TABLE 1. - Proximate and ultimate analyses of test anthracites

	Chestnut		Buckwheat No. 1 and Rice (mixed)	
	Dry, percent	Dry, ash-free basis, percent	Dry, percent	Dry, ash-free basis, percent
Proximate:				
Volatile	5.9	8.0	5.7	7.0
Fixed carbon	67.7	92.0	75.6	93.0
Ash	26.4	-	18.7	-
Ultimate:				
Hydrogen	2.1	2.9	2.2	2.7
Carbon	67.3	91.4	75.5	92.9
Nitrogen	.8	1.1	.8	1.0
Oxygen	2.3	3.1	1.9	2.3
Sulfur	1.1	1.5	.9	1.1
Ash	26.4	-	18.7	-
Heating value...B.t.u.	10,815	14,695	12,060	14,835

TABLE 2. - Screen analyses of test anthracites

Screen size (round holes), inches	Chestnut[1]		Buckwheat No. 1 and Rice (mixed)[2]	
	Direct, percent	Cumulative, percent	Direct, percent	Cumulative, percent
Plus-1-5/8	30.6	30.6	-	-
-1-5/8, + 13/16	68.3	98.9	-	-
-13/16, + 9/16	.5	99.4	3.2	3.2
-9/16, + 5/16	.2	99.6	60.2	63.4
-5/16, + 3/16	.1	99.7	29.2	92.6
-3/16, + 3/32	.3	100.0	5.3	97.9
-3/32, + 3/64	-	-	1.1	99.0
Minus-3/64	-	-	1.0	100.0

[1] Bulk density, 56.16 lb./cu.ft.
[2] Bulk density, 55.26 lb./cu.ft.

DISCUSSION OF RESULTS

The operating test data for the larger, higher ash coal are summarized in table 3 and for the smaller coal in table 4. In addition to the hourly arithmetic averages for each run, averages for each test were also calculated. The length of the runs was governed by the quantity of coal that could be delivered to the plant conveyor when the railroad facilities were not being used for other purposes. A period was terminated when it was estimated that only one coal charge remained in the storage hopper. The coal charged was weighed in carload lots and kept separate for each period.

Information was expected from the tests regarding the extent to which the steam:oxygen ratio might be reduced without adversely affecting the operation, as excess steam is the greatest source of inefficiency in the Lurgi process. With anthracite having high fusion-point ash, presumably less steam would be required to prevent clinkering. However, the effect of lower steam:oxygen ratios could not be studied, since, despite the experimental nature of the work, it was necessary for the producer to be maintained in normal operating condition. Tables 5 and 6 show that 51 to 60 pounds of steam was supplied to the generator per M cubic feet of raw gas produced from dry Chestnut and 53 to 56 pounds for the dry Rice-Buckwheat mixture. Decomposition of steam was 36 to 29 percent with the Chestnut coal and 38 to 35 percent with the Buckwheat-Rice mixture. As the steam:oxygen ratios were not varied extensively, the influence of this variable was not wholly determinable.

TABLE 3. - Operating data for test A[1]

Run No.	A-1	A-2	A-3	A-4	A-5	Average
Date	6/25-26	6/26-27	6/27-28	6/28-29	6/29-30	6/25-30
Duration of run hrs.	26.33	24.67	22.75	26.00	22.00	24.35
Coal (dry) lb./hr.	12,427	16,731	16,437	16,720	15,419	15,547
Coal (dry and ash-free) lb./hr.	9,041	12,191	12,006	12,187	11,221	11,329
Oxygen (100 percent pure)[2] cu. ft./hr.	72,326	82,302	83,047	79,548	80,329	79,510
High-pressure steam[3] lb./hr.	20,165	23,948	24,292	24,546	25,183	23,627
Gas (raw) cu. ft./hr.	393,532	471,963	442,370	428,672	416,611	430,629
Gas (CO_2-free) cu. ft./hr.	290,427	353,972	326,469	316,789	305,376	318,607
H_2 + CO cu. ft./hr.	262,092	320,463	294,618	285,067	277,463	287,941
Gas composition, percent:						
CO_2	26.2	25.0	26.2	26.1	26.7	26.0
C_nH_m	.3	.2	.2	.2	.2	.2
CO	26.2	27.5	26.5	25.7	25.3	26.3
H_2	40.4	40.4	40.1	40.8	41.3	40.6
CH_4	5.4	5.1	5.4	5.7	5.4	5.4
N_2	1.5	1.8	1.6	1.5	1.1	1.5
H_2S grains/100 cu. ft.	258	272	267	299	276	274
Gross heating value:						
Raw B.t.u./cu. ft.	278	276	275	278	275	276
CO_2-free Do.	376	369	373	376	376	374
Steam decomposition percent	35.9	36.2	32.9	30.7	28.9	32.9
Carbon conversion Do.	87.3	77.2	74.3	70.1	73.7	76.5
Temperatures, ° F.:						
High-pressure steam	588	586	592	595	595	591
Oxygen	273	275	277	300	304	286
Generator exit	1,116	1,033	991	954	988	1,016
Water-cooler exit	367	369	372	370	363	368
Waste-heat-boiler exit	313	313	324	313	313	315
Primary-heat-exchanger exit	202	267	267	214	216	233

[1] All data at 60° F. and 30 inches Hg.

[2] Calculated. Actual O_2 ranged from 92.3 to 96.8 percent purity.

[3] Total steam: Includes that from powerplant and from producer jacket.

The test results also indicated the influence of oxygen:coal ratios upon the percentages of carbon converted into raw gas. The highest conversion, calculated on the basis of carbon in the product gas, was obtained in periods A-1 and B-2, when the oxygen:coal ratios were highest. Consumption of oxygen per M cubic feet of raw gas averaged 185 cubic feet for dry Chestnut-size anthracite and 167 cubic feet for the dry Rice-Buckwheat mixture.

