3. GASIFICATION

Two types of gasification products will be discussed in this section, synthesis gas and producer gas. Producer gas is produced by blowing air through a solid fuel bed with or without the addition of steam. It results in a low-heating-value, inexpensive gas with a high percentage of nitrogen. The production of synthesis gas requires more expensive methods to satisfy the heat demand of the endothermic reaction of the carbon of the fuel with steam because dilution of the process gas with nitrogen is undesirable. Oxygen may be introduced to supply the required heat internally by burning a portion of the fuel. Alternatively heat may be transferred through externally heated walls of the reactor, or a cyclic process with separate periods of heating and gasification may be used, such as the conventional water-gas set. The usable constituents of synthesis gas, for most applications, are carbon monoxide and hydrogen.

Synthesis Gas

Although the preparation and use of certain types of synthesis gas are not new, developments of the last few years have markedly increased the interest in new gasification methods (27).[1] In modern gasification processes, use of "tonnage oxygen" to secure the heat necessary for the process by partial combustion of the solid fuel and use of high pressures have considerably altered gasification techniques. These, together with fuel preparation and other variations, have given rise to a number of types of gasification processes. Some of these gasification processes were originated in Europe and have received further development work in the United States. This work and the processes originated by organizations in the United States will be described in this section of the report, and the European work will be covered in part 1.

Representative processes and variations in operation are presented in table 32.

TABLE 32. - Modern synthesis-gas processes

Size of fuel	Operating pressure	Heat supply for consumption by gasification process		
		Internal heating		External heating
		With oxygen	Preheated recirculating gases	
Coarse nut size or briquet	Atmospheric	Thyssen-Galoczy Leuna slagging	Pintsch-Hillebrand	Didier-Bubiag Bureau of Mines, Grand Forks, N. Dak. Freiberger
	Elevated pressure	Lurgi		
Small particle in suspension	Atmospheric	Winkler Bureau of Mines, Morgantown, W.Va. DuPont-Babcock and Wilcox Koppers Coal Syndicate	Schmalfeldt-Wintershall	Battelle process
	Elevated pressure	Texas Co. process Bureau of Mines, Morgantown, W.Va.		

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[1] Underlined numbers in parentheses refer to citations in the bibliography at the end of this section.

It would be impossible to cover each of the processes in detail; however, the following discussion presents a short description of the main types and pertinent operating data.

Externally Heated Annular Retort, Bureau of Mines, Grand Forks, N. Dak.

The Bureau of Mines at Grand Forks, N. Dak., has been experimenting with an externally heated retort for gasification of lump lignite at atmospheric pressure. A diagram of this retort is shown in figure 19. This unit, which has been developed as a commercial-scale pilot plant, consists basically of two concentric steel cylinders separated by a 3-inch annular space. The outer steel cylinder of 310 alloy composition is 4 feet i.d., 20 feet 6 inches long. Approximately 17 feet of its length is heated by a surrounding cylindrical furnace. The furnace consists of a combustion space 7 inches wide, with 18-inch thickness of brick refractory outer wall. Burners are set tangentially in this wall around the tube at three levels to secure temperature control over the length of the tube.

Lignite 1-1/2 by 3/8-inch in size is fed to the charging dome at the top of the retort using a rotary feeder, to maintain the charging dome partly full. The lignite descends slowly by gravity through the annular space between the two cylinders, where the gasification takes place. A residue consisting of ash and char is removed continuously from the bottom of the retort. The lignite feed rate is controlled, at a given gasification rate, by adjusting the rate of residue removal. The product gas flows from the annulus into the center of the inner tube through the gas offtake. This offtake is located, depending upon the type of inner tube in use, at either the bottom of the annulus or at a point approximately one-third of the tube length from the bottom. The gas leaves at the top of the retort and enters the scrubbing system. Using the full-length annulus design, where the gas offtake is near the bottom, steam is admitted only with the lignite feed. With the divided annulus arrangement, steam is added both to the upper and lower reaction zones. In the full-length annulus design, saturated steam is introduced at the top of the annular space through a jacket surrounding the gas offtake pipe. The lignite is dried in the upper portion of the unit by heat from the outer wall, and the additional steam generated also enters into the process. As the temperature of the lignite increases, tars and light oils distill. These are cracked and undergo reaction with the steam at lower levels. Gas formed by this reaction and by the reaction of the steam with the solid carbon of the lignite is withdrawn through the inner steel cylinder. A portion of the sensible heat of the gas is transferred to the lignite, especially at the higher levels, through the inner cylinder wall.

In the experimental work a portion of the product gas is used for heating the retort. Air, preheated in a heat exchanger, is mixed with the gas at the flame nozzle, and some of the products of combustion are recycled with this air to reduce the flame temperature, lengthen the flame travel, and provide a greater bulk of gases.

The 310 alloy steel tube has given satisfactory service, and only negligible corrosion and minor deformation of the tube have resulted from 4,740 hours at high temperature. Plant operation has been stable with no major difficulties. Runs normally were made continuously for 1 month and terminated only because the program of the tests had been completed.

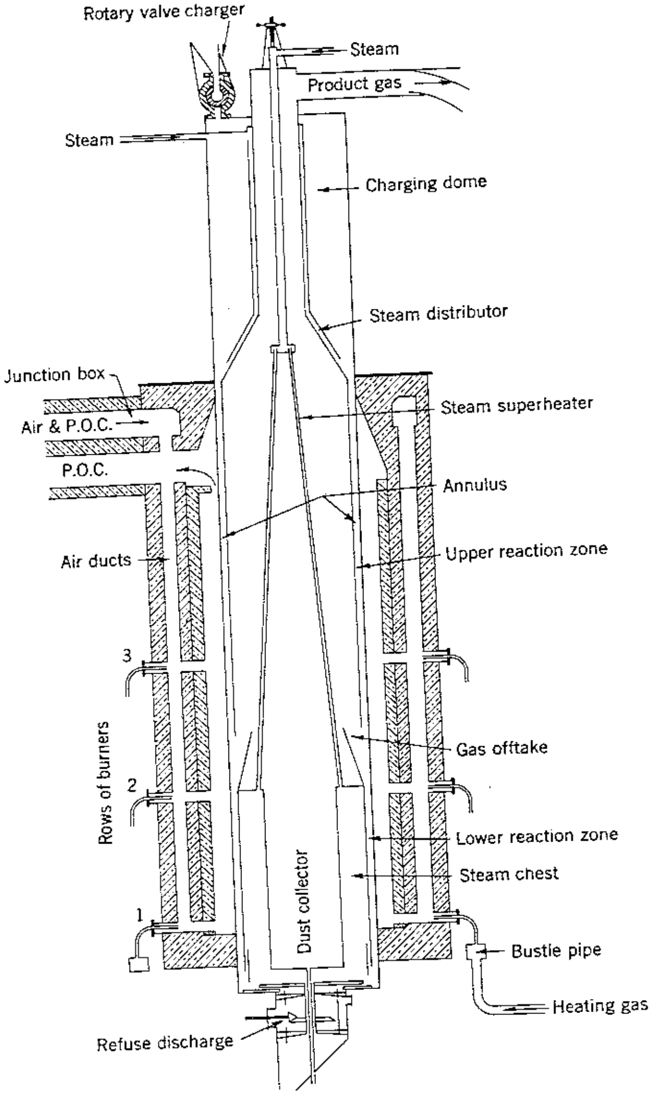

Figure 19. - Bureau of Mines externally heated gasifier, Grand Forks, N. Dak.

Data from the operation of the pilot plant are presented in table 33. Additional information on this plant is available in several publications (7, 8, 11, 12, 23, 24, 25). It will be noted that the capacity of the generator is increased when steam-dried lignite is used. This is the result of reducing the length of the annular space required for drying the fuel and consequent increase in the heat available for gasification. Although a variety of gas ratios may be made in this unit, the most practical operation is secured at the H_2:CO ratio of 2.0, the lowest ratio readily obtainable.

TABLE 33. - Typical results with externally heated retort, Bureau of Mines, Grand Forks, N. Dak.

