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1	1.75
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	2,420

experiments
particle size
4-mesh
increased
from 86.6

TABLE 10. - Size consist of char at various percentages of carbon gasified during run 11

Run and period		11-M	11-F	11-A
Carbon gasified, percent		86.6	69.1	57.3
U. S. mesh No. <u>1</u> /	Opening inch <u>2</u> /	Percent	retained on screen	
Plus-4	+0.185	21.2	27.9	33.9
Plus-8	+ .093	28.0	22.6	36.2
Plus-16	.046	13.9	13.3	14.1
Plus-30	.0232	13.0	13.3	7.2
Plus-50	.0116	11.5	10.6	4.4
Plus-100	.0058	7.6	6.3	2.3
Plus-200	.0029	2.1	2.7	.6
Minus-200	-.0029	2.7	3.3	1.1
Average size, inch		.122	.137	.172

1/ Numbers are U. S. Standard series.

2/ Standard square-mesh screen openings.

From the results of run 11, during which the lignite feed rate was the only variable of the respective operating conditions, it may be concluded that:

1. The percentage of carbon gasified varies inversely with the feed rate.
2. The gas yield per ton of raw lignite decreases with an increase in the lignite feed rate.
3. The temperatures of the inner tube measured at approximately 1 foot (point D) and 5 feet (point F) above the gas offtake decreases with an increasing feed rate. As the average reaction temperature is related to the inner tube temperatures, this should also decrease.
4. The hydrogen-carbon monoxide ratio of the gas and the amount of undecomposed steam per M c.f. of gas generally increase with increasing feed rate. However, at the higher ratios the change is small.

Run 12

The gas generator was blown in on September 8, 1949, and operation continued without interruption or difficulty until September 26, 1949. During the 438 hours of operation, 170,182 pounds of lignite, which had been previously dried by the Fleissner process at 400 p.s.i. steam pressure, was gasified, and 5,759 M c.f. of product gas containing 3,219 M c.f. of hydrogen was produced at rates varying from 10.7 to 16.4 M c.f. per hour.

There were marked differences between the gasification of the steam-dried lignite with 12 to 15 percent moisture and of the natural lignite with approximately 37 percent, as shown in table 11. This table summarizes the results of comparable periods of runs 11 and 12 under experimental conditions usually used for the generation of a nominal 2.5, 3.5, and 4.5 hydrogen-carbon monoxide ratio of the product gas:

TABLE 11. - Comparison of gasification of natural and steam-dried lignite at various H₂-CO ratios

	H ₂ -CO ratio of gas = less than 2.0		H ₂ -CO ratio of gas = 2.5		H ₂ -CO ratio of gas = 3.5		H ₂ -CO ratio of gas = 4.5	
	Steam-dried	Natural	Steam-dried	Natural	Steam-dried	Natural	Dried	Natural
(1) Type of lignite	12-A	11-A	12-B	11-L	12-E	11-I	12-3	11-II
(2) Run and period								
(3) Average combustion space temperatures, °F.: Thermocouple No. 1 Thermocouple No. 2 Thermocouple No. 3 Thermocouple No. 4	570 404	1,926 1,853 1,822 1,750 1,600	489 392	1,750 1,822 1,850 1,571 1,460	1,750 1,750 1,555 1,460	1,750 1,803 1,850 1,571 1,459	307 247	1,749 1,850 1,850 1,571 1,459
(4) Lignite charged	305	641	489	404	319	423	307	463
(5) m.a.f. lignite	401	377	392	230	244	245	247	276
(6) Steam in upper reaction zone: Water available from moisture and water of formation Steam admitted to upper reaction zone Subtotal: Steam available upper reaction zone	312 147	310 63	156 257	189 132	104 227	199 225	98 300	221 233
(7) Steam admitted to lower reaction zone: lb./hr. m.a.f. lignite	136	378 1,01	415 1,05	321 1,39	331 1,36	414 1,69	308 1,61	454 1,65
(8) Total steam available: lb./hr. m.a.f. lignite	425 1,07	210 2,55	158 0,51	336 1,59	132 0,54	245 1,00	232 0,94	273 0,99
(9) Undecomposed steam	113	281	206	224	93	373	315	420
(10) Decomposed steam	312	337	405	233	270	286	310	307
(11) Decomposed steam	73.4	52.2	65.0	51.0	58.4	43.4	49.5	42.2
(12) Product gas, SCC	14.0	12.6	16.1	9.2	10.0	10.3	11.0	11.1
(13) Product gas, SCC	69.7	64.8	83.7	79.5	86.5	83.5	89.2	89.6
(14) Carbon gasified	67.3	57.3	76.8	67.2	77.8	69.1	77.5	67.3
(15) Ratio H ₂ -CO	1.85	3.04	2.29	3.99	2.87	4.02	3.71	4.63
(16) Average temperature opposite U	1,265	1,050	1,222	1,122	1,180	1,051	1,175	1,025
(17) Average temperature opposite V	1,053	671	1,044	867	1,005	772	1,045	724
(18) Average temperature at gas off-take	1,359	1,137	1,270	1,184	1,226	1,135	1,243	1,109
(19) Average pressure charging dome		0.6	9.7	15.0	9.7	10.9	9.0	11.9
(20) Average pressure char zone		5.3	5.6	10.8	4.9	7.7	6.2	10.7
(21) Heat used, gross	105	137	106	140	123	136	119	137
(22) Gas used for heating	40.0	48.3	37.9	52.0	43.5	51.5	45.4	51.2
(23) Average size of char		0.172	0.259	0.105	0.187	0.137	0.235	0.149
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42.4	35.2	45.4	51.5	43.5	52.0	37.9	48.3	38.3	40.0
0.284	0.149	0.222	0.37	0.187	0.106	0.259	0.172		

(20) Gas used for heating . . . percent product gas made
 (21) Average size of char inches
 (22) Water available from moisture and water of formation calculated from oxygen content of the ultimate analysis.