TABLE 4. - Operating data for test B[1]

Run No.	B-1	B-2	B-3	B-4	B-5	Average
Date	6/30-7/1	7/1-2	7/2-3	7/3-4	7/4-6	6/30-7/6
Duration of run ... hrs.	22.83	16.33	31.33	22.67	36.42	25.92
Coal (dry) ... lb./hr.	14,661	14,579	15,038	16,358	15,099	15,147
Coal (dry and ash-free) ... lb./hr.	11,873	11,812	12,124	13,192	12,180	12,236
Oxygen (100 percent pure)[2] ... cu. ft./hr.	78,878	84,051	84,796	84,015	86,322	83,612
High-pressure steam[3] ... lb./hr.	25,882	28,102	27,485	27,046	26,336	26,970
Gas (raw) ... cu. ft./hr.	464,667	526,273	505,725	505,949	499,323	500,387
Gas (CO_2-free ... cu. ft./hr.	348,500	393,652	379,294	380,474	377,488	375,882
H_2 + CO ... cu. ft./hr.	314,580	354,182	340,859	340,353	340,039	338,003
Gas composition, percent:						
CO_2	25.0	25.2	25.0	24.8	24.4	24.9
C_nH_m	.1	.2	.2	.1	.2	.2
CO	26.9	26.6	26.9	26.7	27.5	26.9
H_2	40.8	40.7	40.5	40.6	40.6	40.6
CH_4	5.6	5.7	5.9	6.1	5.9	5.8
N_2	1.6	1.6	1.5	1.7	1.4	1.6
H_2S ... grains/100 cu. ft.	208	165	179	184	184	184
Gross heating value:						
Raw ... B.t.u./cu. ft.	278	280	283	282	285	282
CO_2-free ... Do.	371	375	378	374	379	375
Steam decomposition ... percent	34.6	38.1	35.5	35.6	35.1	35.8
Carbon conversion ... Do.	76.8	88.0	82.4	75.1	81.0	80.7
Temperatures, ° F.:						
High-pressure steam	597	593	600	599	590	596
Oxygen	300	289	280	284	267	284
Generator exit	1,009	1,006	1,074	1,052	1,036	1,035
Water-cooler exit	374	374	368	368	368	370
Waste-heat-boiler exit	327	340	340	336	334	335
Primary-heat-exchanger exit	234	257	255	255	255	251

[1] All data at 60° F. and 30 inches Hg.

[2] Calculated. Actual O_2 ranged from 92.3 to 96.8 percent purity.

[3] Total steam: Includes that from powerplant and from producer jacket.

The capacity of the gasifier was not determined when operating with American anthracites because of the restrictions imposed upon operating conditions by the necessity of producing gas for the grid and the limited supply of oxygen available for each gasifier. The highest throughput of coal (273 pounds on a dry basis per square foot of reaction zone area per hour, or 199 pounds (dry, ash-free)) was obtained during periods A-2 and A-4. The results show, however, that the lowest rate of carbon conversion was in period A-4; hence, it is assumed that the carbon losses were highest in this period. In test B-4 the throughput of coal was 267 pounds on a dry basis per square foot or 215 pounds on a dry, ash-free basis; the carbon conversion was only 75.1 percent, the lowest of any of the tests of the Rice-Buckwheat mixture. Therefore, with the limited oxygen available, the throughput rate was increased at the expense of increased unburned carbon in the ash. Comparison of these results with data reported on the use of anthracite in the Bureau of Mines experimental Lurgi gasifier shows that the steam:oxygen ratios are similar, 0.325 to 0.287 pound of steam per cubic foot of oxygen for the Bureau's experimental unit and 0.33 to

0.28 pound for the commercial-size gasifier. The steam:coal ratio for the Bureau's experimental Lurgi unit was 2.78 pounds of steam per pound of coal (dry, ash-free), whereas the steam:coal ratio was only 2.09 pounds of steam per pound of coal (dry, ash-free) in test A and 2.21 pounds in test B. In calculating the weight of coal on a dry basis the moisture content determined in the Steinkohlengas laboratories was used, since it was believed that the moisture determination made by the Bureau of Mines before the coal was shipped would not represent the coal as charged. However, the Bureau's analysis of the ash content was used, because the ash determinations made in the Steinkohlengas laboratories were higher in all tests than those shown by the Bureau's regular ASTM procedures. These differences are believed to have been due to variations in sampling.

TABLE 5. - Process components calculated on unit basis for test A[1]