Lignite gasified	Natural Dakota Star	Natural Dakota Star	Steam-dried Dakota Star
Run and period	11-M	11-A	12-D
Combustion space temp. °F.			
1	1,750	1,926	1,926
2	1,802	1,853	1,850
3	1,579	1,758	1,690
4	1,461	1,600	1,597
Lignite feed rate lb./hr.	343	641	489
Moisture and ash free lignite do.	197	390	392
Steam addition:			
A. Available from lignite moisture + H_2O of formation lb./hr.	165	310	158
B. Fed to top of annular reaction space lb./hr.	309	68	257
C. Fed to bottom of annular reaction space lb./hr.	308	210	198
D. Total steam available:			
Lb./hr	782	588	613
Lb./lb. MAF lignite	3.97	1.56	1.56
Undecomposed steam lb./hr.	342	281	208
Decomposed steam:			
Lb./hr	440	307	405
Percent of total steam available	56.7	52.2	66.0
Product gas:			
M std. cu. ft./hr	10.6	12.6	16.4
Std. cu. ft./lb. MAF lignite	53.8	32.4	41.7
Product (H_2 + CO):			
M std. cu. ft./hr	7.7	9.7	13.4
Std. cu. ft./lb. MAF lignite	39.1	24.9	34.2
Carbon gasified percent	86.6	57.3	76.0
Heat used net B.t.u./cu. ft. of product gas	119	122	98
Product gas for heating percent of gas made	53.8	48.3	37.9
Product gas composition, percent:			
CO_2	24.1	18.3	14.6
Illuminants	0.1	0.2	0.0
CO	11.0	19.0	24.9
H_2	61.7	57.9	57.0
CH_4	2.3	3.8	2.9
C_2H_6	0.3	0.3	0.1
N_2	0.5	0.5	0.5
H_2/CO ratio	5.59	3.04	2.29

Table 34 (7) presents data covering heat transfer through the metal wall of the retort.

TABLE 34. - Heat-transfer and operating data, externally heated retort, Bureau of Mines, Grand Forks, N. Dak.

	Overall heat transfer through retort tube[1]								
Range	Low			Medium			High[2]		
Run and period..............	11-G	11-K	11-L	11-C	11-M	13-M	12-A	12-C	12-D
Heat transfer................ ....B.t.u./sq.ft./hr.	2,100	2,300	2,300	3,200	3,300	3,200	4,400	4,300	4,200
H_2/CO ratio of gas...........	4.84	3.57	3.99	2.75	5.59	3.77	1.85	2.30	2.29
Lignite feed rate.....lb./hr.	389	359	404	500	343	451	481	445	489
Carbon gasified...... percent	75.0	68.4	67.2	69.4	86.6	77.5	65.3	76.1	76.0
Product gas.....M cu. ft./hr.	10.2	8.5	9.2	11.7	10.6	11.7	14.0	14.6	16.4

[1] Files: Bureau of Mines, Grand Forks, N. Dak.
[2] Experiments made with steam-dried lignite.

Representative analyses of Dakota Star lignite charged to gasifier

	Natural lignite		Steam-dried lignite	
Analysis, percent	As received	Moisture free	As received	Moisture free
Proximate:				
Moisture	34.2		13.3	
Volatile matter	28.5	43.3	38.3	44.2
Fixed carbon	30.5	46.3	41.3	47.7
Ash	6.8	10.4	7.1	8.1
Ultimate:				
Hydrogen	6.7	4.3	5.8	4.3
Carbon	42.6	64.8	56.7	65.7
Nitrogen	.6	.9	.7	.9
Oxygen	42.4	18.3	28.6	19.6
Sulfur	.9	1.3	1.2	1.4
Ash	6.8	10.4	7.0	8.1
B.t.u./lb.	7,160	10,880	9,570	11,030

Externally Heated Retort for Pulverized Coal, Battelle Memorial Institute

Experimental work utilizing external heating with pulverized lignite has been completed at the Battelle Memorial Institute at Columbus, Ohio (16).

In this process, gasification was carried out in a vertical steel reaction tube, which was heated over the greater part of its length by a surrounding gas-heated furnace. The pulverized coal was fed at the top of this reaction tube, and the products of gasification were withdrawn from the bottom. Two reactor tubes were used at different times during the experiments - one a 5-inch-i.d. tube of 25-12 chromium-nickel alloy, and the other a 8.25-inch-i.d. tube of 25-12 chromium-nickel alloy. Both tubes were 11 feet long and were heated over a length of approximately 9 feet. Pulverized coal was fed from a rotary table feeder through an adapter incorporating a venturi section, steam being admitted at the venturi throat.

Gasification occurred along the tube length, and the solids entrained in the gas stream were removed by gas baffles in the ash receiver. The gases then were scrubbed.

The lignite utilized in the tests was subjected to some type of drying, and in the article (16) it was stated that the gasification characteristics were affected appreciably by the drying methods. Activity of lignite dried at 220° F., as determined in terms of a calculated gasification constant, was over 25 percent less than for lignite dried in air at 100° F., or for steam-dried lignite.

Data covering the analysis of the fuel used and the results of the gasification are presented in table 35 (16).

TABLE 35. - Operating data for the Battelle externally heated gasifier

Run No.	39	45	49
Tube diameter ... ft.	0.407	0.687	0.687
Tube temperature ... °F.	2,098	2,047	2,025
Lignite feed rate ... lb./hr.	16.0	21.8	49.4
Steam rate ... do.	21.6	26.0	50.2
Excess steam ... percent	58	39	18
Gas produced ... cu. ft./hr. at standard conditions	552	793	1,264
Gas composition, percent:			
CO_2	9.4	7.8	10.8
O_2	1.5	.7	.7
CO	31.5	33.8	29.3
CH_4	3.2	3.7	5.4
H_2	50.2	49.6	48.9
N_2 1/	4.2	4.4	4.9
Gross heating value ... B.t.u./cu.ft.	297	308	308
Gas temperature at tube exit ... °F.	-	-	1,602

1/ Presumed to be present because of air leak in apparatus.

Lignite analysis: Air-dried at 220° F. to 11.5 percent moisture

Proximate analysis, percent:	
Moisture	11.5
Volatile matter	38.0
Fixed carbon	43.8
Ash	6.7
Total	100.0

Ultimate analysis, percent:	
Carbon	57.2
Hydrogen	5.1
Oxygen	29.7
Nitrogen	.9
Sulfur	.4
Ash	6.7
Total	100.0

Heating value, B.t.u./lb. 9,540

The heat transfer of the Battelle externally heated unit has been calculated from the data presented in table 35. It appears that the heat-transfer rates attained with the Battelle gasifier are comparable, with a maximum of 4,500 B.t.u. and a minimum of 3,200 B.t.u. per square foot per hour, to those attained with the Grand Forks externally heated retort.

For translation of this process to a commercial scale, it was proposed that a number of tubes of approximately the same diameter and 27 feet long be placed in a common furnace heated by pulverized fuel. However, the calculations made regarding the practicability of the process resulted in the conclusion that the investment cost would be unfavorable, and no further studies were made.

Koppers Pulverized-Fuel Process

The Koppers pulverized-fuel process was originated in Germany on the pilot-plant scale but had not been used commercially before the end of World War II.

A diagram of a typical Koppers unit is shown in figure 20 (21).

Basically, the unit consists of two facing nozzles set at opposite ends of a generator. Oxygen and fuel are fed through the nozzles, and superheated steam enters around each nozzle. The two nozzle streams upon meeting cause turbulence, and fuel-O_2-steam reaction is reasonably complete in the area between the nozzles. The remainder of the reaction occurs in the vertical cylinder leading to the gas outlet above the unit. The larger ash particles, not carried off by the gas stream, fall into ash collectors at the bottom of the reactor.

A unit built for experimental work at Louisiana, Mo., (3, 4) has a generator space 6-1/2 feet i.d. and 9 feet long. Considerable mechanical difficulty has been encountered in operating this particular unit, as well as difficulty in reaching the anticipated operating efficiency. Although the unit was not operated on lignite, some data are presented in table 36 (19) on a low-rank coal from Rock Springs, Wyo.

Bureau of Mines Atmospheric-Pressure Gasifier, Morgantown, W. Va.