The inner tube temperatures, as measured at points opposite D and F (see fig. 4) 1 foot and 5 feet above the gas offtake, respectively, are consistently higher under comparable conditions when the dried lignite is gasified. At a nominal 2.5 ratio the temperature increase amounted to 162° F. at point D and 373° F. at point F; at the 3.5 ratio the increase was 58° F. at point D and 139° F. at point F; whereas at the 4.5 ratio it became 124° and 120° F. at point D, and 273° and 261° F. at point F, respectively. An increase in the feed rate does not affect operating conditions as much with dried lignite as does an equivalent change in the feed rate of natural lignite. For example, at the lowest hydrogen-carbon monoxide ratio, an increase of 82 pounds of moisture- and ash-free lignite per hour using dried lignite did not appreciably affect the D and F temperatures, whereas an increase of only 63 pounds of moisture- and ash-free lignite per hour from natural lignite decreased the temperature at D by 68° F. and at F by 157° F.

Because the D and F temperatures under comparable experimental conditions are always higher when the dried lignite is used, the average reaction temperature in the annulus must be higher also. In addition, the fact that the temperatures at F were considerably above those during run 11 for comparable experiments indicated that the drying and carbonization were completed within a shorter vertical-tube distance and therefore a longer reaction zone was available for gasification. With a longer reaction zone and higher reaction temperatures, the percentage of carbon gasified should be greater when equivalent feed rates are used. Under comparable conditions for the low hydrogen-carbon monoxide ratio gas, 78.8 percent of the carbon was gasified when steam-dried lignite was used and only 57.3 percent with natural lignite. For the medium-ratio series, 85.8 percent gasification was obtained with the dried lignite, but this decreased to 67.2 percent when natural lignite was gasified. At the high ratios, the percentage of carbon gasified with dried lignite was 77.5 and 77.7, which corresponds to 69.1 and 67.3 percent for the natural lignite.

Because the percentage of gasification is higher with the dried lignite, the gas yield per ton of moisture- and ash-free material must necessarily be greater when dried lignite is fed to the retort. Again, reference to table 11 shows the gas yield per ton of moisture- and ash-free lignite under the three sets of operating conditions for dried lignite to be 83.7, 88.5, 89.2, and 88.7 M c.f., SGC¹⁰ as compared to 64.8, 79.6, 83.6, and 80.6 M c.f., SGC, for the natural lignite. The difference in gas yield is less at the higher ratio because the spread in the percentage of gasification between dried and natural lignite under those conditions amounted to only 8.4 and 10.3 percentage units.

The negligible influence of the feed rate of dried lignite on the inner tube temperature in the range investigated indicates that a relatively high feed rate can be reached without materially lowering the percent gasification. Therefore, the rate of gas production should be greater with the dried lignite. This was verified during period 12-D, when a production rate of 16.4 M c.f. per hour of gas at SGC was reached at a ratio of 2.3. This gas production was the highest ever obtained from the gas producer. Previously the capacity of the retort was limited by the fact that sufficiently high inner tube temperatures, and therefore a satisfactory percentage of gasification, could not be maintained at a high lignite-feed rate. With the dried lignite, the capacity may now be limited by the mass velocity of product gas and water vapor passing through the gas offtake. This factor of critical mass velocity is discussed in the section Influence of Mass Velocity of Gas and Water Vapors Leaving Gas Offtake on Behavior of Gas Generator.

¹⁰/ Gas volume measured by displacement meter; standard gas conditions, saturated gas at 60° F. and 30 inches of mercury.

The percentage of steam decomposed is greater for the dried lignite under comparable conditions. The comparison between the dried and natural lignite is 66.0 to 52.2 percent at low ratios, 58.4 to 51.0 percent at the medium-ratio range, and 49.5 and 49.6 to 43.4 and 42.2 percent at the high-ratio range.

Lower heat consumption, based on the B.t.u. consumed per cubic foot of product gas, was obtained during the experiments with dried lignite. Comparison with the comparable periods on natural lignite show a 10- to 20-percent decrease in gross B.t.u. used per cubic foot of product gas, with the largest reduction at the lower ratios. Actual data for the heat consumption gave 137 B.t.u. for the natural lignite and 108 B.t.u. for the dried lignite per cubic foot of product gas at a nominal 2.5 hydrogen-carbon monoxide ratio; at the nominal 4.5 ratio, the heat consumption was 136 and 137 B.t.u. for the natural lignite, and for the dried lignite 119 and 112 B.t.u. per cubic foot of product gas.

The average size of the char from steam-dried lignite was in each case larger than that of the char from natural lignite, even though the percentage of gasification was greater. For the dried lignite, the average size of the char was 0.259, 0.187, 0.235, and 0.284 inches, and for the natural lignite during comparable periods, the average size was 0.172, 0.106, 0.137, and 0.149 inches. Because of larger particle size, the pressure drop through either upper or lower reaction zone was reduced. The decrease in pressure drop was more noticeable at the higher ratios.

Approximately 50 pounds of water per 100 pounds of natural lignite is formed from the oxygen and equivalent hydrogen present, and with this steam concentration a H_2 -CO ratio less than 2 could not be produced in the gasifier at safe operating temperatures. With dried lignite of 12 to 15 percent moisture, the water of formation would be reduced to 33 pounds per 100 pounds of dried lignite, and a ratio of less than 2 would be possible under the present operating conditions. The second specific objective of run 12 was accomplished during periods A and B when a gas with an H_2 -CO ratio of 1.85 was generated. Table 11 provides the pertinent information obtained from these periods. It should be noted that, even with a 63-pound-per-hour increase in the moisture- and ash-free lignite charged, no appreciable change was found in the percentage of carbon gasified, hydrogen-carbon monoxide ratio, or heat consumption per cubic foot of gas produced. The percentage carbon gasified was 65.3 and the ratio 1.85 in each case. The heat, consumption based on the gross heating value was 106 and 103 B.t.u. per cubic foot of gas produced for periods A and B, respectively.