	A-1	A-2	A-3	A-4	A-5	Average
Ratios per pound fuel (dry):						
Oxygen .... cubic feet	5.82	4.92	4.96	4.76	5.21	5.13
Steam .... pounds	1.62	1.43	1.48	1.47	1.63	1.53
Gas produced .... cubic feet	31.7	28.2	26.9	25.6	27.0	27.9
Gas (CO_2-free) .... Do. ..	23.4	21.2	19.9	19.0	19.8	20.7
$CO + H_2$ .... Do. ..	21.1	19.2	17.9	17.1	18.0	18.7
Ratios per pound fuel (dry, ash-free):						
Oxygen .... Do. ..	8.00	6.75	6.92	6.53	7.16	7.07
Steam .... pounds	2.23	1.96	2.02	2.01	2.24	2.09
Gas produced .... cubic feet	43.5	38.7	36.9	35.2	37.1	38.3
Gas (CO_2-free) .... Do. ..	32.1	29.0	27.2	26.0	27.2	28.3
$CO + H_2$ .... Do. ..	29.0	26.3	24.5	23.4	24.7	25.6
Ratios per cubic feet pure oxygen:						
Gas produced .... Do. ..	5.44	5.74	5.33	5.39	5.19	5.42
Gas (CO_2-free) .... Do. ..	4.02	4.30	3.93	3.98	3.80	4.01
$CO + H_2$ .... Do. ..	3.62	3.89	3.55	3.58	3.45	3.62
Steam .... pounds	.28	.29	.30	.31	.31	.30
Fuel (dry) .... Do.	.17	.20	.20	.21	.19	.19
Fuel (dry, ash-free) .... Do.	.13	.15	.15	.15	.14	.14
Ratios per M cubic feet gas produced:						
Fuel (dry) .... Do.	31.6	35.5	37.2	39.0	37.0	36.1
Fuel (dry, ash-free) .... Do.	23.0	25.8	27.1	28.4	26.9	26.2
Steam .... Do.	51.2	50.7	54.9	57.3	60.5	54.9
Oxygen .... cubic feet	184	174	188	186	193	185
Ratios per M cubic feet gas (CO_2-free):						
Fuel (dry) .... pounds	42.8	47.3	50.1	52.8	50.5	48.7
Fuel (dry, ash-free) .... Do.	31.1	34.4	36.8	38.5	36.7	35.5
Steam .... Do.	69.4	67.7	74.4	82.5	74.3	73.7
Oxygen .... cubic feet	249	233	254	251	263	250
Ratios per hour per square feet, reaction zone cross-section:						
Gas produced .... Do. ..	6,421	7,701	7,218	6,994	6,797	7,026
Gas (CO_2-free) .... Do. ..	4,739	5,775	5,327	5,169	4,983	5,199
Fuel (dry) .... pounds	203	273	268	273	252	254
Fuel (dry, ash-free) .... Do.	148	199	196	199	183	185
Ratios per M cubic feet $CO + H_2$:[2]						
Fuel (dry) .... Do.	47.4	52.2	55.8	58.7	55.6	53.9
Fuel (dry, ash-free) .... Do.	34.5	38.0	40.7	42.8	40.4	39.3
Steam .... Do.	77.3	74.5	84.6	86.5	89.9	82.6
Oxygen .... cubic feet	276	257	282	279	290	277

[1] All volumes are at 60° F. and 30 inches Hg., dry.

[2] Figures uncorrected for CH_4 in gas.

TABLE 6. - Process components calculated on unit basis for test B[1/]

	B-1	B-2	B-3	B-4	B-5	Average
Ratios per pound fuel (dry):						
Oxygen ... cubic feet	5.38	5.77	5.64	5.14	5.72	5.53
Steam ... pounds	1.77	1.93	1.83	1.65	1.74	1.78
Gas produced ... cubic feet	31.7	36.1	33.6	30.9	33.1	33.1
Gas (CO_2-free) ... Do. ..	23.8	27.0	25.2	23.3	25.0	24.9
$CO + H_2$ ... Do. ..	21.5	24.3	22.7	20.8	22.5	22.4
Ratios per pound fuel (dry, ash-free):						
Oxygen ... Do. ..	6.64	7.12	6.99	6.37	7.09	6.84
Steam ... pounds	2.18	2.38	2.27	2.05	2.16	2.21
Gas produced ... cubic feet	39.1	45.6	41.7	38.4	41.0	41.2
Gas (CO_2-free) ... Do. ..	29.4	33.3	31.3	28.8	31.0	30.8
$CO + H_2$ ... Do. ..	26.5	30.0	28.1	25.8	27.9	27.7
Ratios per cubic feet pure oxygen:						
Gas produced ... Do. ..	5.89	6.26	5.96	6.02	5.78	5.98
Gas (CO_2-free) ... Do. ..	4.42	4.68	4.47	4.53	4.37	4.49
$CO + H_2$ ... Do. ..	3.99	4.21	4.02	4.05	3.94	4.04
Steam ... pounds	.33	.33	.32	.32	.31	.32
Fuel (dry) ... Do.	.19	.17	.18	.20	.18	.18
Fuel (dry, ash-free) ... Do.	.15	.14	.14	.16	.14	.15
Ratios per M cubic feet gas produced:						
Fuel (dry) ... Do.	31.6	27.7	29.7	32.3	30.2	30.3
Fuel (dry, ash-free) ... Do.	25.6	22.0	24.0	26.1	24.4	24.4
Steam ... Do.	55.7	53.4	54.4	53.5	52.7	53.9
Oxygen ... cubic feet	170	160	168	166	173	167
Ratios per M cubic feet gas (CO_2-free):						
Fuel (dry) ... pounds	42.1	37.0	39.7	43.0	40.0	40.4
Fuel (dry, ash-free) ... Do.	34.1	30.0	32.0	34.7	32.3	32.6
Steam ... Do.	74.3	71.4	72.5	71.1	70.0	71.9
Oxygen ... cubic feet	226	214	224	221	229	223
Ratios per hour per square feet, reaction zone cross-section:						
Gas produced ... Do. ..	7,581	8,587	8,251	8,255	8,147	8,164
Gas (CO_2-free) ... Do. ..	5,686	6,423	6,189	6,208	6,159	6,133
Fuel (dry) ... pounds	239	238	245	267	246	247
Fuel (dry, ash-free) ... Do.	194	193	198	215	199	200
Ratios per M cubic feet $CO + H_2$:[2/]						
Fuel (dry) ... Do.	46.6	41.2	44.1	48.1	44.4	44.9
Fuel (dry, ash-free) ... Do.	37.7	33.3	35.6	38.8	35.8	36.2
Steam ... Do.	82.8	78.5	79.9	79.0	78.7	79.8
Oxygen ... cubic feet	251	238	249	247	254	248

[1/] All volumes are at 60° F. and 30 inches Hg., dry.

[2/] These figures are uncorrected for CH_4 in gas.