The atmospheric-pressure gasifier at Morgantown, designed and built in cooperation with the Babcock & Wilcox Co., was completed in 1951. Information regarding this unit is available in several Bureau of Mines reports (5, 6, 29). Several changes in design have been made in the course of experimental work. The most recent arrangement is shown in figure 21. The gasifier is a vertical, cylindrical column lined with refractory materials. It is divided by restricting refractory material into two zones, with the primary reaction zone at the bottom and the secondary reaction zone above. The refractory lining in the primary zone is protected by cooling coils, which also are used to support the upper brickwork at the point of restriction. Pulverized coal, preheated to about 325° F. in a steam-coil heater, is intimately mixed with oxygen and steam in a reactant injection nozzle to secure turbulence. These nozzles are placed to direct the coal, oxygen, and steam into the reaction chamber at an angle 32° from the vertical and tangential to a circle of 12 inches diameter. A small percentage of the gas made 10 to 15 percent passes downward through the slag throat and insures a flow of slag. Approximately 40 percent of the coal ash is removed as slag and contains little or no carbon.

The major portion of the product gas is removed at the top, after passing through the secondary reaction and gas-cooling zones. The remainder of the ash is entrained with this gas as a finely divided residue containing approximately 60 percent carbon. Although this unit has been described as a slagging type, it also has been operated satisfactorily under nonslagging conditions. The carbon accompanying the ash has not caused difficulty, and no deposits formed on the cooling surfaces.

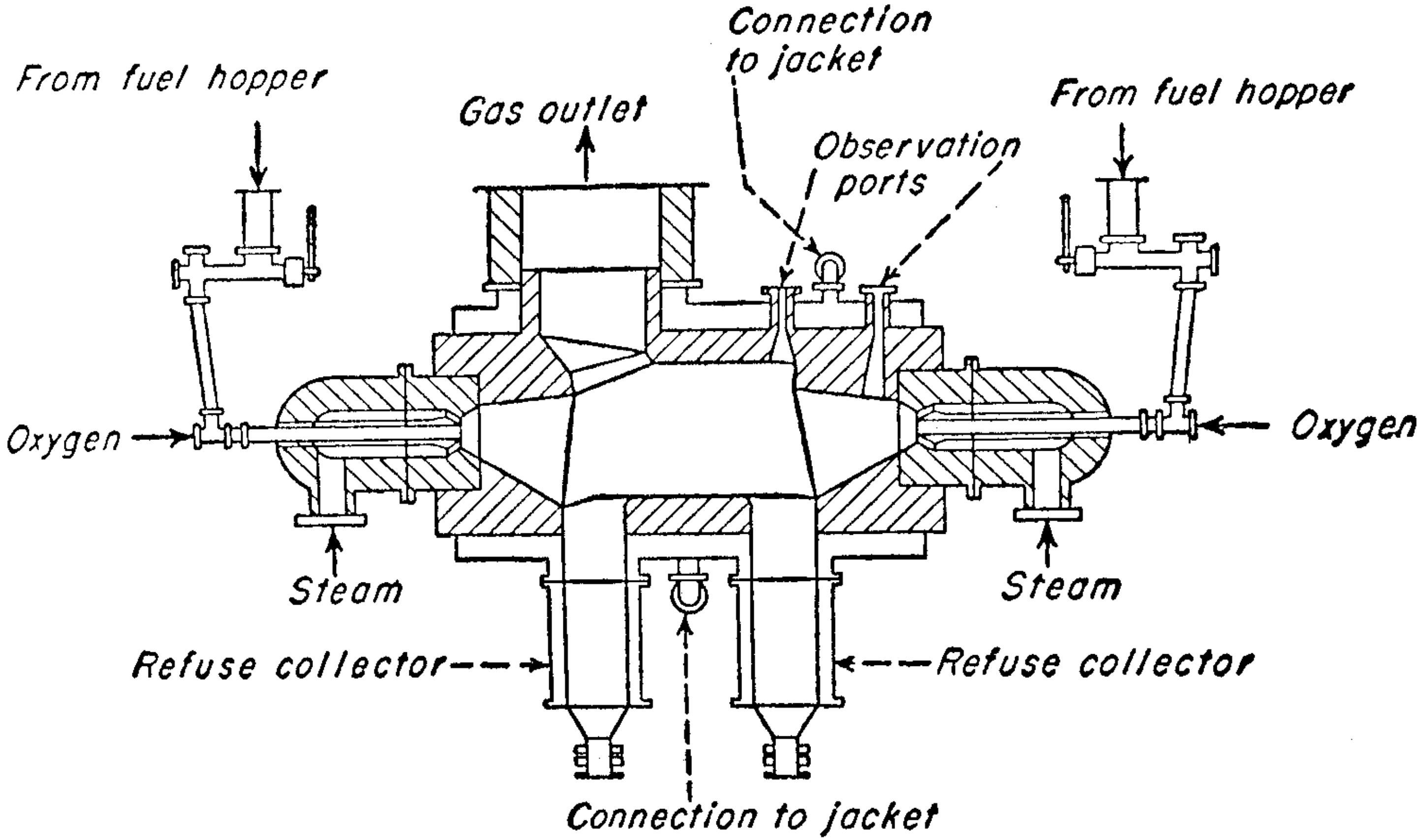

Figure 20. - Koppers pulverized atmospheric gasifier. See reference (22) in section 3.
(By permission of Industrial and Engineering Chemistry)

TABLE 36. - Typical performance data for Koppers gasifier, Bureau of Mines, Louisiana, Mo.

Rock Springs, Wyo., coal (typical analysis given below)		
Steam temperature	°F.	1,700
Gasification temperature	do.	2,480
Feed rates:		
Raw coal	lb./hr.	2,297
Oxygen - 95% pure	std. cu. ft./hr.	21,600
Steam	lb./hr.	1,800
Oxygen (100%) to dry coal ratio,	std. cu. ft./lb.	9.0
Steam to dry coal ratio	lb./lb.	0.8
Steam decomposed	percent	16
Products:		
Total gas	std. cu. ft./hr.	72,500
(H_2 + CO)	do.	59,240
Dry coal	lb./M std. cu. ft. of (H_2+CO)	38.8
Oxygen	std. cu. ft./M std. cu. ft. of (H_2+CO)	349
Steam	lb./M std. cu. ft. of (H_2+CO)	30.4
Carbon gasified	percent	83.4

Typical analysis of Rock Springs, Wyo., coal (moisture-free basis)

Proximate, percent			Ultimate, percent					
Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	B.t.u.
41.6	51.8	6.6	4.8	72.8	1.5	13.2	1.1	12,960

Approximate moisture of raw coal, 10 to 14 weight-percent.

Recent data on operation of the Morgantown, W. Va., atmospheric gasifier charging a subbituminous C coal from Lake De Smet, Wyo., are shown in table 37. This coal is the lowest-rank coal gasified to date in the Morgantown unit and is only slightly higher in rank than lignite.

Recent announcements (10, 22) have reported that the Du Pont Corp., in cooperation with Babcock & Wilcox, has developed a very large pilot plant for the production of synthesis gas at their Belle, W. Va., works. It appears, from the information released, that many of its features parallel the design of the Morgantown, W. Va., atmospheric gasifier.

