

Calibrated totalizing meters were provided for gas, air, and steam. Orifices with indicating manometers were installed to indicate instantaneous rates of flow. Provision was made for collecting and weighing condensate formed in the steamline after the steam meter and before entrance into the gasifier. The amount of condensate was subtracted from the meter reading to obtain a more accurate rate of steam admission.

Static pressures throughout the pilot plant were measured with standard U-tube manometers. Lignite was weighed on a periodically checked suspension-type scale, while other weights, including that of refuse, were determined with platform scales.

Auxiliary Equipment

Product gas was disposed of by burning it in a small furnace constructed of castable refractory supported by an outer sheet-metal wall. Air for combustion was preheated while passing between the refractory casing and outer wall. A water spray in a packed section of the stack cooled the products of combustion to below 500° F. The cooled gases were diluted with air and exhausted into the atmosphere.

OPERATION OF RETORT

Operating Procedure

Operation of the small gasifier was based on experience gained in operating the commercial-scale unit (8), with necessary modifications due to changes in heating and in relative size.

Before starting, the unit was tested for leakage at 3 p.s.i.g. and the electrical heating system rechecked.

The annular reaction space was filled with crushed metallurgical coke and sufficient 1-1/2- by 1/2-inch rescreened as-received lignite to fill the feed hopper. Coke was used for starting to prevent plugging of lines and excessive contamination of discharged water by tar and oil formed before gasification temperature was reached.

A routine check of gaslines, water seals, and instrument operation was made, the water spray in the scrubber turned on, and the electrical heating system energized.

The temperature in the heating chamber was allowed to reach 300° F. rapidly; further increases by 50° to 60° F. per hour were automatically controlled. When the temperature in the heating chamber had reached about 1,200° F., steam was introduced into the reactor at 10 lb. per hr., and the refuse receiver was purged with nitrogen. At 1,600° F. in the heating chamber, removal of coke was begun. Temperatures were increased steadily so that, after 10 more hours, the temperature of the top compartment in the heating chamber was 1,750° F. and in the two lower compartments 1,850° F. When gas production reached 250 cu. ft. per hr., as indicated by an orifice meter in the ventline, gas was routed through the scrubbing and metering system, and the gas-disposal furnace was started.

Preselected operating conditions were then established by adjusting the rate of char removal, temperatures in the heating compartments, and rates of steam and air admission. After steady-state conditions had been reached, a test period was started. The duration of tests varied from 6 to 24 hours.

At the beginning and end of each period readings were taken from the totalizing instruments, the feed hopper was filled, and char receivers were emptied to insure complete cutoff for rate determinations and material balances. Indicating and recording instruments were read hourly during transition and test periods for control purposes. Char receivers were changed, and blowover dust from the scrubbing system was removed and collected as required by operating conditions. Reaction-tube surface temperatures were determined with an optical pyrometer.

The data reported here are averaged hourly readings recorded during the test period.

After each test period flows of lignite and air were stopped while steam admission and refuse discharge were continued until the temperature in the top heating compartment started to rise rapidly because the lignite bed had passed. The temperature of this compartment was then reset to 1,500° F. A similar procedure was followed for the other compartments. When the volume of gas became too low to maintain pressure at the gas offtake, the gas was released through the ventline.

After all char was removed, the heat was cut off, the char outlet closed, and the steam stopped. The entire unit was thoroughly purged with nitrogen to insure elimination of combustible gas from the system. Final cooling, aided by air purging, was allowed to proceed slowly to ambient temperature before inspection of the unit.

Sampling

During test periods, lignite, residue, and product gas were sampled.

Lignite was sampled from the bottom of the traveling bucket before and after the hopper was charged. The combined samples, comprising approximately 15 percent of total feed for a test, were split, crushed, and riffled to obtain a sample for proximate and ultimate analyses. Small grab samples of lignite were taken during loading for immediate moisture determination. Large variations in moisture content were compensated for by adjusting the rate of flow of steam to maintain the desired steam-lignite ratio.

Char removed during a test period was split, crushed, and riffled to obtain a representative sample for proximate and ultimate analyses.

Gas was normally sampled by passing a portion of the scrubbed gas through a dry sampling drum of approximately 5-cu. ft. capacity at a rate of about 0.6 cu. ft. per hour - sufficient to displace the contents of the sampling tank every 8 hours. The rate of gas flow through the drum could be adjusted so that representative samples could be obtained even during short tests.

A portion of the gas containing unreacted steam was passed through a condenser, and the condensate and dry gas were measured to determine the concentration of water vapor in the gas. Two to six determinations were made during a test, depending upon the duration of the test and operating conditions.

LIGNITE TESTED

The lignite used was Dakota Star, strip-mined near Hazen, Mercer County, N. Dak. The stoker-size lignite was rescreened to 1-1/2- by 1/2-inch before use to eliminate fines produced by handling. It was charged to the reactor as received.

The range of lignite compositions as charged to the gasifier is shown in table 2. Major differences were due to changes in moisture content which ranged from 34.0 to 37.4 percent. Ash varied from 4.8 to 5.9 percent. On a moisture- and ash-free basis, the composition was uniform and closely comparable with that of Dakota Star lignite previously tested (1, 2).

TABLE 2. - Composition of Dakota Star lignite charged to gasifier^{1/}

Proximate analysis, <u>percent</u>		Ultimate analysis, <u>percent</u>	
Moisture	33.2 - 37.4	Hydrogen	6.7 - 7.1
Volatile matter	26.7 - 28.7	Carbon	40.4 - 43.5
Fixed carbon	30.7 - 32.6	Nitrogen5 - .6
Ash	4.8 - 5.9	Oxygen	43.0 - 46.4
		Sulfur6 - .8
		Ash	4.8 - 5.9
Gross heating value, B.t.u. per lb.		6,920 - 7,230	

Fusibility of ash, °F.