No data are presented for the quantity of residual ash or for the combustible material remaining in the ash. It was not practicable to obtain this information because of the method used in disposing of the ash. The ash discharged from the gasifier dropped onto a belt conveyor which was used to remove ash from all the units in the plant. Although analyses were made for combustible matter in the ash, the results did not represent the actual operation of the gasifier, because the lighter, low-carbon portion of the ash was carried away in the wash water used to flush the ash onto the conveyor.

The oxygen for the tests was supplied by Linde-Frankl air-separation plants designed to produce oxygen of 95 percent purity; however, the oxygen actually used ranged from 93.2 to 96.8 percent purity. The oxygen data shown in tables 3 and 4 have been adjusted to a 100-percent-purity basis. As already pointed out, most of the tests probably were conducted under less than optimum oxygen conditions, as the supply was determined by the amount available rather than by the quantity considered necessary. The oxygen-metering equipment had certain limitations, and at various times the oxygen supply to the gasifier appeared to fluctuate. The reasons for these fluctuations could not be determined; however, the tests indicated that they are inherent in the oxygen system rather than in the gasification process.

Gas analyses were run on an hourly basis with a conventional fuel-gas apparatus. Attempts were made to limit the carbon dioxide in the gas to 24-26 percent, since this was indicated as a satisfactory range for the coal regularly used in the gas producer. No attempt was made to vary the gas composition beyond this range. Calorific values of the gas were calculated to a CO_2-free basis.

Table 7 was prepared to show operating data from various fixed-bed generators burning anthracite. The table indicates that the highest gasification rate (cubic feet/square foot/hour) was obtained in the tests conducted at Dorsten, Germany. The quantity of coal gasified per square foot of reaction zone was two or more times that reported for the other gasifiers.

The tests with Pennsylvania anthracite in Germany indicated that certain changes are necessary in the mechanical grate of the Lurgi gasifier. The German plant was designed to gasify a mildly caking coal containing ash of a character different from that of the anthracite. As a result, the ash-discharge mechanism was unsatisfactory for the anthracite tests. Although the grate was designed for water-cooled operations, it is being operated without water, because the cooling effect of the steam feed is considered sufficient to protect the grate.

PROCESS EVALUATION

Cost estimates have been made by Alberts, Gumz, and others[10 11] on the production of gaseous fuels from solid fuels, employing the Lurgi gasification technique. However, most of the data used in these estimates were extrapolated from bench-scale and pilot-plant investigations. Gasification of the specially prepared anthracite in Germany provides operating data that is used to evaluate the overall economics of a proposed process for producing a high-B.t.u. gas. A flowsheet of a complete process based on these data, which includes shift conversion, purification, and methanation, is shown in figure 6. Composition of the gases at various steps of the process are also shown. The projected plant theoretically would be completely integrated with a mining operation and designed to produce daily 90 million standard cubic feet of a synthetic pipeline gas. Calculations for methanation are based to some extent

---

[10] Alberts, L. W., Bardin, J. S., Beery, D. W., Jones, H. R., and Vidt, E. J., Production of Methane From Coal: Chem. Eng. Prog., vol. 48, No. 10, October 1952, pp. 486-493.

[11] Gumz, W., and Foster, J. J., A Critical Survey of Methods of Making a High B.t.u. Gas From Coal: Gas Production Res. Committee, Am. Gas Assoc. Res. Bull. 6, July 1953, 88 pp.

on operational data[12] from laboratory experimentation. Although the Bureau feels that the assumptions made for this plant are sound, it recognizes that further experimental work is necessary on hot-dust removal, shifting gases containing large proportions of steam, and methanation to verify the assumptions made in connection with this proposed process.

As the Steinkohlengas, A. G., gasifier was designed primarily for a mildly-caking coal, it appears that the final determination of the economics of producing high-B.t.u. gas from anthracite would require not only a complete engineering study of the major units comprising the Lurgi process, followed by a detailed investigation of the capital investment involved, but the erection of a prototype installation designed to take full advantage of the special characteristics of anthracite. For those reasons, only the raw-material costs developed in the German tests have been given in this report.

The proposed process (see fig. 6) begins at the coal-preparation plant, where the run-of-mine coal is processed into a material suitable for gasification. The design of the preparation plant would depend, of course, on the type, size, and carbon and ash content of the carbonaceous material that would give optimum operating results. Therefore, the final design of a preparation plant must await further studies on the entire gasification process.

The feed selected is transferred to a storage bin and fed through a lock hopper into the gasification unit. The plant would have 19 gasifiers (12-foot i.d.) if rough-cleaned Chestnut anthracite were used; however, the gasification plant would have eighteen 12-foot gasifiers for a washed and screened Rice-Buckwheat mixture. Based on carbon conversions of 80.7 and 76.5 percent obtained in the tests for the Buckwheat-Rice mixture and Chestnut, respectively, the feed to the gasifiers would be 217 tons per hour of coal, 107 tons per hour of oxygen (95 percent), and 773,000 pound per hour of steam for the Rice-Buckwheat mix and 267 tons per hour of coal, 122 tons per hour of oxygen (95 percent), and 814,000 pound per hour of steam for Chestnut.

The raw Lurgi gas leaving the generators would pass through a heat-recovery system consisting of waste-heat boilers and heat exchangers. It is calculated that in the waste-heat boilers 155,500 pound per hour of steam would be produced at 345 p. s. i. and 600° F.

To provide enough oxygen (95 percent pure) for the process, a 2,600-ton oxygen plant would be required for gasifying Chestnut and a 2,400-ton oxygen plant for the Buckwheat-Rice mixture. The oxygen would be fed into the gas generators at a pressure of about 360 p. s. i.