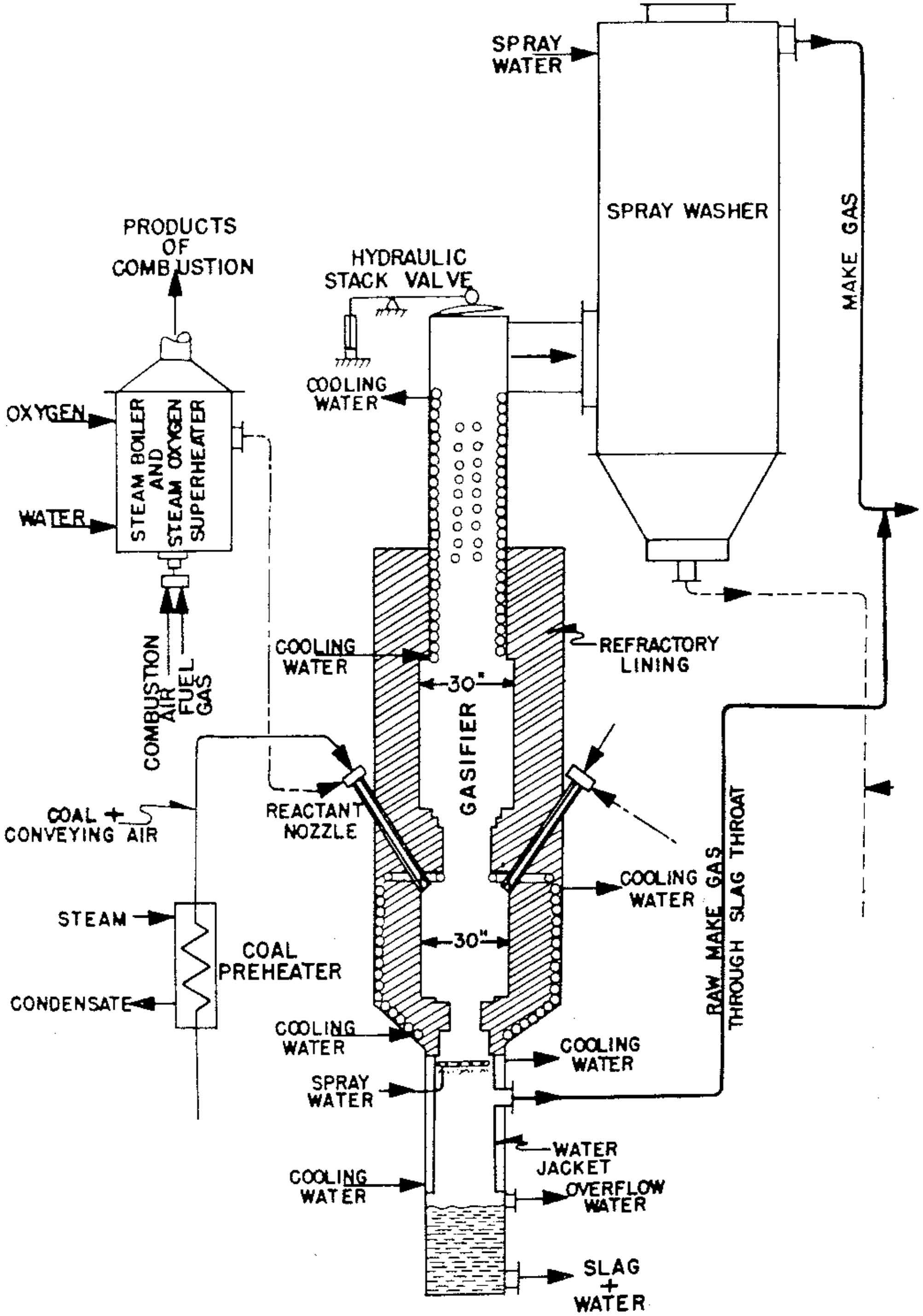

Figure 21. - Bureau of Mines pulverized atmospheric gasifier, Morgantown, W. Va.

TABLE 37. - Results using Morgantown atmospheric-pressure gasifier with dried subbituminous C Lake de Smet coal[1]

Run No.	Coal rate, lb./hr.	Process steam, lb./lb. raw coal	Process oxygen, std. cu. ft./lb. coal	Carbon in coal gasified, percent	Material requirements/M std.cu. ft. of (CO + H_2)			Ash in slag at slag tap, percent of ash input	Ash in carbonaceous residue out top of gasifier, percent of ash input
					Coal, as charged, lb.	Process oxygen, std. cu. ft.	Process steam, lb.		
52A	531	0.12	8.58	98.5	45.3	389	5.5	73.2	32.7
52C	531	.12	7.51	94.2	43.8	329	5.4	19.6	49.7
52B	531	.12	6.95	93.1	43.2	300	5.3	2.9	54.2
53A	500	.13	9.17	95.4	45.2	414	5.9	67.3	27.0
53B	500	.13	7.98	99.4	40.9	326	5.3	12.9	40.0
53C	500	.13	6.98	96.5	41.8	292	5.4	17.4	63.8
54A	545	.073	7.71	96.2	42.7	329	3.1	23.3	56.3
54B	545	.073	6.29	86.7	45.9	289	3.4	.3	55.4
54C	545	.073	5.91	83.2	48.8	288	3.6	.3	71.7
54D	545	.073	5.49	78.8	51.9	285	3.8	.0	62.3
54E	545	.073	4.95	72.0	58.5	290	4.3	2.7	77.7
54J	613	.065	7.81	98.0	42.7	334	2.8	86.2	26.2
54I	613	.065	7.41	96.4	41.8	310	2.7	43.8	48.5
54H	613	.065	6.88	92.1	44.7	308	2.9	26.2	58.7
54G	613	.065	6.39	88.5	47.6	305	3.1	11.5	56.8
54F	613	.065	5.82	82.6	49.6	289	3.2	.5	60.0

Average analysis of Lake de Smet coal as charged in above experiments:

	Ultimate analysis, percent							B.t.u./lb.	
Run No.	Moisture	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Ash	Gross	Net
54	10.1	4.3	56.9	1.1	15.8	0.7	11.1	9,785	9,285
52, 53	7.6	4.1	58.5	1.2	16.2	.9	11.5	9,935	9,474

[1] Unpublished data, Morgantown, W. Va.

Bureau of Mines Pressure Gasifier, Morgantown, W. Va.

A pressure gasifier operating on powdered coal at 30 atmospheres pressure has been developed at the Morgantown, W. Va., station of the Bureau of Mines. A sketch of the gasification unit is shown in figure 22. In this process coal is pulverized to 70 percent through a 200-mesh screen. It is conveyed by a fluidized coal feeder to the gasifier. The gasifier has an overall length of 12 feet and is 30 inches i.d. A water coil is used to cool the outside metal walls of the pressure vessel over most of the length of the gasifier. The gasification section, which occupies the upper 3 feet 10 inches of the vertical cylinder, is refractory lined. This section is 8 inches i.d. Below the gasification section a spray ring is installed through which pass the products of gasification, and the bottom of the unit forms a water-filled slag pot. Steam for the unit is heated to 1,000° F. before being injected, but the oxygen is not preheated. Coal, steam, and oxygen are mixed in a special burner, which creates a high degree of turbulence in the entering reactants. This nozzle is set axially at the top of the gasifier tube. The gasification products and the slag formed flow down out of the gasification section and pass through the water spray ring. Gas is withdrawn just below this ring, and the slag, broken into fragments by water quenching, falls into the slag pot.

Development on this unit has been described in various publications (3, 5, 6, 19, 30). After certain operating difficulties in the original equipment have been solved, the general operation has proceeded smoothly. In a recent report (30) it was stated that the expected heat loss through the gasifier wall will be low in commercial-scale models because of the reduced surface-to-volume ratio in larger units. Thus it might be possible to use water-cooled refractory walls or possibly bare water-cooled interior walls. Such a procedure would be attractive economically with respect to cost of maintenance of these surfaces.

In table 38 operating data are presented for the Morgantown, W. Va., pressure gasifier in comparison with the atmospheric-pressure gasifier at the same station. The effect of pressure on the gasification process within the range 100-450 p.s.i.g. is shown.

Lurgi Pressure-Gasification Process

In the Lurgi process, the use of high pressure and oxygen are combined with a fixed bed of lump fuel and dry removal of the ash. This is one of the oldest satisfactory synthesis-gas producers in operation today. Commercial-size units have been installed in Germany since 1936.

The standard Lurgi generator, as installed in Germany, was approximately 22.3 feet tall, 10 feet o.d., and 9 feet i.d. Sketch of a typical Lurgi unit is presented in figure 23 (21). The outer shell was water cooled with a water jacket, and the inside wall was protected by a brick lining down to within 3 feet of the rotating grate, which supports the fuel bed. The lining was installed primarily to prevent generation of excessive amounts of steam in the jacket. The generator was operated at approximately 20 atmospheres pressure. Fuel was fed periodically to a coal lock hopper device from which the generator could be fed continuously. A gas disengaging space at the top of the generator was kept free of fuel with a skirt, which provided a base for a mechanical scraper to remove accumulations of pitch and carbon.