Initial deformation temperature	2,250 - 2,400
Softening temperature	2,330 - 2,450
Fluid temperature	2,400 - 2,480

^{1/} As received.

The size distribution is presented in table 3. Lignite charged to the gasifier was of uniform average size, varying from 0.89 to 1.01 inch. From 67.4 to 83.3 percent of the lignite was larger than 0.75 inch.

TABLE 3. - Size distribution of Dakota Star lignite charged to gasifier

U. S. mesh No.	Screen opening, inch	Percentage retained
	0.75	67.4 - 83.3
	.50	7.5 - 16.7
	.371	3.2 - 6.7
4	.185	2.0 - 5.2
8	.093	1.2 - 4.1
16	.046	.7 - 2.1
-16	.046	.9 - 2.4
Average size, inch		.89- 1.01

RESULTS OF TESTS

Comparison of Small and Commercial-Scale Gasifiers

Summary data for the tests reported here and information on the composition of gas are included in tables 8 and 9 in the appendix.

In the small gasifier, with a uniform nominal temperature of 1,900° F. over the length of the heating chamber, approximately 20 percent more gas was produced - 82.7 as compared with 68.1 cu. ft. per hr. and sq. ft. - than in the large gasifier where the heating chamber was maintained at 1,925° F. in the lower portion and 1,600° F. at the top. This increase in capacity was obtained despite a lower steam-lignite ratio. A lower ratio would normally decrease gas production (under otherwise similar conditions) owing to lower initial concentration of water vapor. Based on a gas production of 14,100 cu. ft. per hr., as obtained during period 17-B in the large gasifier (7), about 17,000 cu. ft. per hr. could be expected if the large unit were operated with the heating chamber at a uniform temperature of 1,900° F. If the effect were proportional to the reactor volume, gas production would be 23,000 cu. ft. per hr. However, because of heat-transfer limitations, the required amount of heat probably cannot be transferred through the metal wall at the limiting operating temperature. Temperatures were maintained at 1,600° F. in the upper part of the large gasifier to protect auxiliary exhaust equipment. Consequently, heat transfer at the entrance of the annulus was lower. The heating system of the small gasifier allowed nearly uniform, high temperatures, even at the entrance of the annulus, thus reducing the length of the drying and preheating zones and providing a proportionally larger space for gasification. The increase in unit capacity of the small gasifier was due to increased rate of heat transfer. The ratio of heat-transfer rates of small to large units was 1.19, nearly the same as the product-gas ratio. Increased rate of heat transfer was due to the high uniformly distributed temperature in the heating chamber. Difference in heat transfer due to reduced wall thickness in the small unit would be negligible.

"Nominal temperature" of the heating chamber of the small gasifier means the automatically controlled temperature in each of the three heating compartments. The other measured temperature in each compartment was somewhat lower. Thus, average temperatures were lower, being 1,768° F. for a nominal 1,800° F. and 1,866° F. for a nominal 1,900° F. A nominal temperature of 1,900° F. was not exceeded because experience with the commercial-scale gasifier had shown this temperature to be the maximum safe operating temperature for 310 alloy steel.

Reduction of the nominal temperature of the small gasifier to 1,800° F. resulted in performance more nearly approaching that of the large unit, the performance ratio being close to 1. Gas production per hour per square foot was 68.1 and 61.7 cu. ft. for the large and small gasifier, respectively. The ratio of gas production per unit heating surface was 0.91 and per unit volume 1.21, again close to the heat-transfer-rate ratio 1.05. Because nearly equal percentages of carbon were gasified, the performance ratios on the basis of lignite paralleled those for gas production.

Relationship of Gas Production, Rate of Feeding, and Heating Chamber Temperature, Small Gasifier

For nearly the same extent of carbon gasification and steam-lignite ratios, gas production increased 34 percent, from 970 to 1,300 cu. ft. per hr., when the nominal temperature was raised from 1,800° to 1,900° F. This increase was the same as the increase in feed rate, made possible because the carbon conversion thus remained the same at 1,900° F. The production of (H₂+CO) increased about 38 percent because of a higher concentration of carbon monoxide in the gas. The hydrogen content decreased slightly.

The gross heat input to the gasifier per cubic foot of product gas was 107 and 103 B.t.u. at 1,800° and 1,900° F., indicating that total heat requirements and losses did not change appreciably over this temperature range. The H₂-CO ratio

decreased only slightly, owing chiefly to the higher carbon monoxide content and only slightly due to a decrease in hydrogen.

Production of Crude Ammonia-Synthesis Gas

Figure 10 shows the influence of the rate of air flow on gasifier performance at nominal temperatures of 1,800° and 1,900° F.

At 1,800° F. and an air flow of 7.4 cu. ft. per lb. of as-received lignite, gas with a (H₂+CO)-N₂ ratio of 2.9 was produced, suitable for conversion to ammonia-synthesis gas. At 1,900° F. and an air flow of 3.74 cu. ft. per lb., the ratio was 3.7. As this rate of gas production exceeded design capacity, higher air and steam rates could not be used. The high velocity of the gas made the lignite bed unstable, resulting in considerable entrainment of fine residue in the gas. Because the project was terminated, changes to handle larger gas volumes could not be made. The hydrogen-carbon monoxide ratio of the gas was nearly independent of air admission at 1,800° F., varying only from 2.2 to 2.5 over the total range of air admission. At 1,900° F. the H₂-CO ratio varied from 1.9 to 2.4 over a smaller range of air admission.