In the gas leaving the heat-recovery system a certain amount of dust is entrained, which, it is proposed, should be removed hot before it reaches the shift converter. (The Lurgi gasifiers require excess steam to prevent clinkers and protect the grate, since they are not designed to handle hard clinkers; therefore, the steam decomposition of only 32.9 and 35.8 percent for the Chestnut and Buckwheat-Rice gasified resulted in large quantities of unreacted steam in the raw gas.) The dust-removal system should remove the dust at temperatures high enough to allow the unreacted steam to pass into the shift converter with the gas. The dedusted gas would enter the shift-conversion unit at about 700° F. and 330 p. s. i.

---

[12] Greyson, M., Demeter, J. J., Schlesinger, M. D., Johnson, G. E., Jonakin, J., and Myers, J. W., Synthesis of Methane: Bureau of Mines Rept. of Investigations 5137, 1955, 50 pp.

TABLE 7. - Test results on the gasification of anthracite in fixed-bed generators[1/]

Place	Dorsten plant		Hirschfelde[3/] gas works	Holten[4/] plant		Nechells[5/] gas works	USBM[6/] Lurgi gasifier	Wellman-Galusha[7/] trial tests
Coal	Anthracite, Chestnut	Anthracite (Rice-Buckwheat)	Wiesche lean coal	Korean anthracite	Korean anthracite	British anthracite	Anthracite Buckwheat No. 4	Anthracite, Rice
Proximate analysis (dry), percent:								
Fixed carbon	67.7	75.6	86.9	82.2	71.9	92.7	80.4	84.3
Volatile matter	5.9	5.7	7.7	2.3	3.3	4.8	8.0	4.8
Ash	26.4	18.7	5.4	15.5	24.8	2.5	11.6	10.9
Moisture	-	-		-	-	-	-	6.4
Coal (dry) lb./hr.	15,547	15,147	525	879	1,029	587	10.3	2,594
Coal (dry, ash-free) do.	11,329	12,236	494	743	774	572	9.1	2,311
Oxygen (100 percent pure) cu. ft./hr.	79,510	83,612	3,230	7,483	7,435	2,952	88.5	23,997
Steam, high pressure lb./hr.	23,627	26,970	1,325	3,134	3,161	1,209	25.3	3,879
Gas produced cu. ft./hr.	430,629	500,387	22,115	36,597	33,097	19,006	405	119,430
Gas (CO_2-free) do.	316,607	338,003	16,185	25,325	21,679	13,247	283	99,724
Gas composition, percent:								
CO_2	26.0	24.9	27.0	30.8	34.5	30.3	[2/]30.1	16.5
C_nH_m	.2	.2	.2	.1	.2	-	.3	.15
CO	26.3	26.9	20.3	24.0	21.3	19.8	24.0	41.00
H_2	40.6	40.6	38.5	41.2	40.7	43.3	35.1	40.00
CH_4	5.4	5.8	12.3	3.1	2.8	6.2	6.9	.85
N_2	1.5	1.6	1.7	.8	.5	.4	3.1	1.5
Temperatures, ° F.:								
Steam	591	596	914	871	882	-	-	-
Pressures, atmospheres:								
Generator	23.0	23.0	21.0	20	20	20.0	30.0	Atmospheric
Reaction-zone area sq. ft.								
Grate area do.	61.4	61.4	11.2	10.86	10.86	3.1	.196	78.5
Gasification rate cu. ft./sq. ft./hr.	7,026	8,164	1,450	3,370	3,048	6,053	2,066	1,521
Coal (dry) gasified lb./sq. ft./hr.	254	247	46.8	80.9	94.8	187	52.5	33.0
Ratios per M cubic feet gas:								
Coal (dry) lb.	36.1	30.3	23.7	24.0	31.1	30.9	25.4	21.7
Coal (dry, ash-free) do.	26.2	24.4	22.3	20.3	23.4	30.1	22.5	19.4
Oxygen (100 percent pure) cu. ft.	185	167	146	204	225	155	219	201
Steam lb.	54.9	53.9	59.9	85.6	95.5	63.6	62.5	32.5

[1/] All volumes at 60° F. and 30 inches Hg., dry.

[2/] Gas contains 0.5 percent O_2.