The repeated handling and screening in preparing the dried lignite increased the percentage of fine particles and at times the reject approached nearly 45 percent of the dried lignite elevated to the vibrating screen when a 1-1/2- by 3/8-inch cut was taken for gasification. Replacing the 3/8-inch screen by a 1/16-inch screen reduced the reject losses and resulted in an increase of the usable material from about 55 to 93 percent of the total dried lignite. Two periods, each of about 22 hours duration, were performed with 1-1/2- by 1/16-inch feed without difficulty or formation of excessive dust in the gas. Table 12 compares the gasification of the 1-1/2- by 3/8-inch and 1-1/2- by 1/16-inch feeds under equivalent experimental conditions.

TABLE 12. - Influence of size consist of steam-dried lignite on gasification process

12-13/J	12-F	12-HI/I	12-E
1/2	1/2	1/16	

TABLE 12. - Influence of size consist of steam-dried lignite on gasification process

(1) Run and period	12-E 1-1/2 x 3/8		12-HI/I 1-1/2 x 1/16		12-F 1-1/2 x 3/8		12-LJ/J 1-1/2 x 1/16	
	Percentage retained		Percentage retained		Percentage retained		No sample available	
(2) Screened size of feed	3.6	32.0	3.5	13.8	1.5	14.4		
(3) Sieve analysis of feed:	U.S. mesh No. 2/							
Opening, inches 1/								
Plus-1.050	34.9	18.0	30.8	21.4	32.2	29.4		
Plus-0.742	10.0	9.9	21.8	6.7	20.0	1.4		
Plus-0.525	5.5	5.1	1.8	1.8	0.6	0.6		
Plus-0.371	11.5	15.4	30.5	13.6	22.5	1.1		
Plus-0.185	8.1	8.1	6.1	6.1	12.8	5.8		
Plus-0.093	319	244	300	242	390	318		
Plus-0.046	331	1.36	329	1.36	430	1.35		
Plus-0.0292	132	0.54	131	0.54	174	0.55		
Plus-0.0116	463	1.90	460	1.90	604	1.90		
Minus-0.371	187	276	177	283	259	345		
(4) Moisture	59.6	10.8	61.5	10.7	57.2	12.4		
(5) Ash	88.5	77.8	88.9	80.6	78.1	71.0		
(6) Lignite charged	2.87	1,006	2.69	1,078	3.08	1,154		
(7) MAF lignite	1,180	1,226	1,257	1,239	1,184	1,053		
(8) Total steam, upper reaction zone:	9.7	4.9	15.7	5.8	10.0	4.9		
Lb./hr.	120	43.5	119	113	41.1	98		
(9) Total steam, lower reaction zone:	0.63	0.187	0.12	0.12	1.50	2.39		
Lb./lb. m.a.f. lignite	0.187	0.187	0.187	0.187	0.197	0.171		
(10) Total steam available: 2/	1,180	1,226	1,257	1,239	1,184	1,053		
Lb./lb. m.a.f. lignite	1,180	1,226	1,257	1,239	1,184	1,053		
(11) Undecomposed steam	1,180	1,226	1,257	1,239	1,184	1,053		
(12) Decomposed steam	59.6	10.8	61.5	10.7	57.2	12.4		
(13) Decomposed steam	88.5	77.8	88.9	80.6	78.1	71.0		
(14) Product gas, SGC	2.87	1,006	2.69	1,078	3.08	1,154		
(15) Product gas, SGC	1,180	1,226	1,257	1,239	1,184	1,053		
(16) Carbon gasified	9.7	4.9	15.7	5.8	10.0	4.9		
(17) Ratio H ₂ /CC	120	43.5	119	113	41.1	98		
(18) Average temperature opposite D	43.5	0.63	42.9	41.1	1.50	2.39		
(19) Average temperature opposite F	0.63	0.187	0.12	0.12	1.50	2.39		
(20) Average temperature at gas off-take	1,180	1,226	1,257	1,239	1,184	1,053		
(21) Average pressure at charging dome	9.7	4.9	15.7	5.8	10.0	4.9		
(22) Average pressure at char zone	120	43.5	119	113	41.1	98		
(23) Heat used, gross	43.5	0.63	42.9	41.1	1.50	2.39		
(24) Product gas used for heating	0.63	0.187	0.12	0.12	1.50	2.39		
(25) Dust content of product gas	1,180	1,226	1,257	1,239	1,184	1,053		
(26) Average size of char	9.7	4.9	15.7	5.8	10.0	4.9		
Standard series	1,180	1,226	1,257	1,239	1,184	1,053		
Standard square-mesh screen openings	9.7	4.9	15.7	5.8	10.0	4.9		
Total steam includes added steam, moisture and water of formation.	1,180	1,226	1,257	1,239	1,184	1,053		

1/ Numbers are U.S. Standard series.
2/ Standard square-mesh screen openings.
3/ Total steam includes added steam, moisture and water of formation.

The percentage of carbon gasified was increased from 77.8 and 71.0 percent to 80.6 and 72.8 percent, respectively, when the smaller-size feed was used. Even with a slightly higher percentage gasification and the increase of smaller sizes, no difference in the average size of the char was apparent, being 0.187, 0.187, 0.197, and 0.171 inch for the 4 periods compared. The hydrogen-carbon monoxide ratio was lower and the percentage of steam decomposed slightly higher when the lignite containing a higher fraction of fines was gasified. Hydrogen-carbon monoxide ratios were 2.69 and 2.93 for these periods and for the others 2.87 and 3.08. When the smaller-sized fuel was used 61.5 and 60.3 percent of the total steam available was decomposed, compared with 59.6 and 57.2 when the coarser material was gasified.