TABLE 38. - Comparative typical results of Morgantown pressure and atmospheric gasifiers

	Pressure gasifier				Atmospheric pressure			
Run No.	14	17	23	30	21	31	29	18
Gasifier pressure...p.s.i.g.	100	250	300	450	atmos.	atmos.	atmos.	atmos.
Duration of run...hr.	10.0	7.2	5.2	4.0	7.00	6.50	10.75	2.50
Raw coal rate...lb./hr.	463	588	869	1,120	355	407	514	598
Process steam inlet temperature...°F.	931	1,132	660	627	618	563	572	594
Process-oxygen inlet temperature...do.	60	58	660	627	618	563	572	594
Coal inlet temperature...do.	327	310	315	246	300	304	285	287
Oxygen input per pound coal...std. cu. ft.	9.22	9.35	8.83	9.84	9.05	8.33	8.28	7.83
Steam input per pound coal...lb.	0.30	0.28	0.28	0.33	0.79	0.39	0.43	0.56
Product gas analysis (corrected for inert gas introduced with coal in both cases and at gasifier sight glass in the case of pressure gasifier), percent:								
CO_2...	7.1	7.9	8.5	10.4	17.4	12.7	13.0	14.5
Illuminants...	.5	.7	.6	.5	.4	.5	.7	.4
H_2...	34.4	33.9	34.4	32.9	39.5	36.5	37.4	39.1
CO...	55.4	54.9	53.6	53.4	40.5	49.1	47.7	42.6
CH_4...	.4	.5	.6	.7	.4	.4	.4	.5
(H_2 + CO)...std. cu. ft./hr.	12,870	16,120	23,160	31,180	9,060	10,480	12,570	13,720
Total carbon gasified...percent	87.8	87.9	87.4	92.4	84.6	83.4	80.2	73.0
Coal required per M cu. ft. (H_2 + CO)...lb.	36.0	36.5	37.5	35.9	39.2	38.8	41.0	43.6
Oxygen required per M cu. ft. (H_2 + CO).std. cu. ft.	333	341	331	352	355	323	340	341
Process steam input per M cu. ft. (H_2 + CO)...lb.	10.9	10.2	10.5	11.8	30.9	15.3	17.6	24.3
Coal throughput/(hr.) (cu. ft. volume)...do.	117	409	583	757	8.1	9.3	12.8	13.5

The tests listed above were run on the same coal (Sewickley-bed coal from Monongalia County, W. Va.).

A typical analysis, not from a specific sample, of this coal is as follows:

Coal analysis, as-fired basis, percent

Proximate	
Moisture...	1.5
Volatile matter...	34.5
Fixed carbon...	50.5
Ash...	13.5

Ultimate	
H_2...	5.0
C...	70.0
N_2...	1.5
O_2...	7.5
S...	2.5
Ash...	13.5

Calorific value, B.t.u./lb.	
Gross...	12,610
Net...	12,120

Ash fusibility	Temperature, °F.
Initial deformation...	2,171
Softening...	2,248
Fluid...	2,329

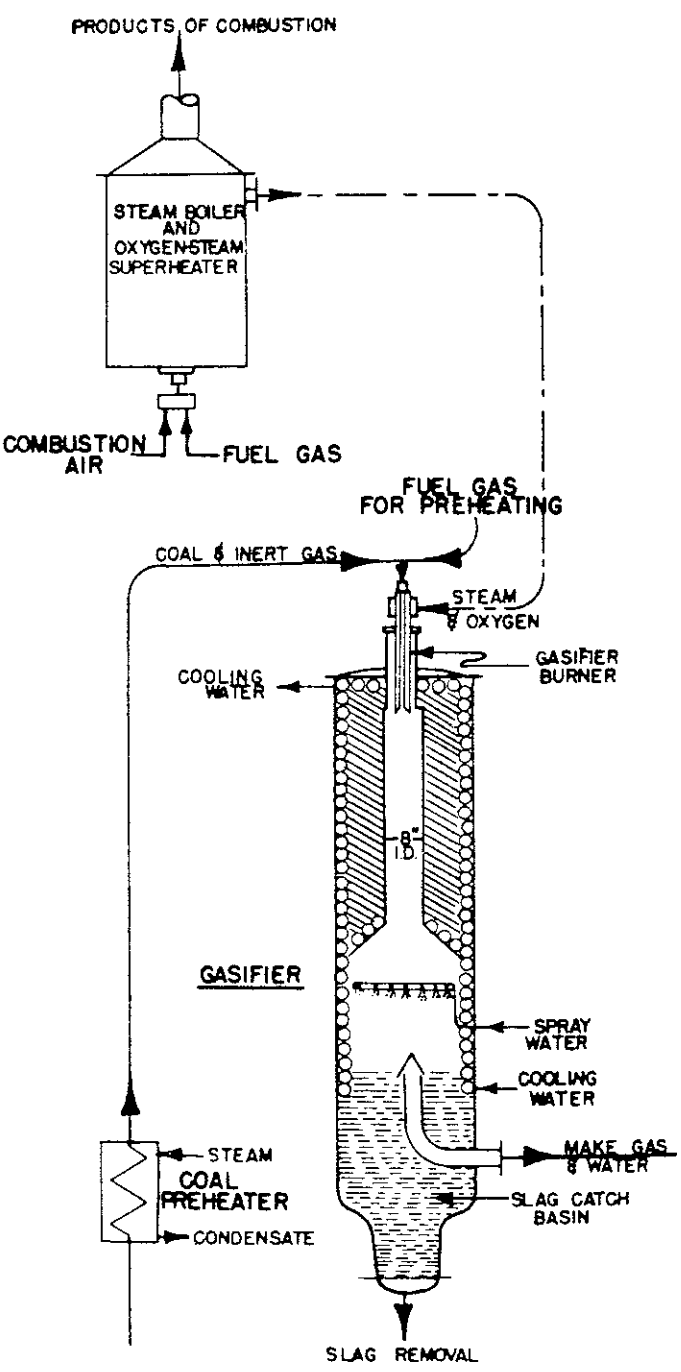

Figure 22. - Bureau of Mines pulverized pressure gasifier, Morgantown, W. Va.