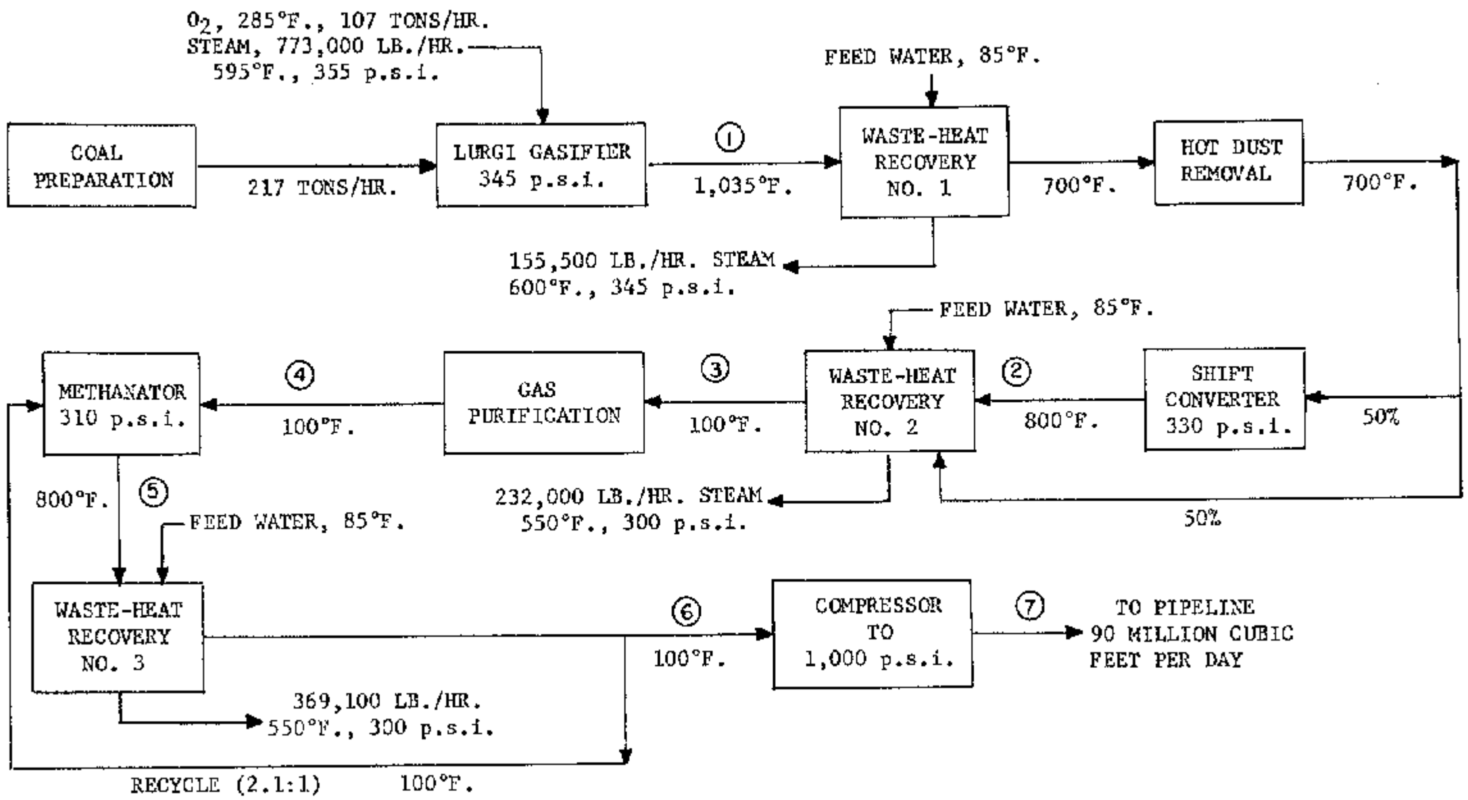
[3/] Newman, L. L., Oxygen in the Production of Hydrogen or Synthesis Gas: Ind. Eng. Chem., vol. 40, No. 10, April 1948, pp. 559-582.

[4/] Pressure Gasification Trials on Korean Anthracite; prepared for Chemical Construction Corp. as part of Gesellschaft Fur Warmetechnik, M. B. H., contract with United Nations Korean Reconstruction Agency.

[5/] Hebden, D., Edge, R. F., and Foley, K. W., Investigations With a Small Pressure Gasifier: British Gas Council Res. Communication GC-14, 1954, 32 pp.

[6/] Cooperman, J., Davis, J. D., Seymour, W., and Ruckes, W. L., Lurgi Process: Use for Complete Gasification of Coals With Steam and Oxygen Under Pressure: Bureau of Mines Bull. 498, 1951, 38 pp.

[7/] Newman, L. L., and Wright, C. C., Oxygen Gasification of Anthracite in the Wellman-Galusha Producer: Proc. Am. Gas Assoc., 1947, pp. 701-712.



STREAM	1	2	3	4	5	6	7
H_2O	42.8	37.0	---	---	8.2	---	---
H_2	23.2	29.0	46.0	67.4	5.3	5.8	5.8
CO	15.4	9.7	15.4	22.5	.6	.7	.7
CO_2	14.2	20.0	31.8	---	1.0	1.1	1.1
CH_4	3.4	3.3	5.2	7.7	78.5	85.4	85.4
ILLUM.	.1	.1	.2	.3	.8	.9	.9
N_2	.9	.9	1.4	2.1	5.6	6.1	6.1
S.C.F.H.	24,897,000	24,897,000	15,685,000	10,711,300	28,116,200	25,817,900	3,752,600

FIGURE 6. - Process Flowsheet. High-B.t.u. Gas by Lurgi Gasification, Followed by Methanation.

The composition of the gas leaving the converter is calculated to be as follows:

	Chestnut percent	Rice-Buckwheat, percent
CO_2	32.5	31.8
CO	15.2	15.4
H_2	45.8	46.0
CH_4	5.0	5.2
C_nH_m	.1	.2
N_2	1.4	1.4

After leaving the converter, the gas passes through a heat-recovery system, where 232,000 pounds per hour of steam is produced at 300 p. s. i. and 550° F. The temperature of the gas entering the purification train will depend on the process, that is, ethanolamine, Rectisol, or hot carbonate. An ethanolamine system requires iron oxide and activated char to remove residual H_2S and organic sulfur. The gas is purified at 100° F. and a pressure of 310 p. s. i.

The composition of the purified gas is as follows:

	Chestnut, percent	Rice-Buckwheat, percent
CO_2	-	-
C_nH_m	0.2	0.3
CO	22.5	22.5
H_2	68.0	67.4
CH_4	7.3	7.7
N_2	2.0	2.1

In the Rectisol process H_2S, organic sulfur compounds, and CO_2 are extracted at low temperatures. The hot carbonate process, recently developed by the Bureau of Mines,[13] removes CO_2 and H_2S at 200° F. and 310 p. s. i.

Following the purification system, the gas enters the methanation unit, where a product gas is made having the following constituents:

	Chestnut, percent	Rice-Buckwheat, percent
CO_2	1.1	1.1
C_nH_m	.5	.9
CO	.7	.7
H_2	6.0	5.8
CH_4	85.7	85.4
N_2	6.0	6.1
Gross heating value, B.t.u./cu. ft.	900.0	906.0

The temperature of the reaction is controlled by a gas recycle stream. A third waste-heat recovery system is used to produce 369,100 pounds of steam per hour at 300 p. s. i. and 550° F.