Proximate and ultimate analyses of the residue from the gasification of the dried lignite are presented in table 13. No consistent changes like those noted in previous comparisons of the char analyses at different percentages of carbon gasified are apparent, owing perhaps to the relatively large variations in the pyritic sulfur content of the feed. Dried lignite for period 12-A had the highest sulfur content and period 12-F, the lowest. Residue from period 12-A, with 65.3 percent of the carbon gasified and 2.2 percent sulfur in the feed, had an ash content of 37.6 percent, whereas, residue from period 12-F had at 71.0 percent gasification and 0.7 percent sulfur in the feed, only 27.6 percent ash. Sieve analyses for the same periods are presented in table 14, indicating again an increase in particle size with decreasing gasification.

TABLE 13. - Analyses of residue from gasification process at various percentages of carbon gasified during run 12

Run and period number	12-HI/I	12-F	12-A
Carbon gasified, percentage	80.6	71.0	65.3
Proximate analysis, percent:			
Moisture	1.2	1.0	1.0
Volatile matter	8.7	8.0	9.0
Fixed carbon	55.7	63.4	52.4
Ash ^{1/}	34.4	27.6	37.6
Ultimate analysis, percent:			
Hydrogen	1.0	1.2	0.8
Carbon	64.4	69.5	64.1
Nitrogen	.4	.5	.4
Sulfur	2.64	1.69	5.55
Oxygen			
Ash ^{1/}	34.4	27.6	37.6
SO ₃ ^{2/3/}	2.64	4.27	10.96
CO ₂ ^{2/}	6.70	2.36	1.64
Heating value, B.t.u./lb.	9,890	10,680	9,890
Softening temperature of ash, °F.	2,450	2,420	2,360

1/ Ash uncorrected for sulfur and carbon reported as SO₃ and CO₂.

2/ In ash, reported as percent of original residue.

3/ Sulfur reported as equivalent SO₃.

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2,360

TABLE 14. - Size consist of residue at various percentages of carbon gasified during run 12

Run and period	12-HI/I	12-F	12-A
Carbon gasified, percent	80.6	71.0	65.3
U. S. mesh No. ^{1/} Opening, inch ^{2/}	Percentage retained		
0.742	0.0	0.0	1.4
.525	6.3	3.6	5.1
.371	10.1	11.7	15.1
4	23.2	34.6	37.3
8	14.6	10.6	12.7
16	14.3	7.2	7.9
30	13.7	9.2	8.1
50	8.9	9.8	6.8
100	4.6	6.5	3.1
200	2.0	3.0	1.3
Minus-200	2.3	3.8	1.2
Average size, inch187	.197	.244

^{1/} Numbers are U. S. Standard series.

^{2/} Standard square-mesh screen openings.

Conclusions concerning comparison of the gasification of steam-dried Dakota Star lignite of 12 to 15 percent moisture with natural Dakota Star lignite of approximately 37 percent moisture under nearly identical experimental conditions may be summarized as follows:

1. A greater gas-production rate can be reached using dried lignite as a feed at normal combustion space temperatures.
2. A considerably higher amount of moisture- and ash-free lignite, originating from dried lignite, can be fed to the retort and a high percentage of gasification maintained.
3. With equal feed rates of moisture- and ash-free lignite, the percentage of carbon gasified and, consequently, the gas yield per ton of moisture- and ash-free lignite are substantially higher when dried lignite is gasified.
4. The hydrogen-carbon monoxide ratio of the product gas is lower and the steam decomposition higher when dried lignite is gasified.
5. The B.t.u. consumption per cubic foot of product gas is reduced when dry lignite is gasified.
6. The average reaction temperature and the portion of the reaction space actually used for gasification is increased with dried lignite as the feed.
7. The average particle size of the residue is larger and the pressure drop through the annulus is lower when dried lignite is used.

Tentative additional conclusions concerning the gasification of steam-dried lignite may be summarized as follows:

1. Steam-dried lignite may be used to produce gas with a ratio of 1.85 without excessive combustion space temperatures.

2. Reduction of the feed size of the charge from 1-1/2- by 3/8-inch to 1-1/2- by 1/16-inch increased the portion of dried lignite recovered after screening from approximately 45 to 93 percent and caused no difficulty in the operation of the retort.
3. Under comparable experimental conditions, the percentage of carbon gasified increased slightly and the H₂-CO ratio of the product gas decreased when the smaller-size feed was gasified.

Run 13

Run 13 was begun on November 18, 1949, and continued without operational difficulty until December 18, 1949. During the 730 hours the gasifier was in operation, 164.3 tons of natural Dakota Star lignite was used in the production of 6,979 M c.f. of gas containing 3,887 M c.f. of hydrogen at rates varying from 7.9 to 11.7 M c.f. per hour.

The data obtained from run 13 may best be presented graphically as is done in figures 13, 14, 15, and 16. The abscissa of these curves is the total water available for the gasification process per ton of moisture- and ash-free lignite. The total water was calculated as the sum of the steam introduced to both reaction zones, and of the inherent and potential moisture in the lignite. The inherent and potential moisture was taken as the water obtained from the oxygen and equivalent hydrogen, as indicated by the ultimate analysis. Ordinates of the curves are the gas yield per ton of moisture- and ash-free lignite, percentage of carbon gasified, percentage of gas made, and the hydrogen-carbon monoxide ratio of the product gas. The gas yield and total water available per ton were presented on the moisture- and ash-free basis to eliminate variations in the feed rate and inconsistencies in the moisture and ash content of the feed. The lower curve in figures 13, 14, and 16 represents the conditions when the live steam admitted to the char zone was increased by 50-pound increments from approximately 50 pounds per hour to 293 pounds per hour with no steam being added to the lignite zone. The upper curve in the corresponding figures, represents the conditions when a constant steam load of approximately 100 pounds per hour was maintained in the char zone, and the steam was increased by 50-pound increments to the lignite zone. In all cases, the combustion space temperatures and feed rate were approximately constant.

