83.7	39.8	349	443	2,520
103E	225	1,171	9.16	.436	90.4	36.0	330	427	2,694
104A	225	1,105	9.77	.471	92.2	36.3	354	459	2,701
95C	300	787	8.61	.305	79.0	39.6	341	445	2,270
$101E_r$	300	805	8.35	.298	76.5	42.2	352	511	2,383
100C	300	785	8.55	.611	80.1	40.9	349	524	2,157
93A	300	797	8.48	.624	83.9	38.8	329	583	2,060
92D	300	834	9.92	.289	89.6	40.6	403	862	2,360
98A	300	835	10.08	.291	89.1	36.2	365	760	2,378
100T	300	814	10.29	.299	91.6	39.1	403	887	2,494
99B	300	756	10.87	.319	89.3	35.9	390	779	2,462
101A	300	784	10.81	.610	96.1	34.3	371	832	2,420
94D	300	812	10.38	.594	97.7	34.5	358	745	2,440
100A	300	1,457	8.84	.301	91.0	36.0	318	370	2,513
92B	300	1,593	8.10	.297	70.3	44.8	363	461	1,830
94C	300	1,509	8.46	.596	81.1	40.4	361	390	1,935
102D	300	1,456	8.70	.617	79.2	40.4	351	351	2,333
102C	300	1,445	10.83	.313	99.4	34.3	371	499	2,936
95D	300	1,476	10.64	.309	95.9	35.4	376	550	3,045
$93B_r$	300	1,484	10.78	.611	97.8	36.2	390	481	2,640
99A	300	1,432	11.10	.619	94.9	34.8	386	559	2,459
93B	300	1,623	9.57	.552	92.7	36.7	351	473	2,405
97B	119	1,142	9.57	.454	88.0	37.8	361	522	2,680
104E	119	1,098	9.83	.466	94.0	36.2	356	408	2,958
103D	331	1,145	9.59	.439	89.5	35.4	340	403	2,522
97D	330	1,156	9.40	.448	89.6	37.0	348	418	2,570
96A	225	696	8.93	.422	71.9	46.8	418	826	2,150
103B	225	658	9.39	.451	87.9	39.9	375	657	2,777
96C	225	1,646	9.48	.443	87.9	37.3	353	341	2,565
103C	225	1,649	9.47	.445	91.0	37.6	356	344	2,804
$103A_r$	225	1,146	8.16	.439	79.0	40.8	333	320	2,428
97E	225	1,111	8.35	.466	81.3	41.4	343	405	2,255
97A	225	1,121	11.24	.457	96.6	36.5	410	755	2,815
104D	225	1,141	10.96	.451	97.6	34.7	380	562	3,041
104C	225	1,114	9.69	.249	91.8	34.9	338	453	2,914
96E	225	1,150	9.52	.239	87.4	35.5	338	444	2,650
96B	225	1,125	9.73	.670	87.8	37.3	363	478	2,465
104B	225	1,099	9.81	.689	91.8	35.4	348	429	2,597