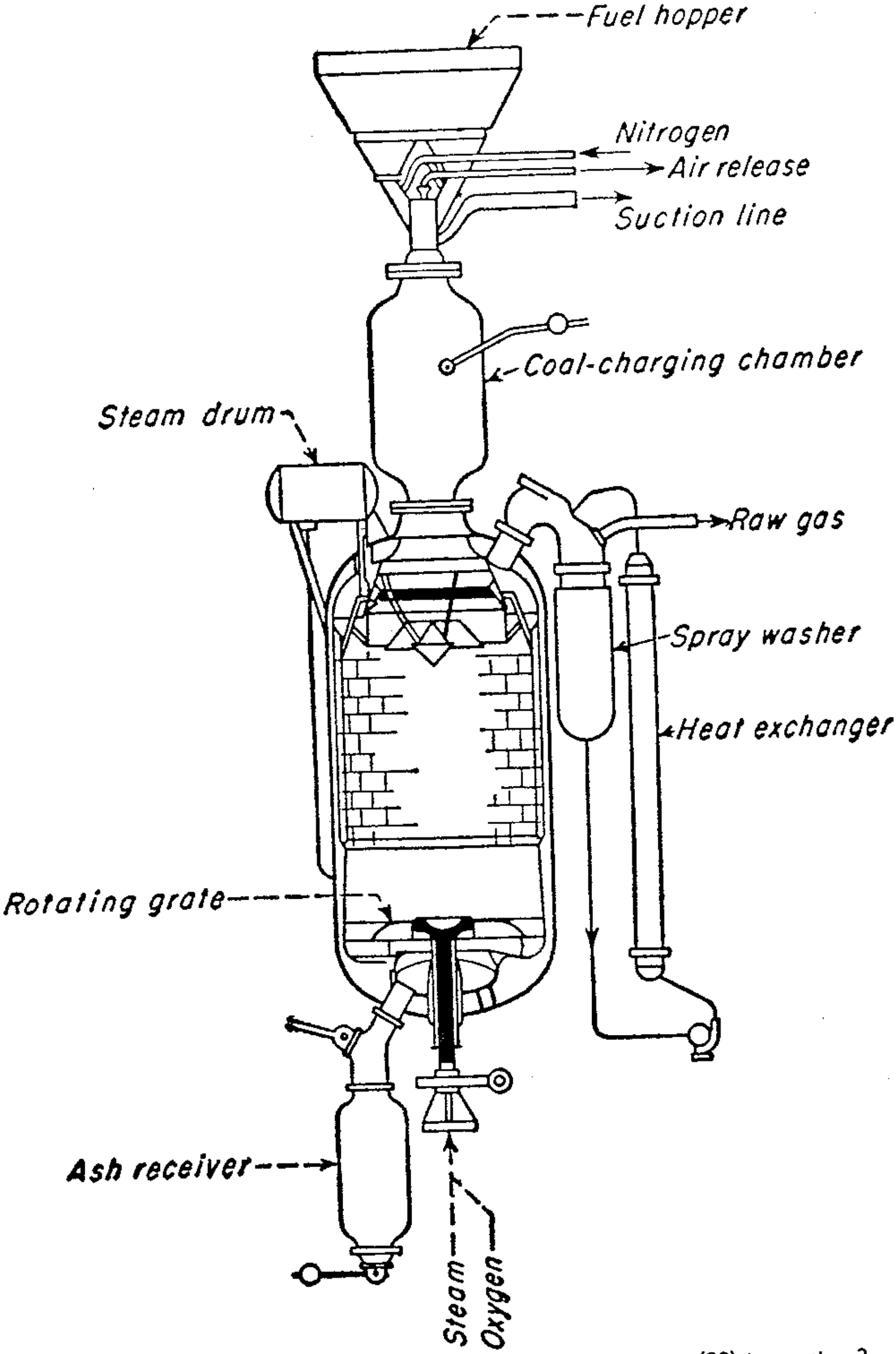

Figure 23. - Lurgi fixed bed pressure gasifier. See reference (22) in section 3.
(By permission of Industrial and Engineering Chemistry)

A rotating grate with attached plows was used to remove the ash from the fuel bed continuously and discharge it to an ash receiver below. Steam and oxygen were admitted through the hollow grate shaft into the reaction zone. Since the ash was removed dry, it was necessary to maintain a temperature below the ash-fusion temperature in the fuel bed. In the German plants the practice was to maintain the bed temperature below 2,100° F. The German brown coal being used had an ash-softening temperature of 2,400° to 2,700° F. (21).

Several things about the Lurgi unit are distinctive to the process. It is one of the few pressure units in which lump coal is utilized as a feed. In addition, the gas produced contains a reasonably large percentage of methane. This is not always an advantage; methane may be worthwhile to increase the gas heating value but is not desirable for most synthesis requirements; however, it is a definite advantage if high-B.t.u. gas is desired for utility distribution.

The Bureau of Mines has carried out some work at Pittsburgh on gasification of char from higher rank coals in a small experimental Lurgi generator, 13.5 inch i.d. (13). High gasmaking capacities were obtained in this unit, up to 7,250 cubic feet per square foot of grate area per hour, compared to rates in the range of 2,000 cubic feet per square foot per hour in conventional German practice. Methane content of the product gas was lower than in conventional German practice. It is suggested that methane content could be increased, if desired, by increasing bed height. The total height of the experimental generator was only 5.5 feet, versus 22.3 feet total height for the conventional Lurgi unit.

Typical operating data for gasification of char in the Bureau of Mines experimental unit are presented in table 39 (13).

Texaco Pressure-Gasification Process

In the Texas Co. coal-gasification pilot plant at Montebello, Calif., work has been in progress using a pulverized coal slurry for the base feed, oxygen for internal heating, and pressure (15). A process flowsheet is shown in figure 24.

The fuel is prepared by grinding it in a wet mill and mixing it with water in a conventional thickener to a ratio of 40 to 60 percent coal. This ratio depends on the particle size and density of the coal. From the thickener, the slurry is pumped through a heater under several hundred pounds pressure and raised to approximately 1,000° F. The heated mixture of steam and coal enters the top of the reaction chamber either axially or at a tangential angle near the top of the chamber. Oxygen, which may or may not be heated, enters the chamber near the feed nozzle but in such a manner as not to impinge upon the side of the reaction vessel. The amount of steam entering the process is regulated by installing a cyclone separator or settling drum after the preheater and withdrawing any excess. The temperature within the vertical cylindrical reactor is sufficient to liquefy the ash. The molten ash flows through a restricted opening below the reactor and falls into a reservoir of cold water. The resultant thermal shock disintegrates the particles, and they are removed as a finely divided solid suspended in the water. The gas is run through a waste-heat boiler to recover the sensible heat. It is reported that the complete range of coals from lignite to anthracite has been used, with a percentage gasification up to 95 percent. However, up to the present, detailed data on operation of this pilot plant have not been published.

TABLE 39. - Test results of Lurgi pilot generator, Bureau of Mines, Pittsburgh, Pa.

Test No.	85A	85B	86	90	91	91a	91b	92
Fuel:								
Kind	Char	Char	Char	Char	Char	Char	Char	1/Char
Rate ... lb./hr.	98	110	114	146	98	98	98	177
Steam:								
Lb./hr.	203	240	241	352	261	261	261	499
Lb./100 lb. fuel	212	229	211	241	267	267	267	282
Lb./1,000 cu. ft. gas	54	54	55	59	65	65	65	79
Oxygen ... cu. ft./M cu. ft. (CO + H_2)	256	236	235	226	228	234	233	208
Steam decomposition ... percent	38.3	39.6	41.9	40.2	35.8	35.8	35.8	33.6
Gas production of generator area:								
Cu. ft./sq. ft.	3,740	4,411	4,401	6,017	4,029	4,029	4,029	7,246
Cu. ft./ton of fuel	78,300	80,100	79,200	83,600	82,500	82,500	82,500	82,100
Gas analysis, percent:								
CO_2	26.8	26.8	26.8	28.6	28.3	29.0	27.7	29.2
Illuminants	.5	.4	.5	.1	.4	.4	.2	.2
H_2S	.4	.4	.4	.2	.2	.2	.2	.2
O_2				.3	.4	.4	.4	.2
H_2	41.1	41.2	41.4	40.2	39.5	39.8	40.1	41.4
CO	20.5	21.4	19.8	20.1	20.3	18.2	18.4	19.8
CH_4	8.7	7.9	9.0	7.1	8.6	9.3	8.4	6.4
C_2H_6	1.3	1.1	1.3	1.0	0.4	0.6	1.4	0.7
N_2	0.7	0.8	1.0	2.4	1.9	2.1	3.2	1.9
Ratio, H_2:CO	2.0	1.9	2.09	2.0	1.95	2.19	2.18	2.09
Calorific value:								
Raw gas	321	311	320	289	295	300	304	281
Washed to 2.5 percent CO_2	432	419	425	393	402	412	409	386
Superheater temperature ... °C.	212	212	315	360	404	404	404	420
Gasification pressure ... p.s.i.	300	300	300	300	300	375	405	300

The fuel used in the above test was char resulting from the carbonization of Pittsburgh seam coal (West Virginia), Jamison mine, No. 368. The proximate analysis of the char is as follows:

Volatile matter.. 20.9 percent Fixed carbon..... 68.4 percent Ash.... 10.7 percent

1/ Char sized 3/4 by 1/8 inch.