Figure 13 illustrates the influence of the location of steam introduction on the gas yield per ton of moisture- and ash-free lignite. At equal amounts of water available, the curves indicate that the gas yield was higher when at least part of the steam admission was to the lignite zone. The effect of the different location of steam introduction was more apparent at the higher steam rates. At 4,000 pounds of total water available per ton of moisture- and ash-free lignite, 79.5 M c.f. of product gas per ton of moisture- and ash-free lignite was produced when at least part of the steam was admitted to the lignite zone, and 71.5 M c.f. was produced with steam admission only to the char zone. The gas yield increased more rapidly when a portion of the live steam was introduced to the lignite zone. Based on 1 ton of moisture- and ash-free lignite, the addition of 200 pounds of live steam to the char zone at 3,500 pounds of total steam increased the gas yield from 69.0 to 70.0 M c.f., whereas the same addition resulted in an increase in yield from 74.0 to 76.5 M c.f. when admitted to the lignite zone.

Extrapolation of the gas-yield curves to the water equivalent of a 37-percent-moisture lignite would give the gas yield when no steam is added, and the process would then be considered that of carbonization. At this point, about 51 M c.f. of



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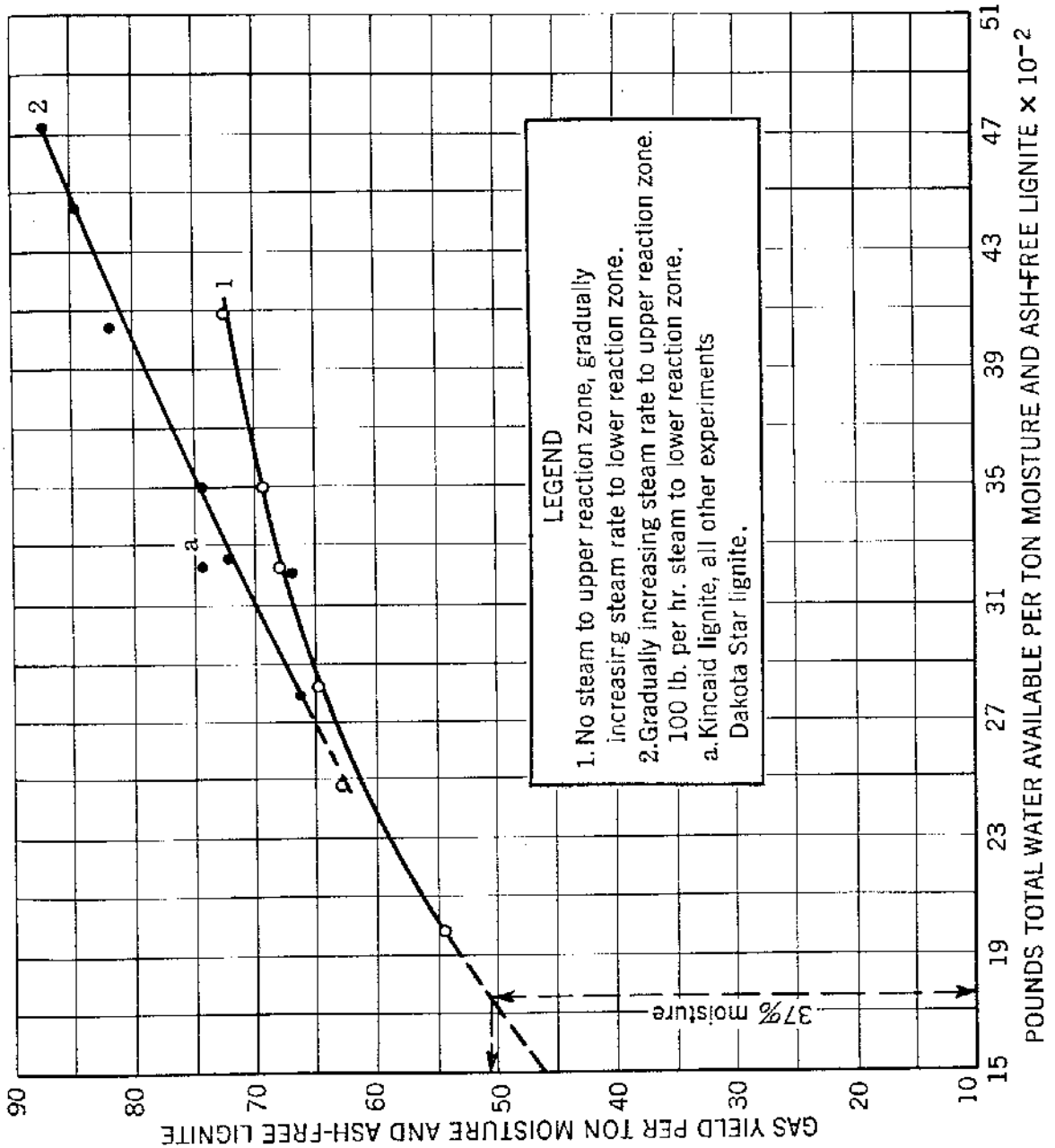


Figure 13. - Gas yield per ton of moisture- and ash-free lignite as a function of total water available and location of steam admission.