The maximum increase of the rate of (H₂+CO) production over that without air admission was 65 percent at 1,800° F. and 50 percent at 1,900° F. Total gas production, including carbon dioxide and nitrogen from the air, was almost doubled at the highest rates of air admission. For similar (H₂+CO)-N₂ ratios, the rate of production of (H₂+CO) increased 35 percent when the nominal temperature was raised from 1,800° to 1,900° F. This increase was nearly equal to that obtained without addition of air. Thus, the effect of the temperature in the heating chamber on gasifier capacity is approximately the same whether or not supplementary heating is employed.

Obviously, the amount of external heat required for gasification can be reduced when a portion of the heat is supplied internally. The data indicated essentially a direct relationship between air supplied per pound of lignite and external heat requirements per cubic foot of total gas or (H₂+CO). Deviations were chiefly caused by variation in the percentage of carbon gasified. At 1,800° F., without air, 107 B.t.u. was required per cu. ft. of product gas; with an air-lignite ratio of 7.4 cu. ft. per lb., these requirements were reduced by approximately 44 percent to 60 B.t.u. per cu. ft. At 1,900° F. with an air-lignite ratio of 3.7, they were reduced from 103 to 71 B.t.u. Reduction in external heat requirements per cubic foot of (H₂+CO) ranged from 131 to 99 B.t.u. per cu. ft. at 1,800° F. and from 122 to 112 at 1,900° F.

Heat requirements per cubic foot of product gas in the large unit varied from 135 to 107 B.t.u. over a wide range of experimental conditions. The lower value was obtained with gasification of steam-dried lignite containing 12 to 15 percent moisture. Higher heat requirements in the large unit resulted from higher heat losses due to differences in heating systems; however, a similar reduction of external heat requirements can also be expected in the commercial-scale unit.

The internal heat supplied by a known air-lignite ratio could not be predetermined accurately owing to uncertainties in estimating the reactor temperature and consequently the extent of conversion of carbon dioxide to carbon monoxide. In figure 11 calculated and experimental values are compared as a function of air-lignite ratio. The calculated curves are based on the assumption that oxygen had reacted with lignite to form only carbon monoxide or only carbon dioxide; because

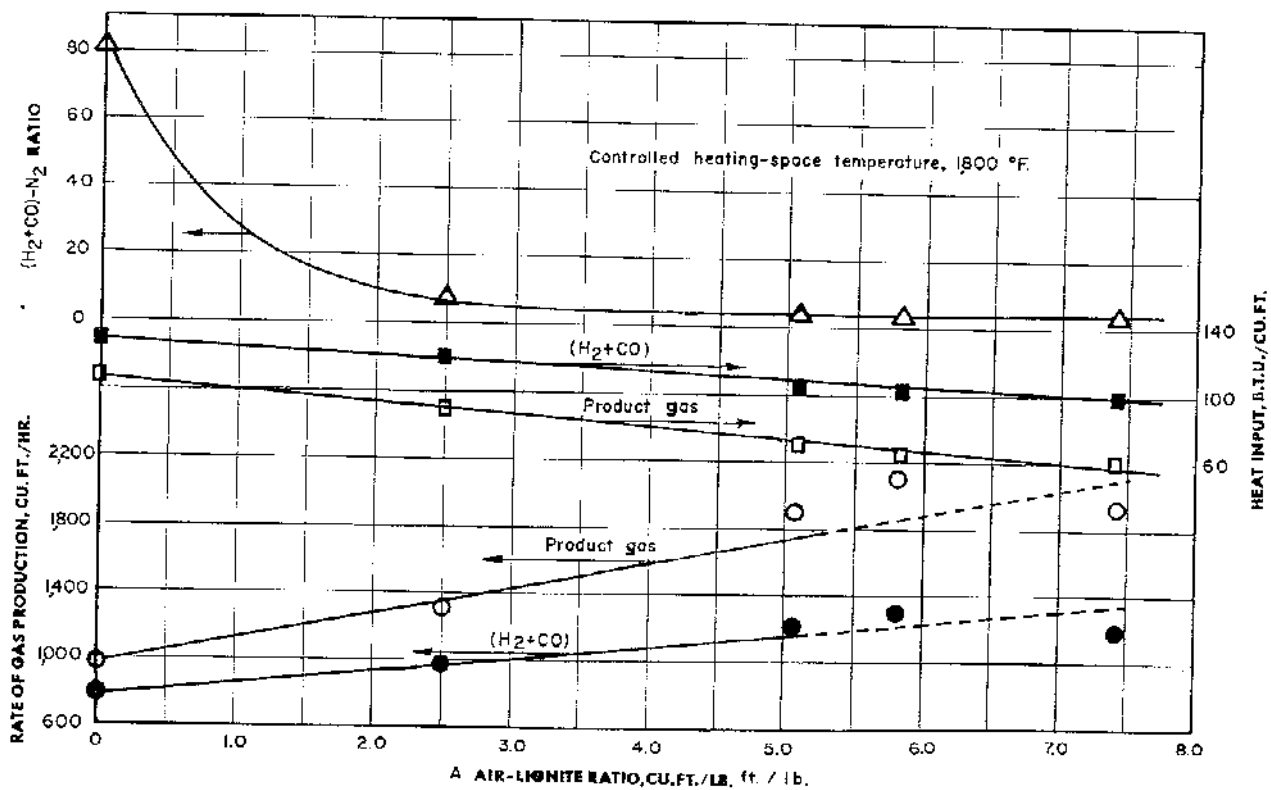
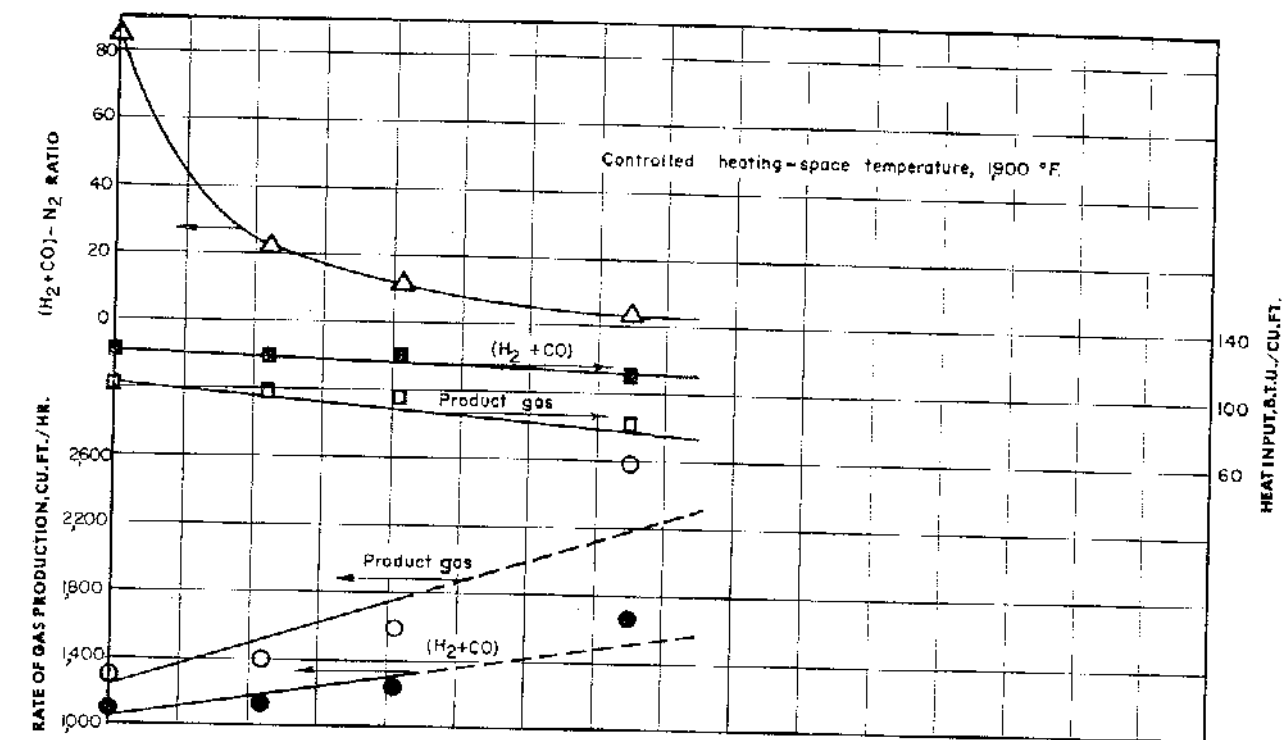