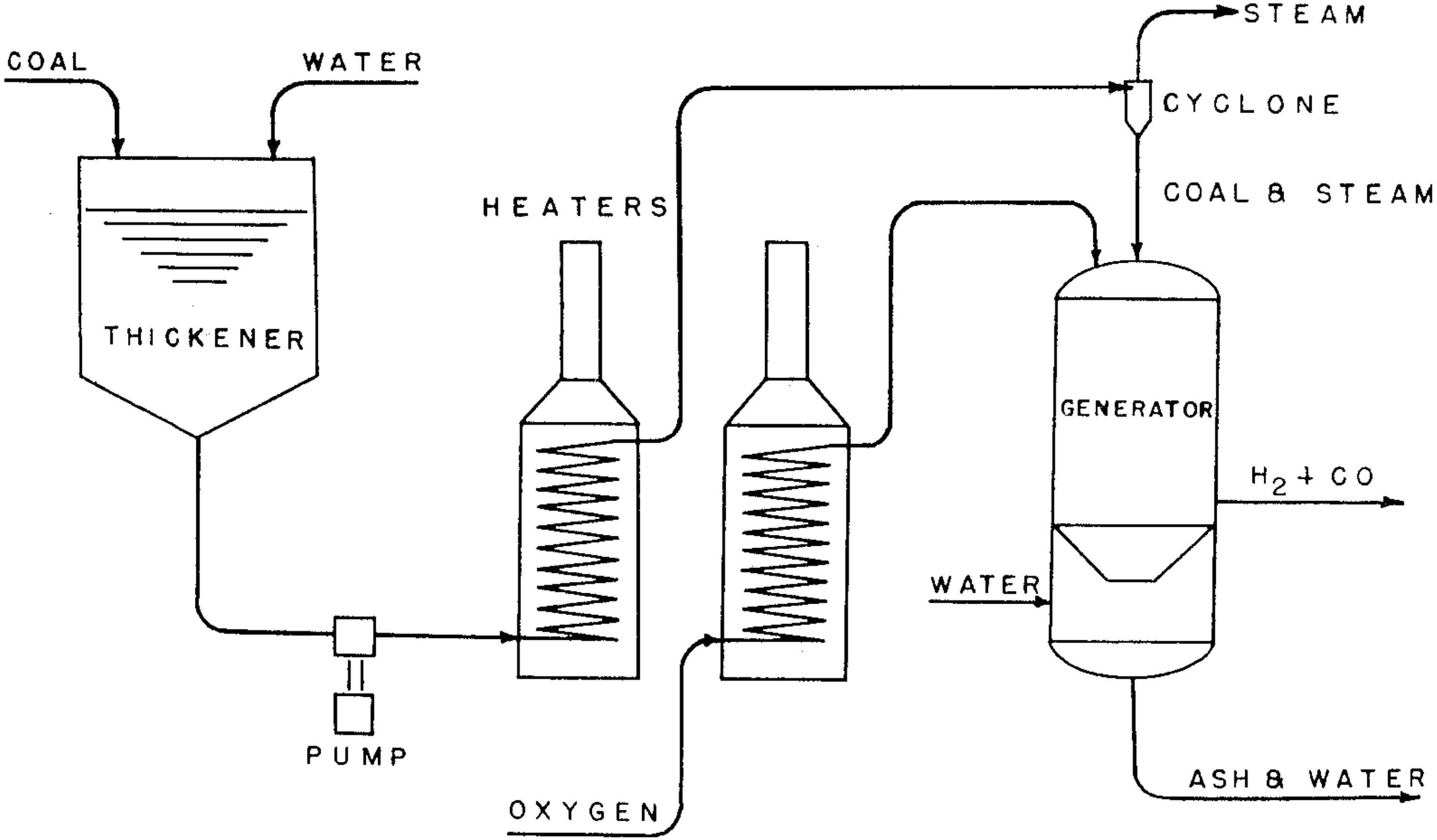

Figure 24. - Texas Co. pulverized pressure gasifier. See reference (16) in section 3.
(By permission of Am. Inst. Min. Met. Eng.)

General Discussion of Operating Features

Before the individual gasification processes are summarized, it may be worthwhile to point out that there are general advantages and disadvantages, which are true of the majority of the processes utilizing various operation design features. The following pages summarize the main advantages and disadvantages of these features without distinction as to any individual gasification process. It should be kept in mind that any specific advantage or disadvantage may not apply to a particular process that falls in a group but generally is true of the group as a whole.

Pulverized Coal

1. Versatility. Gasification of pulverized coal, where the fuel is gasified while suspended, is more readily adaptable to both caking and noncaking coals than is gasification of lump fuel in fixed beds.

2. Contact time. The contact time required in pulverized operation is normally very short because of a large surface area available for reaction.

3. Slurry operation. Pulverized coal in slurry has the distinct advantage of simplifying the charging of the coal to the gasifier continuously while under higher pressures. Charging lump fuel against high pressure is more difficult.

4. Cost of pulverizing. Gasification of coarse-size coals requires only the breaking and sizing of comparatively large fractions of the coal. Gasification of pulverized coal requires finely divided coal, which adds to gasification cost.

5. Ash in gas. A larger percentage of the ash is carried by the gas stream in pulverized processes than in processes having coarse fuels in fixed beds. This complicates the problem of securing clean gases.

6. Countercurrent versus concurrent flow. In most pulverized-coal gasification systems the gas and coal particle move concurrently. This has the effect of removing the particle from the reaction space after a very short contact time and, since the two move at approximately the same rate of speed, of reducing any scrubbing action of the gas on the surface of the coal particle. Since the gas leaves the process at a high temperature in pulverized systems, the heat economy associated with countercurrent flow of product and reactants is not present inherently in this type of operation. In concurrent flow, the concentration of the reactants, carbon and steam, decreases continuously toward the gas outlet. For this reason complete conversion of the carbon may be difficult to achieve in units of economically feasible size.

7. Refractory service. When pulverized coal is used with internal heating, the high heat-release rates have created problems in maintaining the surrounding refractory walls.

Pressure Gasification

1. Capacity. Higher pressures increase the rate of throughput per unit volume while maintaining a high rate of gasification.

2. Many of the synthesis uses to which the product gas can be put, such as the manufacture of synthetic fuels, require gas at elevated pressures. In this case, no further compression of the gas is required (18).

3. Scrubbing. For some purposes, it is possible in pressure operation to remove enough of the attendant CO_2 and H_2S by water scrubbing. The following table lists gas composition before and after scrubbing at 20 atmospheres (20, p. 1631).

	Gas analysis, percent	
	Before scrubbing	After scrubbing
$CO_2 + H_2S$	30.6	3.0
Illuminants	.6	.5
O_2	.1	.1
CO	16.5	22.8
H_2	34.0	48.7
CH_4	16.3	22.6
N_2	1.9	2.3

4. Design. The use of pressure requires reaction vessels and piping of heavy construction. This complicates the design of pressure-gasification equipment.

Internal and External Heating

1. Heat availability. In an internally heated unit, intimate contact between the source of the heat and the reactants allows uniform and rapid assimilation of the heat. In the externally heated unit, the heat is supplied through a wall, which means that only a portion of the reactants are in direct contact with the heat source at any particular moment. Therefore, higher capacities per unit volume are possible with internal heating.

2. Heat loss. Externally heated units are subject to heat loss from the comparatively large exposed surfaces. In internally heated pulverized gasification, the advantage of low external losses is offset by the high temperatures of the product gas, which must be utilized to provide good thermal efficiencies.

3. Heat source. External heating makes it possible to use cheaper fuels for heating in the form of producer gas, products of combustion, or other similar low-cost source of supply, since there is no contact of the heating gas and the product gas. In internal heating, a supply of reasonably pure oxygen is needed to eliminate nitrogen dilution. The cost of oxygen may be a significant item in the cost of gas produced by internal heating methods.

4. Preheated gases or preheated steam. To avoid using oxygen, preheated gases and steam have been used for internal heating. This requires the use of either large volumes of gas or steam or very high temperatures that are difficult and expensive to secure.

The figures presented in table 40 indicate the relative oxygen and steam requirements for the various processes and the relative capacities of the units. Not all of the gasification units were operating at maximum capacity at the time these tests were made. However, the figures are indicative of the order of magnitude and are useful for comparison.

TABLE 40. - Capacity figures for various gasification processes[1]

Type	Fuel tested	Capacity			Oxygen used	Oxygen required cu. ft. /M cu.ft. (H_2+CO)	Pressure p.s.i.g.	Carbon gasified percent	Steam added, lb/M cu. ft.(H_2+CO)
		Cu. ft. (H_2+CO)/hr.	Cu. ft. (H_2+CO)/(Sq. ft. grate area)(hr.)	Cu. ft. (H_2+CO)/(cu. ft. reaction space)(hr.)					
Grand Forks, externally heated	Dried lignite, lump	13,400	-	260	No	None	Atmos.	79	35
Battelle, externally heated	Dried lignite, pulverized	450-980	-	135-300	No	do.	do.	65-80	40-50
Koppers	Subbituminous, pulverized	59,250	-	200	Yes	350	do.	83.5	30
Morgantown atmospheric	Bituminous, pulverized	13,000	-	395	Yes	320-350	do.	73-85	15-30
	Subbituminous, pulverized	14,500	-	440	Yes	270-400	do.	76-97	
Morgantown pressure	Bituminous, pulverized	31,000	-	21,000	Yes	330-350	450	90	10-12
Lurgi	Bituminous, char, lump	4,200-5,400	4,200-5,400	780-1,000	Yes	200-255	300-400	-	90-130

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[1] These figures are from data presented in this section for experimental units. They are not necessarily representative of maximum production or optimum conditions.