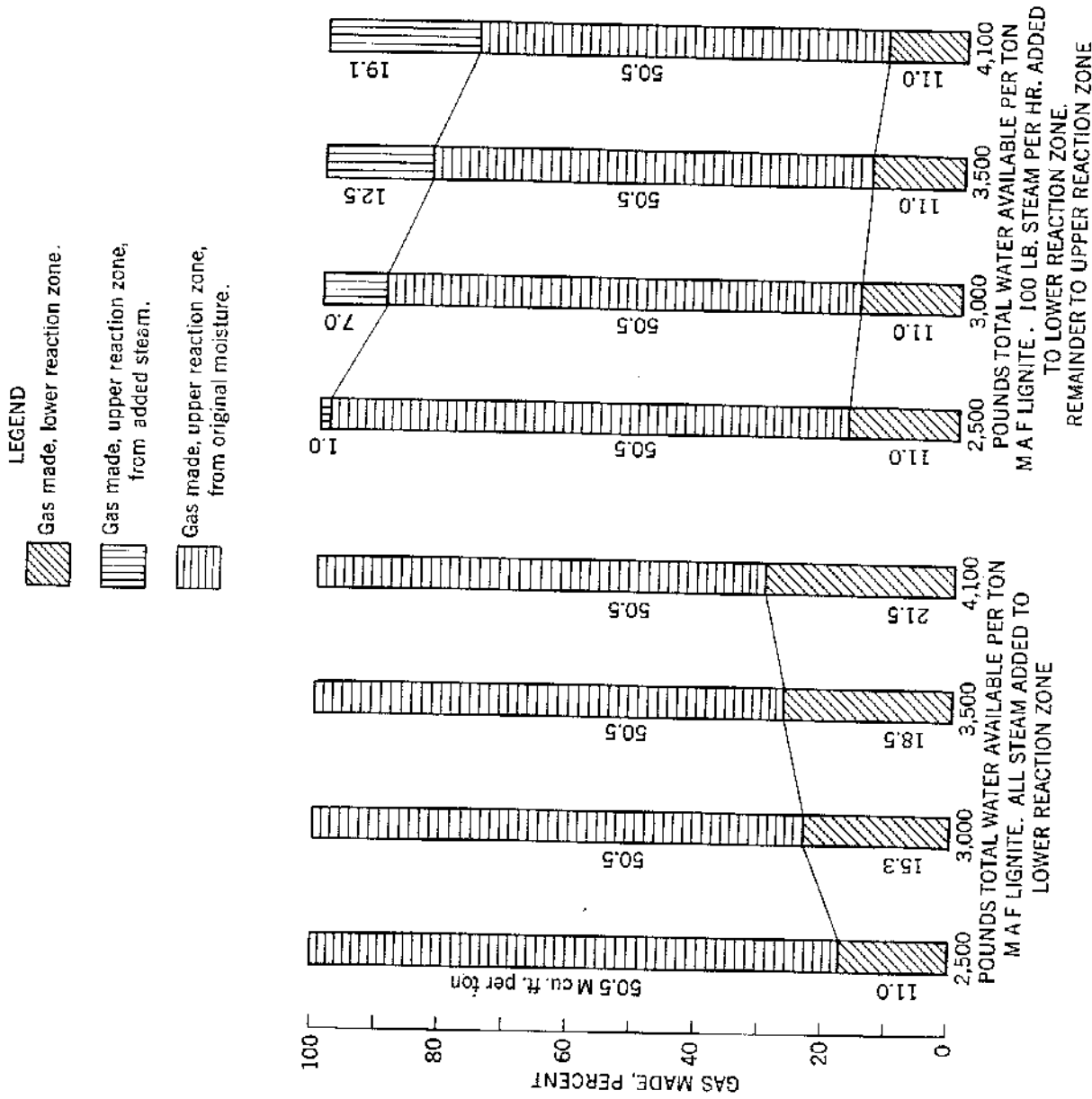


Figure 14. - Distribution of product gas as a function of total water available and location of steam admission.