Figure 10. - Gasification of lignite as a function of air-lignite ratio.

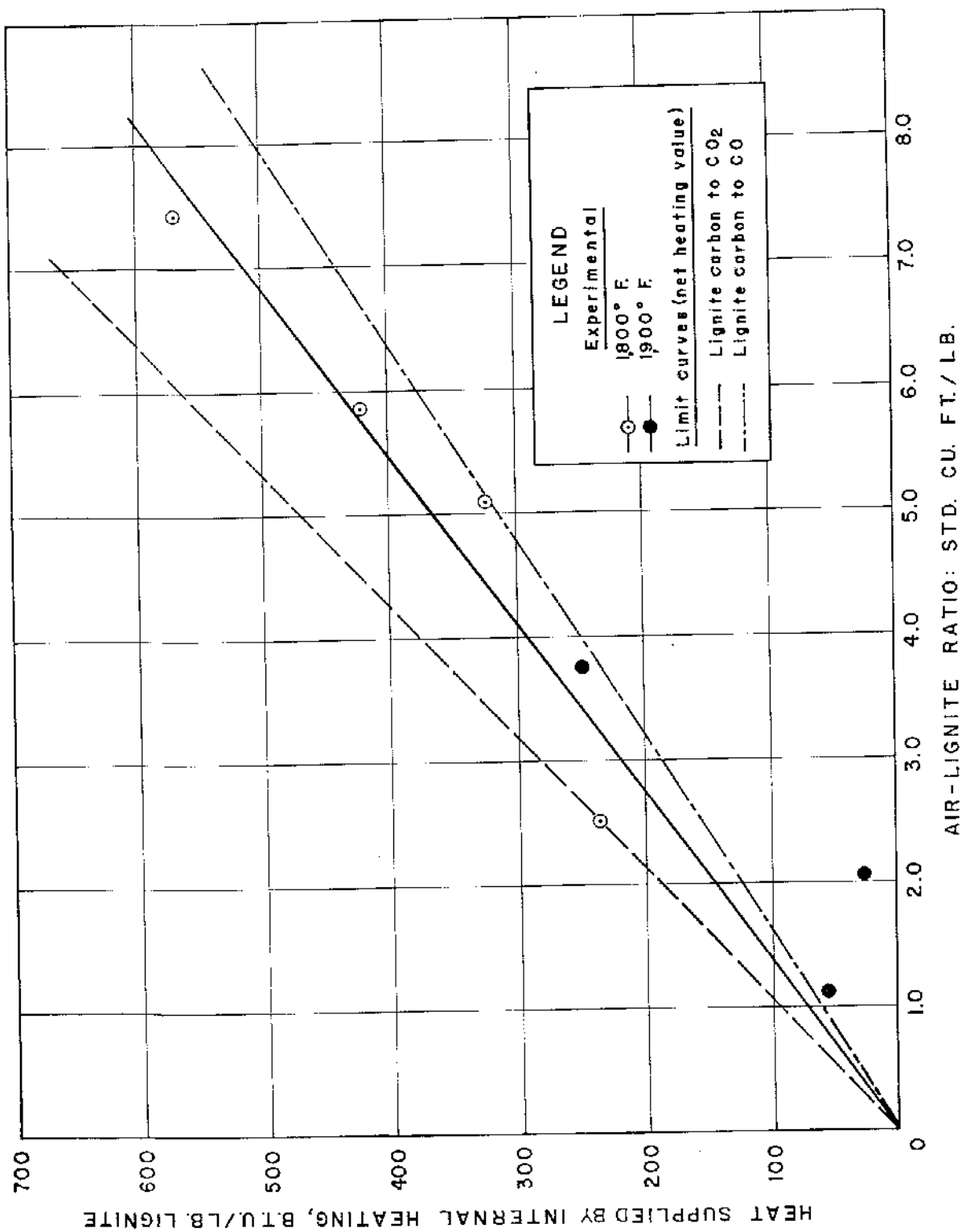


Figure 11. - Comparison of experimental and theoretical internal heating for lignite gasification.

of the high temperature, the net heating value of lignite was used. Data for the experimental points were obtained by difference between external heat requirements per M c.f. of (H₂+CO) without internal heating and with internal heating at various air-lignite ratios. In general, the experimental data tend to lie near the lower limit curve, indicating that a major portion of the carbon dioxide was converted to carbon monoxide. Higher temperatures (1,900° F.) favored formation of carbon monoxide.

Composition of Products

Gas analyses in table 4 are presented in order of increasing air rate for each temperature level. Without addition of air the H₂-CO ratio decreased when the nominal temperature was increased from 1,800° to 1,900° F. At 1,800° F. and the maximum air rate of 490 cu. ft. per hr., the (H₂+CO)-N₂ ratio was 2.9 and the H₂-CO ratio 2.3. At 1,900° F. the lowest (H₂+CO)-N₂ ratio produced was 3.7, and the corresponding H₂-CO ratio was 2.4.

In tests at 1,800° F. the carbon dioxide content of the gases increased with an increase in air rate to a maximum of 16.6 percent in the raw gas, or 20.5 percent in the nitrogen-free gas. This increase would be anticipated because more oxygen reacted with the carbon at a relatively low temperature to give CO₂. For the same tests at 1,800° F., the amount of (H₂+CO) on a nitrogen-free basis decreased from 82.4 to about 77.0 percent.

TABLE 4. - Composition of product gas^{1/}

Nominal temp., °F.	Test No.	Composition, percent								Ratio H ₂ /CO	Ratio (H ₂ +CO)-N ₂	Calculated heating value, B.t.u./cu.ft.	
		CO ₂	H ₂	CO	CH ₄	C ₂ H ₆	N ₂	O ₂	gross			net	
1,800	1	13.8	0.0	25.6	56.0	2.8	0.8	1.0	0.0	2.21	81.6	292	261
1,800	7	14.5	.0	22.4	51.1	2.5	.1	9.3	.1	2.28	7.90	261	240
1,800	9	16.5	.1	18.1	45.9	2.7	.0	16.6	.1	2.53	3.85	232	207