---

[13] Benson, H. E., Field, J. H., and Haynes, W. P., Improved Process for CO_2 Absorption Uses Hot Carbonate Solutions: Chem. Eng. Prog., vol. 52, No. 10, October 1956, pp. 433-438.

According to the operating data obtained from the tests performed in Germany, the following average quantities of materials would be needed to produce 1,000 cubic feet of high-B. t. u. gas from Chestnut anthracite containing 26 percent ash: Coal, 143 pounds; oxygen (95 percent pure), 769 standard cubic feet; and steam, 217 pounds. The data indicated that to produce the same quantity of gas from a Buckwheat-Rice mixture containing 19 percent ash would require 116 pounds of coal, 674 (95 percent pure) cubic feet of oxygen and 206 pounds of steam.

Although the material requirements enumerated in the preceding paragraph were evolved directly from the German tests, which were conducted under less than optimum conditions, they are used in figure 7 to delineate the cost of producing 1,000 cubic feet of high-B. t. u. gas, the cost of the carbonaceous feed material being the only variable. The cost of oxygen and steam were assumed to be $0.20 per M standard cubic feet and $0.40 per M pound, respectively.

With coal at $4 per ton, the cost of materials, calculated on average test results obtained with the Chestnut, would be about 52 cents per M cubic feet of high-B. t. u. gas; for the Rice-Buckwheat mixture at the same price, the cost would be approximately 45 cents per M cubic feet. The material costs for the two periods (A-1 and B-2) in which the highest carbon conversions were obtained are also used to show what might be expected if the gasifier were operated under more favorable conditions. With the price of coal at $4 per ton, raw-material costs, calculated on test results obtained in periods A-1 and B-2, would be about 49 cents and 42 cents, respectively. In equipment designed primarily for anthracite and operated under optimum conditions, a 95-percent carbon conversion might well be obtained, which would be even more favorable with respect to cost.

Comparison of the results obtained in this study with those reported by Alberts et al. will show the economic merits of the Lurgi pressure gasification of anthracite. Their report indicated that the synthesis gas for the plant described was produced in 12-foot (i. d.) Lurgi units. The material requirements reported for the gasification process were 90.1 pounds of fuel, 488.5 cubic feet of 95 percent oxygen, and 268 pounds of superheated steam per M cubic feet of final pipeline gas. The fuel consumption was based upon a noncaking fuel assumed to have a heating value of 13,000 B.t.u. per pound. The approximate composition of the raw gas reported by Alberts et al., gas leaving the purification and methanation units, and the pipeline gas are shown in table 8.

TABLE 8. - Gas analyses, percent

	Raw Lurgi gas	Gas leaving initial purification	Gas leaving methanation	Pipeline gas
H_2	40	54.8	8.6	10.9
CO	20	27.4		
CO_2	30	4.1	22.1	1.0
CH_4	8	10.9	63.6	80.9
C_2H_6 and illuminants	1	1.4	2.85	3.5
N_2	1	1.4	2.85	3.7
Volumes	100	73.0	35.0	27.5

The gas is then compressed to 1,000 p. s. i. for pipeline transmission. The methane synthesized in the Lurgi gas generator is advantageous in the production of high-B. t. u. gas; however, to make a synthesis gas for manufacturing hydrogen to be used in the direct reduction of iron ore or for the production of ammonia, the Lurgi

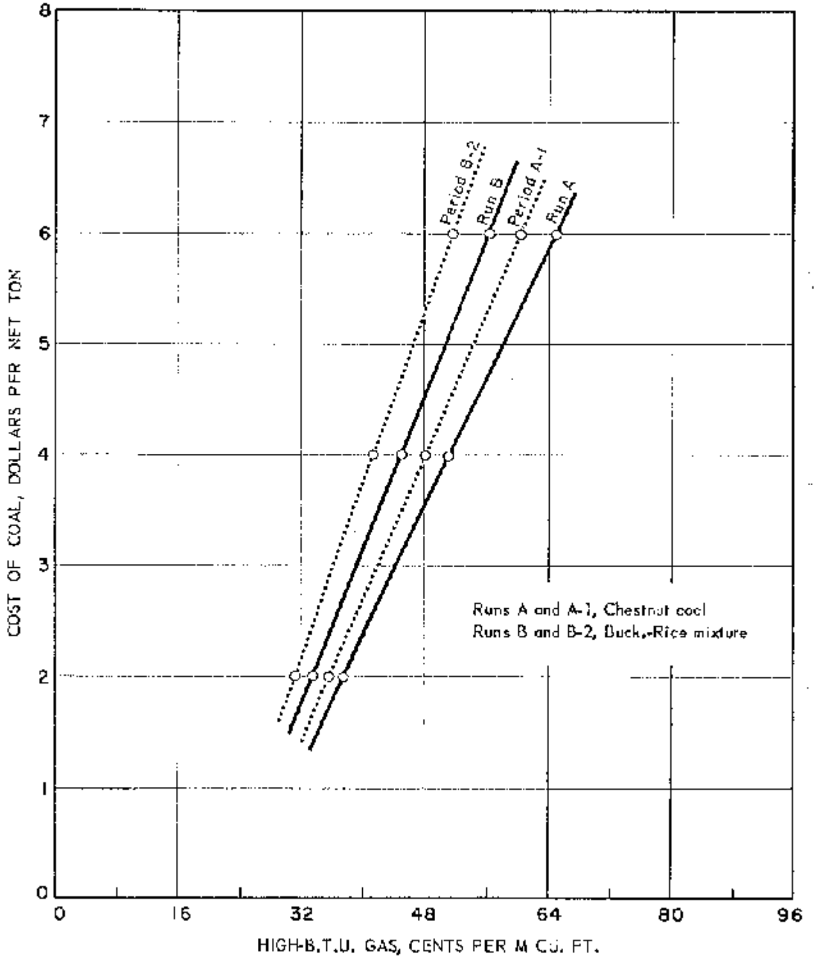


FIGURE 7. - Direct Materials Cost of 1,000 Cubic Feet of High-B.t.u. Gas. (Based on Oxygen at 20 Cents Per M Cu. Ft. and Steam at 40 Cents Per M Lb.)