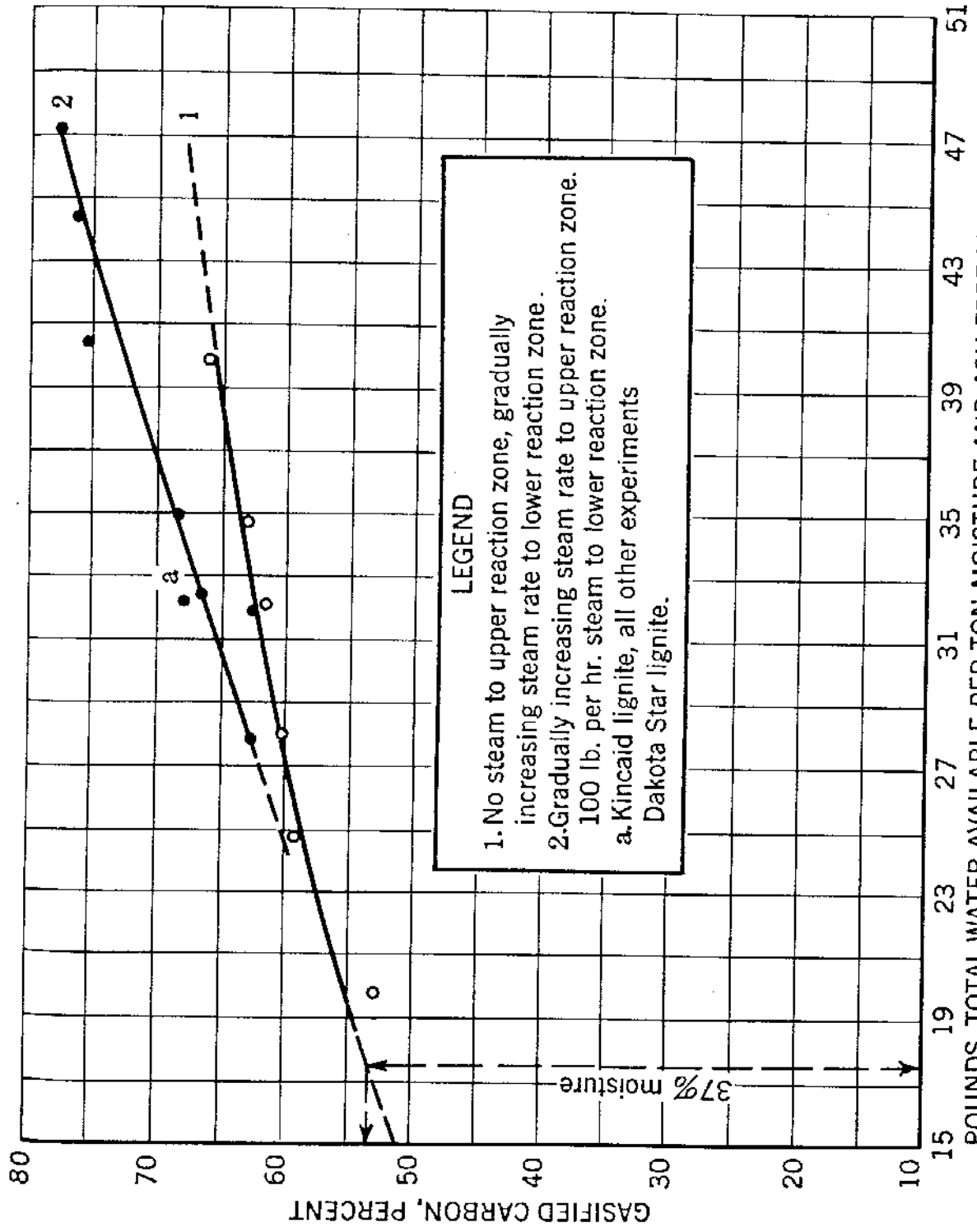


Figure 15. - Percentage of carbon gasified as a function of total water available and location of steam admission.

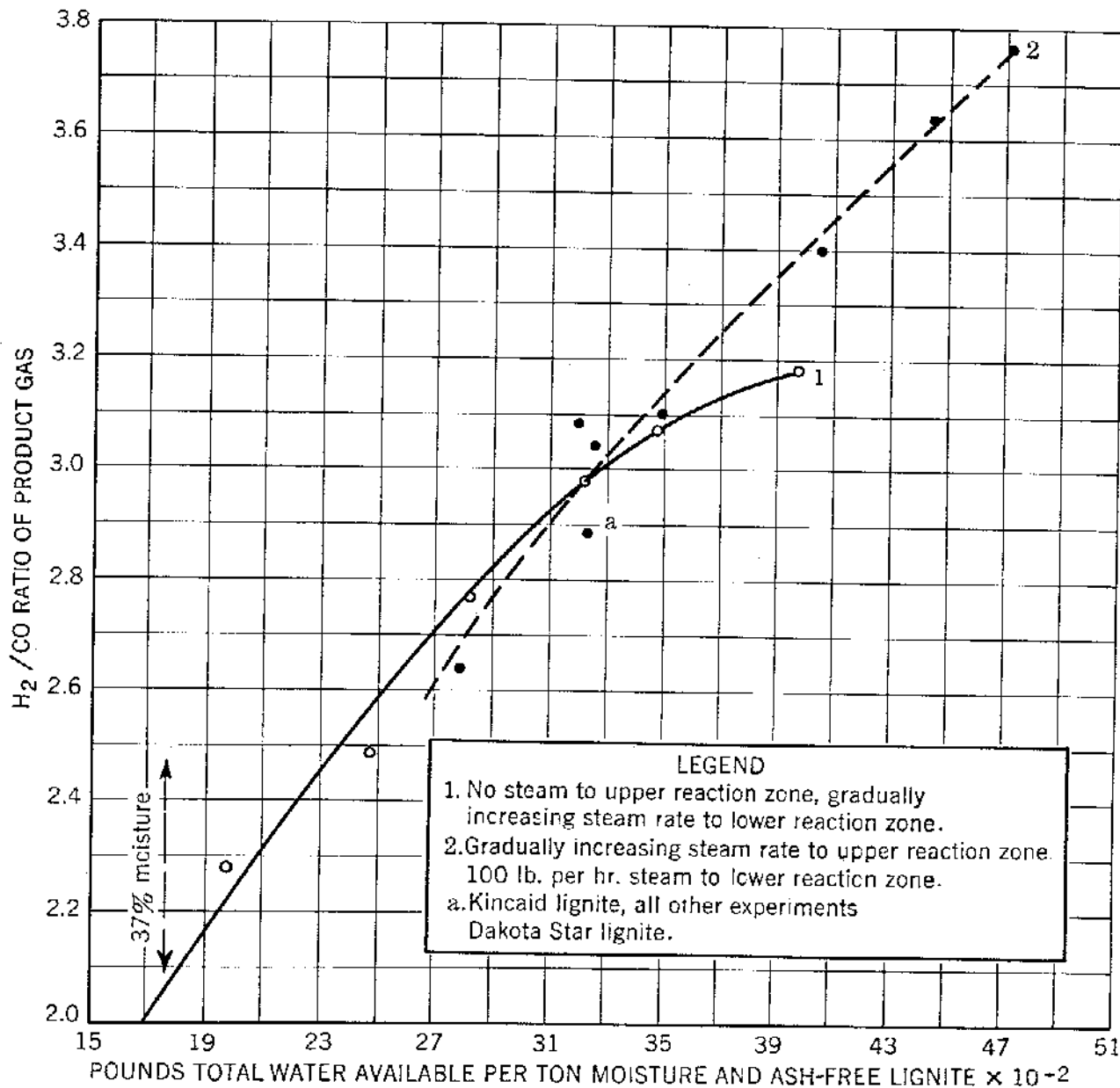


Figure 16. - H₂-CO ratio of product gas as a function of total water available and location of steam admission.

gas would be produced per ton of moisture- and ash-free lignite, or, on a natural lignite basis, at 37 percent moisture and 5.5 percent ash, 32 M c.f. per ton. Thus, a high percentage of the total product gas originates from the reaction of the potential and inherent moisture in the lignite and the intimately associated carbon. This gas yield appears high for a carbonization process, but, owing to the design of the Grand Forks unit, the water vapors are passed down through the hot charge and thus have an excellent opportunity to react with the carbon of the lignite. In a conventional or updraft carbonizer, little or no water-gas reaction would be possible because of the short time of contact and the low temperature of the carbon and water vapor, consequently the volume of gas produced under otherwise equivalent conditions would be less.