Many of the data presented in table 40 have been based on the use of higher rank coals because of the lack of specific information on use of lignite in these particular processes. Lignite could be used in all the processes, however, and in some instances would have a considerable advantage. The noncoking, low-rank coals have a specific advantage for use in fixed-bed gasification, the process providing maximum heat economy and lowest oxygen requirement. For fixed-bed pressure gasification, pretreatment would be required before coals having even slight coking tendency could be used. In slagging processes, the relatively low ash fusion temperature of North Dakota lignite would lower the operating-temperature level required to keep slag molten and reduce difficulties attendant on high-temperature operation. Data for fine-particle gasification of low-rank coal, close to lignite in rank, indicate that gasification capacities equal to or higher than those for higher rank coals can be obtained with comparable oxygen requirement.[2]

Steam Requirements

As would be anticipated, the lowest steam requirements in pound per 1,000 cubic feet H_2 + CO are realized in the pulverized, and particularly in the pulverized-plus-pressure gasification processes where steam requirements run from 12 to 30 pounds. The externally heated units run somewhat higher than this, at 30 to 45 pounds, and the highest demands are made by the Lurgi process. In the Lurgi process, one of the main functions of the steam is to reduce the temperature of the fuel bed to maintain it below the fusion point of the ash.

Oxygen Requirements

In oxygen requirements, the reverse of steam consumption is true, with the Lurgi process using considerably less oxygen than any of the other processes employing oxygen. Since the cost of the oxygen may be a large increment in the cost of the gas, this is a very important consideration. For example, the lack of oxygen requirements is an advantage of the externally heated retort.

Capacities

The capacity figures list a wide range of capacities per unit of reaction space. These may be grouped as follows: (1) Gasifiers without oxygen and at atmospheric pressures, 150 to 300 cubic feet (H_2 + CO) per hour per cubic foot reaction space; (2) Lurgi gasifier with coarse fuel, oxygen, and pressure, 780 to 1,000 cubic feet; and (3) Morgantown pressure gasifier with pulverized fuel, pressure, and oxygen, 21,000 cubic feet. The capacity of each process must be balanced against the relative heat economy and the cost of steam and oxygen required in its operation.

Future and Present Uses of Synthesis Gas

Synthesis gas is a mixture of hydrogen and carbon monoxide. As such it represents a midpoint from raw materials to product in a variety of chemical synthesis operations. In the past, the source of this gas has been the gasification of coke and, of late years, natural gas (31). However, as the supply of natural gas is diminished, the use of direct gasification of the coal supplies will become increasingly important (10). A. R. Powell (26) has presented a rather complete outline of the present and future uses of synthesis gases by industry. In this paper the chemical reactions to be utilized and being utilized are broken down to three groups:

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[2] Unpublished data, Morgantown, W. Va.

(1) The reaction between hydrogen and carbon monoxide with or without the addition of other reactants; (2) the reaction between hydrogen and other reactants; and (3) the reaction between carbon monoxide and other reactants. Listed among those in group (1) are the oxygenated compounds, namely the acids, ketones, alcohols, aldehydes, and esters, as well as hydrocarbons for use as synthetic liquid fuels. At the present time, the largest consumer group (2) is the synthetic ammonia industry. The use of hydrogen for ammonia synthesis, began in 1913, has steadily increased since, and promises to continue to grow in importance. Also included in this group are such uses as the hydrogenation of oils and fats to produce such items as margarine, hydrogenation of coal to produce chemicals and fuels, hydrogenation of organic chemicals and oils, and production of hydrochloric acid (14, 28). Group (3) is at present less important than the other two. However, use has been made of carbon monoxide alone in the metallurgical field, and the use of the synthesis gas in this manner is expected to increase.

Producer Gas

Producer gas is obtained by incomplete combustion of solid fuel with air, usually accompanied by simultaneous addition and partial reduction of steam. The resulting gas has a high nitrogen content and a relatively low heating value. Typical heating value is only about 150 B.t.u. per cubic foot; however, this simple and efficient process represents, in general, the cheapest available means for converting solid fuels to a fuel-gas product.

Because of its low heating value, producer gas is not suitable for utility distribution and is normally used at or near the point of production. The use of producer gas reached its peak in the United States about 40 years ago. By 1910, it was being used extensively in such fields as fuel for internal-combustion engines, in the manufacture of steel and in annealing, drying, evaporating, heating molds, brick kilns, cement kilns, and in ore-roasting furnaces. These uses have been steadily diminished because of expansion in use of competitive fuels, particularly natural gas and petroleum products.

Since producer gas is still the cheapest fuel gas that can be obtained from solid fuels, it retains some immediate and long-term importance for industrial use. In addition to conventional uses, conversion to producer gas may eventually prove to be the most practical and economical method for utilizing coal in the gas turbine as development proceeds in this field (2).

There has been no recent development on gas producers using lignite as fuel in the United States. Older data obtained by the Bureau of Mines indicate that lignite can be gasified successfully in conventional updraft gas producers, although the operating capacities achieved were relatively low (17). Typical operating data are presented in table 41.

In table 42, capacity data for German producers of conventional design, using brown coal and brown-coal briquets, are presented for comparison (1, p. 83).

Most of the more recent development work on gasification of low-rank coals to make producer gas has been carried out in Europe, where producer gas is more important economically at this time than it is in the United States. Information on these developments is reported in the section on European practice.

TABLE 41. - Performance data for updraft producers using lignite

Plant No.	4	11
Proximate analysis, percent:		
Moisture	29.20	27.21
Volatile matter	36.92	47.55
Fixed carbon	27.02	17.50
Ash	6.86	8.21
Sulfur	0.58	0.44
Heating value as fired, B.t.u./lb.	7,442	7,073
Area of grate, sq. ft.	19.6	38.5
Fuel, lb./hr.	[1] 250	[2] 570
Fuel, lb./(sq. ft.)(hr.)	12.8	14.8
Approximate gas made, cu. ft./(hr.)(sq. ft. grate area)	400	450
Depth of bed, ft.	2.0	1.5
Typical gas analysis:		
Component, percent:		
CO	21.0	
CH_4	2.2	
CO_2	12.4	
C_2H_6	0.4	
O_2	0.0	
H_2	18.5	
B.t.u./cu. ft. calc	155	

[1] Charge: 500 pounds every 2 hours.

[2] Charge: 190 pounds every 20 minutes.

TABLE 42. - Standard capacity for German producers

Fuel used	Stationary grate, natural draft, capacity, lb./(sq.ft.)(hr.)	Stationary grate, forced draft, capacity, lb./(sq.ft.)(hr.)	Rotating grate, forced draft, capacity, lb./(sq.ft.)(hr.)
Brown-coal briquets	10.2-12.3	12.3-16.4	16.4-22.6
Brown coal, as mined	16.4-20.5	22.6	32.8-36.9

Note

For briquets: 1 lb. of briquets generates 41.3 std. cu. ft. of gas, moist, at 156 B.t.u./cu. ft.

For brown coal: 1 lb. of brown coal, as mined, generates 20.7 std. cu. ft. of gas, moist, at 114 B.t.u./cu. ft.

Typical ultimate analysis of fuel, percent:

	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Brown-coal briquets	54.5	5.9	33.4	0.8	0.4	5.0
Brown coal, as mined	28.5	8.3	60.0	.4	.2	2.6

	Gross heating value, B.t.u./lb.	Moisture content, percent
Brown-coal briquets	9,200	15.0
Brown coal, as mined	4,750	55.8

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