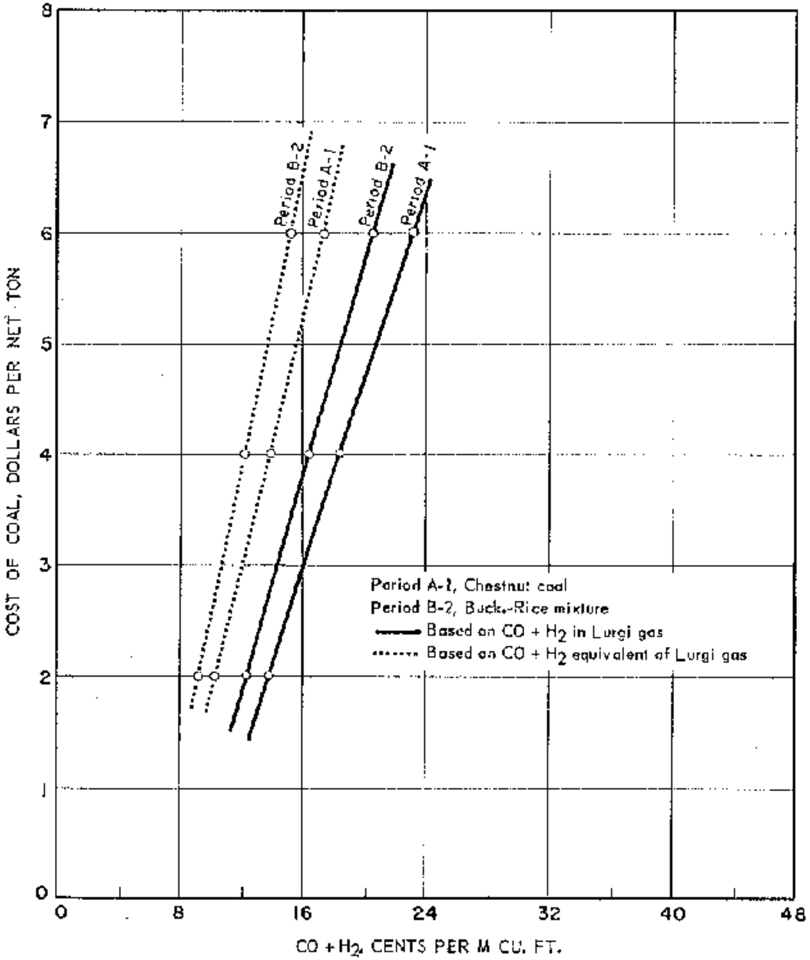


FIGURE 8. - Cost Per 1,000 Standard Cubic Feet of CO+H_2, Made by Gasification of Anthracite in a Lurgi Process. (Based on Oxygen at 20 Cents Per M Cu. Ft. and Steam at 40 Cents Per M Lb.)

generator would have to be operated at a higher gasification rate or with a shallower fuel bed. The higher gasification rate and shallower bed would decrease the contact time and result in a Lurgi gas containing less methane.

The cost of reactants per M cubic feet of $CO + H_2$, based on test results for periods A-1 and B-2, is shown in figure 8 - with the price of coal the only variable and O_2 and steam at $0.20 per M standard cubic feet and $0.40 per M pound, respectively. Since Lurgi gas contains methane, the $CO + H_2$ equivalent of the gas for periods A-1 and B-2 was also calculated, and the material costs, based on the calculations, are also shown in figure 8. Assuming a price of $4.00 per ton, the figure shows that the material costs per M cubic feet of $CO + H_2$ would be about 18 cents for period A-1 and 16 cents for period B-2. Based on the $CO + H_2$ equivalent of the Lurgi gas, the cost per M cubic feet of $CO + H_2$ would be approximately 14 cents for period A-1 and 12 cents for period B-2.

Direct material costs per M cubic feet of high-B. t. u. gas, calculated on the basis of the Dorsten test results, indicate that Lurgi gasification of anthracite is also comparable with other processes proposed for high-B. t. u. gas manufacture, as reported in the literature.[14] [15] [16] [17]

CONCLUSIONS

The results of the tests of American anthracite in the commercial Lurgi gasifier at Dorsten, Germany, show that the overall carbon and oxygen requirements for synthesis-gas production compare favorably with any fluid-bed or coal-suspension process thus far reported for any research or commercial operation.

The differences in the inherent characteristics of the coal used in this test and that regularly gasified at Dorsten were reflected in the performance of the equipment. Bureau of Mines engineers observing the tests agreed with the Lurgi engineers that certain changes would have to be made in the gasifier to take advantage of the high ash-fusion temperature of anthracite. The Bureau recognizes that the ultimate design of an economic anthracite gasification process will require further research and development to improve the various stages that comprise the coal-to-pipeline-gas process.

---

[14] Work cited in footnote 11 (p. 15).

[15] Strimbeck, G. R., Holden, J. H., McGee, J. P., and Hirst, L. L., Recent Work by the Bureau of Mines on the Gasification of Pulverized Coal: Proc. Am. Gas Assoc., 1955, pp. 1006-1037.

[16] Grossman, P. R., and Curtis, R. W., Pulverized-Coal-Fired Gasifier for Production of Carbon Monoxide and Hydrogen: Trans. ASME, vol. 74, 1954, pp. 689-695.

[17] Totzek, F., Synthesis Gas From the Koppers-Totzek Gasifiers: Chem. Eng. Prog., vol. 50, No. 4, 1954, pp. 182-187.