The carbonization of Velva lignite with 37 percent moisture in the 13-inch BM-AGA retort yielded 14.85 M c.f. gas per ton at a carbonization temperature of 1,470° F. (7).

Since the lower reaction zone is approximately 30 percent of the total reaction zone, a comparable portion of the product gas should be formed therein. However, the percentage of the product gas formed in the lower reaction zone, even with no steam added to the lignite zone, was less than 30 percent, although this amount was approached at very high steam rates to the lower reaction zone. This lower production indicates that steam was less efficiently utilized except at the very high steam additions to the lower reaction zone.

Figure 14 compares the distribution of the product gas at the same total water available depending on the position of steam addition. When 2,500 pounds of total water were available per ton of moisture- and ash-free lignite, 82.2 percent of the total 61.5 M c.f. of product gas was made in the upper reaction zone when all the steam was introduced into the lower reaction zone. At the same total water available and with a base load of 100 pounds of steam to the lower reaction zone and the remainder to the upper reaction zone, 82.4 percent of the total 62.5 M c.f. of gas was formed in the upper reaction zone. The gas production increased to 72.0 M c.f. per ton of moisture- and ash-free lignite at 4,100 pounds of total water available per ton when all of the steam was added to the lower reaction zone. Of this 72.0 M c.f., 70.1 percent was produced in the upper reaction zone from the reaction of the carbon and the water originally present in the lignite. The gas production increased to 80.6 M c.f. at the same total water when all except the 100 pounds of steam per hour was added to the upper zone. The percentage of the gas formed in the upper reaction zone under these conditions increased to 86.4 percent. The increase in gas production and of the percentage of total gas produced in the upper reaction zone when a portion of the live steam was introduced in the upper zone at the same total water available also indicated that the steam is more efficiently utilized in the upper reaction zone.

Figure 15 shows the percentage of carbon gasified as a function of the location of steam admission. These curves indicate a higher percentage of carbon gasified when part of the live steam was introduced to the lignite zone, the difference being more pronounced at the higher steam rates. At 2,800 pounds of total water available per ton of moisture- and ash-free lignite, approximately 60 percent of the carbon was gasified with admission of steam to the lower reaction zone only. At the same amount of total water, 62.5 percent of the carbon was gasified when steam was introduced to the upper reaction zone, and a constant load of 100 pounds of steam per hour was maintained in the lower zone. At 4,000 pounds of total water available, the percentages of carbon gasified were 65.5 and 72.0, respectively.

An equal amount of live steam increased the gasification to a greater extent when it was introduced into the upper reaction zone. Beginning with 3,500 pounds of

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total steam per ton of moisture- and ash-free lignite, addition of 200 pounds of steam per ton of moisture- and ash-free lignite to the lower reaction zone increased the gasification from 63.5 to 64.5 percent, whereas the addition of the same amount to the upper reaction zone increased the gasification from 66.0 to 70.0 percent. For a 37-percent-moisture lignite, extrapolation of the curves showed that approximately 53 percent of the available carbon would be gasified without adding steam to the unit.

Figure 16 shows the H₂-CO ratio of the product gas as a function of the location of the steam introduction. Except at the higher steam rates there was little difference in the gas composition, whether the live steam was admitted to the upper or lower reaction zone. At the highest steam rate to the char zone, the hydrogen-carbon monoxide ratio was 3.17, and with the same amount of total steam, but with part admitted to the upper reaction zone, the ratio was 3.39. With no steam introduced to the reactor, the curve may be extended to the average 37-percent-moisture lignite as was done previously. At that point the hydrogen-carbon monoxide ratio of the gas would be between 2.0 and 2.1.

As was to be expected the percentage of the ash in the char decreased and the percentage of the fixed carbon increased with a decrease in the percentage of carbon gasified. This is shown in table 15, where analyses of the residue are presented at the highest, a medium, and the lowest percentage of carbon gasified. The ash decreased from 49.6 to 27.4 percent and the fixed carbon increased from 40.8 to 65.0 percent when the percentage of carbon decreased from 77.5 to 53.1 percent.

TABLE 15. - Analyses of residue from gasification process at various percentages of carbon gasified during run 13

Run and period	13-M	13-E	13-F
Carbon gasified, percent	77.5	65.8	53.1
Proximate analysis, percent:			
Moisture	0.7	0.9	0.8
Volatile matter	8.9	9.5	6.8
Fixed carbon	40.8	53.3	65.0
Ash ^{1/}	49.6	36.3	27.4
Ultimate analysis, percent:			
Hydrogen	1.0	1.2	0.7
Carbon	51.4	62.6	72.7
Nitrogen	.4	.5	.5
Sulfur	3.4	2.7	2.5
Oxygen	-	-	-
Ash ^{1/}	49.6	36.3	27.4
SO ₃ ^{2/3/}	7.2	5.8	5.9
CO ₂ ^{2/}	3.0	2.5	1.9
Heating value, B.t.u./lb.	8,090	9,790	10,980
Softening temperature of ash, °F.	2,440	2,380	2,360

1/ Ash uncorrected for sulfur and carbon reported as SO₃ and CO₂
 2/ In ash, reported as percent of original residue.
 3/ Sulfur reported as equivalent SO₃.

The screen analyses of the residue are given for the same experiments in table 16. Although one would expect the average size of the residue to increase with a decrease in the percentage of carbon gasified, the highest average size of the residue was found at the medium percent of gasification owing to the presence of a few large