1,800	10	16.6	.0	18.1	43.5	2.6	.0	19.1	.1	2.41	3.23	224	199
1,800	11	15.7	.0	18.9	42.0	2.4	.0	20.9	.1	2.27	2.92	218	195
1,900	2	11.8	.0	28.9	55.2	2.9	.0	1.0	.0	1.91	84.1	297	267
1,900	3	12.3	.0	27.8	53.3	2.8	.2	3.6	.1	1.92	22.0	288	259
1,900	4	12.7	.0	26.6	51.3	2.1	.7	6.8	.1	1.93	11.8	276	258
1,900	6	15.9	.2	18.5	45.1	2.9	.1	17.2	.1	2.43	3.70	236	211

^{1/} Sample taken after water scrubber.

Typical analyses of gasification residue and blowover dust are presented in table 5. The tests are arranged in order of increasing air admission and were made at a nominal temperature of 1,800° F.

Variations in the composition of the residue were due chiefly to differences in amount of carbon gasified; the concentration of ash in the residue was directly proportional to the extent of carbon conversion.

Concentration of ash in the dust was appreciably higher than in the residues for tests 1 and 7, which were performed with a relatively low gas velocity. At low velocities small, highly reacted particles were preferentially entrained, thus increasing the ash content of the dust over that of the residue. With higher mass velocities in tests 9 and 10, larger and less completely reacted particles were entrained, approaching those of the residue in size and ash content.

TABLE 5. - Typical proximate and ultimate analyses of gasification residue and blowover dust from tests at 1,800° F.

Test	Residue									Heating value, B.t.u./lb.
	Proximate, percent			Ultimate, percent						
	Mois- ture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	
1	1.5	7.4	57.1	34.0	1.2	66.3	0.4	-	3.6	10,310
7	.8	7.4	56.5	35.3	1.0	66.7	.4	-	3.9	10,400
9	.7	7.0	63.9	28.4	1.3	71.5	.4	-	3.0	11,130
10	.7	7.0	66.2	26.1	1.2	72.2	.5	-	2.4	11,250
Blowover dust ^{1/}										
1		20.9	32.6	46.5	1.0	45.1	0.2	4.3	2.9	6,540
7		23.7	32.2	44.1	1.4	43.5	.3	8.0	2.7	6,260
9		15.2	62.4	22.4	1.5	68.2	.5	6.1	1.3	10,240
10		13.1	68.0	18.9	1.3	72.2	.5	6.1	1.0	10,970

1/ Data converted to moisture-free basis because blowover dust was collected by filtering discharge from water scrubber.

Typical Heat Balances

Typical heat balances, given in table 6, include tests without and with addition of air at nominal temperatures of 1,800° F. (tests 1 and 10) and 1,900° F. (tests 2 and 6). The percentage of carbon gasified was lowest in test 6, (68.5 percent, see table 8) while the rate of gas production was the highest. Due to the high gas production and extent of entrainment, the weight of blowover dust was difficult to determine, and the value appears to be too high. Heat recovered in the product gas, from 62.6 to 72.1 percent of heat input, varied with the extent of carbon gasified (68.5 to 78.0 percent), while that recovered in the solid products ranged from 11.3 to 25.9 percent. However, the sum of potential heat in gas and solids remained relatively uniform, between 83.4 and 88.7 percent of the heat input. Depending upon the extent of entrainment of solids in gas, the potential heat in the blowover dust accounted for 0.1 to 15.7 percent of the total heat input. Calculated as percent of heat input, the heat loss by radiation, convection, and unaccounted-for remained relatively constant at both temperatures when no air was added. For tests with air admission the heat loss was generally lower.

Typical Material and Elemental Balances

Typical material and elemental balances for 4 tests at a nominal temperature of 1,800° F. are given in table 7. As was to be expected, the greatest mass of products appeared in the gas, which accounted for more than 70 percent of the total material input. Rates of recovery of dust varied 50 fold, being chiefly dependent upon rates of gas production. The dust concentration in the gas increased from 0.1 to 2.6 lb. per M c.f. when gas production increased from 969 to 2,114 cu. ft. per hr. Undecomposed steam constituted a relatively constant fraction of the products of gasification in these tests, because the H₂-CO ratio of the gas ranged only from 2.21 to 2.53.

Elemental balances followed the mass distribution in that the major portion of carbon, oxygen, and hydrogen fed to the gasifier was present in the gas. Differences in distribution of carbon, hydrogen, and oxygen were caused by change in operating conditions.

TABLE 6. - Typical thermal balances^{1/}

Temperature, °F. Test Air added, cu. ft. per hr.	1,800		1,900		1,800		1,900	
	B.t.u./hr., thousand	Percent	B.t.u./hr., thousand	Percent	B.t.u./hr., thousand	Percent	B.t.u./hr., thousand	Percent
Heat in:								
Potential heat in lignite as charged	286.9	70.4	382.1	71.3	585.6	78.0	759.6	78.1
Electric power input	103.6	25.4	133.8	25.0	134.8	18.0	183.0	18.8
Sensible and latent heat in steam ^{2/}	16.9	4.2	19.7	3.7	30.0	4.0	30.5	3.1
Total in	407.4	100.0	535.6	100.0	750.4	100.0	973.1	100.0
Heat out:								
Potential heat in gas	283.3	69.5	386.2	72.1	472.8	63.0	609.1	62.6
Sensible heat in gas	15.0	3.7	21.6	4.0	42.4	5.6	47.4	4.9
Potential heat in char	61.9	15.2	59.3	11.1	95.4	12.7	99.8	10.2
Sensible heat in char	1.0	0.3	1.0	0.2	1.7	0.2	1.7	0.2
Sensible and latent heat in undecomposed steam	12.8	3.1	12.5	2.3	34.2	4.6	37.6	3.9
Potential heat in blowover dust	0.5	0.1	1.2	0.2	59.2	7.9	152.8	15.7
Sensible heat in blowover dust ^{3/}	-	-	-	-	1.3	0.2	3.0	0.3
Radiation, convection, and loss	32.9	8.1	53.8	10.1	43.4	5.8	21.7	2.2
Total out	407.4	100.0	535.6	100.0	750.4	100.0	973.1	100.0

1/ Gross heat basis above 60° F.

2/ Calculated as 1058 ÷ Cpm (t_s-60) B.t.u. per pound where Cpm is mean specific heat, and t_s is temperature of process steam, °F.

3/ Dashes show insufficient recovery for calculation.

TABLE 7. - Typical material and elemental balances^{1/}

Test	1		7		9		10	
	Lb./hr.	Percent	Lb./hr.	Percent	Lb./hr.	Percent	Lb./hr.	Percent
Mass Balances								
Material in:								
Lignite	40.0	73.2	50.0	64.7	75.0	58.2	83.0	57.2
Steam	14.6	26.8	17.8	23.0	26.0	20.1	25.8	17.8
Air	None	None	9.5	12.3	28.0	21.7	36.3	25.0
Total in	54.6	100.0	77.3	100.0	129.0	100.0	144.9	100.0
Material out:								
Residue	6.0	11.0	6.3	8.2	8.6	6.7	8.5	5.9
Blowover dust	.1	.1	.2	.3	3.0	2.3	5.4	3.7
Undecomposed steam	8.8	16.2	12.5	16.1	20.1	15.6	22.4	15.5
Gas	38.7	71.0	57.3	74.1	90.8	70.4	104.6	72.1
Total out	53.6	98.3	76.3	98.7	122.5	95.0	140.9	97.2
Elemental Balances								
Carbon in:								
Lignite	17.1	100.0	20.6	100.0	30.2	100.0	34.4	100.0
Carbon out:								
Gas	13.2	77.4	16.3	79.0	22.2	73.5	24.6	71.5
Residue and blow- over dust	4.0	23.2	4.3	21.0	7.4	24.6	8.0	23.3
Total out	17.2	100.0	20.6	100.0	29.6	98.1	32.6	94.8
Hydrogen in:								
Lignite	2.7	2.8	3.5	63.6	5.2	64.2	5.6	65.9
Steam	1.6	37.2	2.0	36.4	3.9	35.8	2.9	34.1
Total in	4.3	100.0	5.5	100.0	8.1	100.0	8.5	100.0
Hydrogen out:								
Gas	3.3	76.8	3.9	70.9	5.1	63.0	5.4	63.5
Undecomposed steam	1.0	23.2	1.4	25.5	2.3	28.4	2.5	29.4
Residue and blow- over dust	.1	2.3	.1	1.8	.3	3.7	0.4	4.7
Total out	4.4	102.3	5.4	98.2	7.7	95.1	8.3	97.6
Oxygen in:								
Lignite	17.4	57.2	23.0	56.1	34.8	53.8	36.9	54.0
Steam	13.0	42.7	15.8	38.5	23.1	35.8	22.9	33.5
Air	None	None	2.2	5.4	6.7	10.4	8.5	12.5
Total in	30.4	100.0	41.0	100.0	64.6	100.0	68.3	100.0
Oxygen out:								
Gas	21.4	70.9	28.2	68.9	40.4	62.5	45.2	66.2
Undecomposed steam	7.8	25.8	11.0	26.8	17.9	27.8	19.9	29.1
Residue and blow- over dust	-2/	-	0.1	0.2	1.4	2.2	2.6	3.8
Total out	29.2	96.7	39.3	95.9	59.7	92.5	67.7	99.1

^{1/} Nominal temperature, 1,800° F.; tests arranged in order of increasing air admission.

^{2/} Oxygen in residue and blowover dust too low to report.

APPENDIX

Summary data are included in tables 8 and 9. Complete data are on file and may be obtained by direct request to the Charles R. Robertson Lignite Research Laboratory, Bureau of Mines, Grand Forks, N. Dak.

Test No.	1	2	3	4	6	7	9	10	11
Date	4-26-54	4-28-54	4-29-54	4-30-54	5-1-54	5-3-54	5-5-54	5-6-54	5-7-54
Durationhr.	24	24	7	6	6.3	11.5	12	12	7
Lignitelb. per hr.	40	52	60	60	108	50	75	83	66
Moisture as chargedpercent	34.2	33.2	35.4	37.3	36.8	37.2	37.4	35.4	34.0
Ash as charged do.	5.6	5.5	5.9	5.0	5.0	4.8	5.0	5.8	5.9
Carbon gasified do.	77.4	78.0	75.7	83.7	68.5	79.0	73.5	71.5	82.6
Lb. per M.c.F. of gas (S.G.C.)	41.2	40.8	43.0	37.7	42.0	38.1	39.3	39.2	34.3
Dry residue (calc.) ^{1/}lb. per hr.	6.1	7.8	9.6	7.0	19.4	6.7	11.7	14.6	8.6
Char ^{2/} do.	6.0	7.3	7.2	8.2	9.0	6.3	8.6	8.5	6.3
Blowover dust ^{2/} do.	0.1	0.2	—	—	13.0	0.2	3.0	5.4	4.4
Ash in charpercent	34.0	35.1	—	37.6	27.2	35.3	28.4	26.1	27.9
Ash in blowover dust do.	46.5	49.6	—	—	15.5	44.1	22.4	18.9	20.6
Gas made, S.G.C. ^{3/}									
Cu. ft. per ton of natural lignite	48,560	49,950	46,500	53,080	47,670	52,540	50,860	51,060	58,360
Cu. ft. per hr. from displacement meter	969	1,299	1,397	1,590	2,576	1,314	1,897	2,114	1,926
Gross heating value (calc.)B.t.u./cu.ft.	292	297	288	276	236	261	232	224	218
Net heating value (calc.) do.	261	267	259	258	211	240	206	199	195
Specific gravity (calc.)	0.531	0.526	0.550	0.570	0.640	0.580	0.636	0.658	0.667
Ratio H ₂ -CO	2.21	1.91	1.92	1.93	2.43	2.28	2.53	2.41	2.27
Ratio (H ₂ +CO)-N ₂	81.6	84.1	22.0	11.8	3.70	7.90	3.85	3.23	2.92
Steam:									
With lignitelb. per hr.	14.6	17.0	18.5	20.9	26.3	17.8	26.0	25.8	21.7
Undecomposed steam ..lb. per M cu. ft. dry gas ^{4/}	9.3	6.8	6.8	9.2	—	9.6	10.8	10.8	10.8
Aircu. ft. per hr.	0.0	0.0	67	123	404	125	379	482	490
Heating system data:									
Gross B.t.u. input per cu. ft. gas made	107	103	97	95	71	88	71	64	60
Heat transferB.t.u./sq. ft. reactor surface - hr.	4,500	5,100	—	—	—	—	—	—	—
Temperature, °F.:									
Upper heating zone, upper end(10)	1,709	1,790	1,785	1,771	1,755	1,705	1,707	1,713	1,667
Upper heating zone, lower end(26)	1,794	1,875	1,880	1,876	1,859	1,800	1,801	1,803	1,754
Center heating zone, upper end(9)	1,755	1,864	1,869	1,867	1,859	1,775	1,773	1,776	1,862
Center heating zone, lower end(37)	1,796	1,898	1,897	1,899	1,897	1,804	1,801	1,802	1,820
Lower heating zone, upper end(38)	1,791	1,893	1,892	1,896	1,895	1,800	1,799	1,799	1,799
Lower heating zone, lower end(8)	1,764	1,878	1,869	1,869	1,860	1,752	1,765	1,758	1,802
Gas leaving offtake(3)	1,282	1,388	1,398	1,380	1,301	1,325	1,296	1,295	1,299
Inner tube, 2 ft. from bottom(4)	1,273	1,289	1,299	1,281	1,222	1,252	1,236	1,243	1,269
Inner tube, 4 ft. from bottom(5)	1,184	1,120	1,133	1,132	1,076	1,153	1,184	1,205	1,235
Gas leaving retort(6)	883	904	960	930	971	918	988	1,045	1,116
Char leaving retort(14)	743	773	799	820	822	736	839	838	863
Optical:									
Retort tube, upper zone	1,702	1,810	1,790	1,900	1,800	1,740	1,750	—	—
Retort tube, center zone	1,697	1,802	1,800	1,825	1,820	1,730	1,700	—	—
Retort tube, lower zone	1,740	1,820	1,830	1,785	1,810	1,735	1,710	—	—

^{1/} Dry residue calculated from ash and carbon balances.
^{2/} Experimental values.
^{3/} Saturated gas at 60° F. and 30" Hg.
^{4/} Dry gas at 60° F. and 30" Hg.

TABLE 9.—Material and heat distribution of reactants and products for lignite gasification, small gasifier 1/

Test	Material distribution																	
	1		2		3		4		6		7		9		10		11	
	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent	Pounds	Percent
Material in:																		
Lignite	40.0	73.2	52.0	75.4	60.0	71.8	60.0	66.4	108.0	65.5	50.0	64.7	75.0	58.0	83.0	57.1	66.0	53.0
Steam	14.6	26.8	17.0	24.6	18.5	22.1	20.9	23.2	26.3	15.9	17.8	23.0	26.0	20.2	25.8	17.8	21.7	17.4
Air 2/					5.1	6.1	9.4	10.4	30.8	18.6	9.5	12.3	28.0	21.8	36.3	25.1	36.8	29.6
Total in	54.6	100.0	69.0	100.0	83.6	100.0	90.3	100.0	165.1	100.0	77.3	100.0	129.0	100.0	145.1	100.0	124.5	100.0
Material out:																		
Char	6.0	11.0	7.3	10.6	7.3	8.7	8.2	9.1	8.9	5.4	6.3	8.2	8.6	6.7	8.5	5.9	6.3	5.1
Blowover dust 3/	0.1	0.1	0.2	0.3	—	—	—	—	13.1	7.9	0.2	0.3	3.0	2.3	5.4	3.7	4.4	3.5
Undecomposed steam	8.8	16.2	8.8	12.8	9.4	11.2	14.4	15.9	25.8	15.6	12.5	16.1	20.1	15.7	22.4	15.5	20.1	16.1
Product gas	38.7	71.0	51.4	74.5	57.3	68.4	68.2	75.6	124.0	75.1	57.3	74.1	90.8	70.6	104.6	72.2	96.7	77.7
Total out 4/	53.6	98.3	67.7	98.2	74.0	88.3	90.8	100.6	171.8	104.0	76.3	98.7	122.5	95.3	140.9	97.3	127.5	102.4
Heat distribution 5/																		
	B.t.u.	Per-	B.t.u.	Per-	B.t.u.	Per-	B.t.u.	Per-	B.t.u.	Per-	B.t.u.	Per-	B.t.u.	Per-	B.t.u.	Per-	B.t.u.	Per-
	Thousands	cent	Thousands	cent	Thousands	cent	Thousands	cent	Thousands	cent	Thousands	cent	Thousands	cent	Thousands	cent	Thousands	cent
Heat in:																		
Potential heat in natural lignite as charged	286.9	70.4	382.1	71.3	427.8	73.2	418.3	70.5	759.6	78.1	349.4	72.0	519.3	75.8	585.6	78.0	477.4	77.3
Electrical power input	103.6	25.4	133.8	25.0	135.0	23.1	150.4	25.4	183.0	18.8	115.1	23.7	134.9	19.8	134.8	18.0	115.1	18.6
Sensible and latent heat in process steam 6/	16.9	4.2	19.7	3.7	21.5	3.7	24.3	4.1	30.5	3.1	20.7	4.3	30.2	4.4	30.0	4.0	25.2	4.1
Total in	407.4	100.0	535.6	100.0	584.3	100.0	593.0	100.0	973.1	100.0	485.2	100.0	684.4	100.0	750.4	100.0	617.7	100.0
Heat out:																		
Potential heat in product gas	283.3	69.5	386.2	72.1	403.0	69.0	438.1	73.9	609.1	62.6	342.6	70.6	440.3	64.3	472.8	63.0	420.3	68.0
Sensible heat in product gas	15.0	3.7	21.6	4.0	26.4	4.5	25.6	4.3	47.4	4.9	22.5	4.6	35.6	5.2	42.4	5.6	40.6	6.6
Potential heat in char	61.9	15.2	59.3	11.1	74.0	12.7	84.9	14.3	99.8	10.2	65.5	13.5	96.2	14.1	95.4	12.7	70.7	11.4
Sensible heat in char	1.0	0.3	1.0	0.2	1.3	0.2	1.6	0.2	1.7	0.2	1.2	0.3	1.6	0.2	1.7	0.2	1.3	0.2
Sensible and latent heat in undecomposed steam ...	12.8	3.1	12.5	2.3	13.9	2.4	21.1	3.6	37.6	3.9	18.4	3.8	30.1	4.4	34.2	4.6	31.9	5.2
Potential heat in blowover dust 3/	0.5	0.1	1.2	0.2	—	—	—	—	152.8	15.7	1.5	0.3	30.6	4.5	59.2	7.9	48.0	7.8
Sensible heat in blowover dust 3/	—	—	—	—	—	—	—	—	3.0	0.3	—	—	1.0	0.1	1.3	0.2	1.2	0.2
Radiation, convection, and unaccounted for	32.9	8.1	53.8	10.1	65.7	11.2	21.7	3.7	21.7	2.2	33.5	6.9	49.0	7.2	43.4	5.8	3.7	0.6
Total out	407.4	100.0	535.6	100.0	584.3	100.0	593.0	100.0	973.1	100.0	485.2	100.0	684.4	100.0	750.4	100.0	617.7	100.0

1/ Hourly basis, material entering and leaving annulus.

2/ No air added during tests 1 and 2.

3/ Dashes show insufficient recovery for calculation.

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