in a Thomas recording calorimeter. Final values of gas composition were obtained by complete analysis of representative samples in a standard Burrell-Orsat gas analyzer.

Sampling Methods

A representative sample consisting of 3 percent of the total lignite was taken from the discharge of the Weightometer for each test period. The total sample was reduced in size, and proximate and ultimate composition was determined by standard methods. Char was sampled by taking 3 percent by weight from each char container with a sampling tube. This composite sample was reduced in size for analysis. The size distribution of both lignite and char was determined. Dust removed from the gas in the water scrubber was collected and the composition determined.

Samples for gas analysis were collected from the effluent of two continuous sampling tanks having a capacity of approximately 30 cubic feet each. Cooled product gas, taken after the coke scrubber, was passed through one tank at a rate of 5 cubic feet per hour and through the other at a rate of 2.5 cubic feet per hour. A sample was taken from the first tank at the end of each 12-hour period and from the second at the end of 24 hours or completion of the test. Analyses from these samples were averaged to obtain the representative gas analyses reported.

Concentration of water vapor in the product gas leaving the retort was determined by drawing between 10 and 50 cubic feet of hot, wet gas through a water-cooled metal condenser, measuring the condensate obtained, and passing the cooled gas through a wet test meter.

Experimental Conditions and Objectives of Test Runs

This progress report covers the period from July 1, 1950, to December 31, 1951, during which time the gasifier was operated approximately 2,900 hours under varying experimental conditions. As previously discussed, the general objectives of this project were to develope a process for continuous gasification of lignite in an externally heated annular metallic retort and establish the technology and economy of this process (3, 4). To accomplish this, the project was divided into specific objectives, of which determination of the useful life of the alloy reaction tube was considered to be of major importance with respect to practicability and economy of the process (13). Simultaneously, other specific objectives were established for each run as part of a systematic investigation of process variables (3).

Lignites Charged

In the test program to evaluate the effect of process variables on gasifier operation, lignite from a single mine - the Dakota Star mine, Hazen, Mercer County, N. Dak. - was used in all of the runs (3). This lignite was used in runs 14, 15, and 16 of the present series through test period 16-G. In the latter part of run 16 and in run 17, comparative data were obtained on the gasification of lignite from 6 additional mines in North Dakota and 1 mine in Saskatchewan, Canada. Lignite for this series of tests was provided by the following mining companies: Baukol-Noonan, Inc., Dakota Briquets & Tar Products, Inc., Dakota Collieries Co., Knife River Coal Mining Co., Truax-Traer Coal Co., and Great West Coal Co., Ltd. (Saskatchewan, Canada). Locations of the eight mines from which lignites were obtained for testing are shown on the map in figure 3.

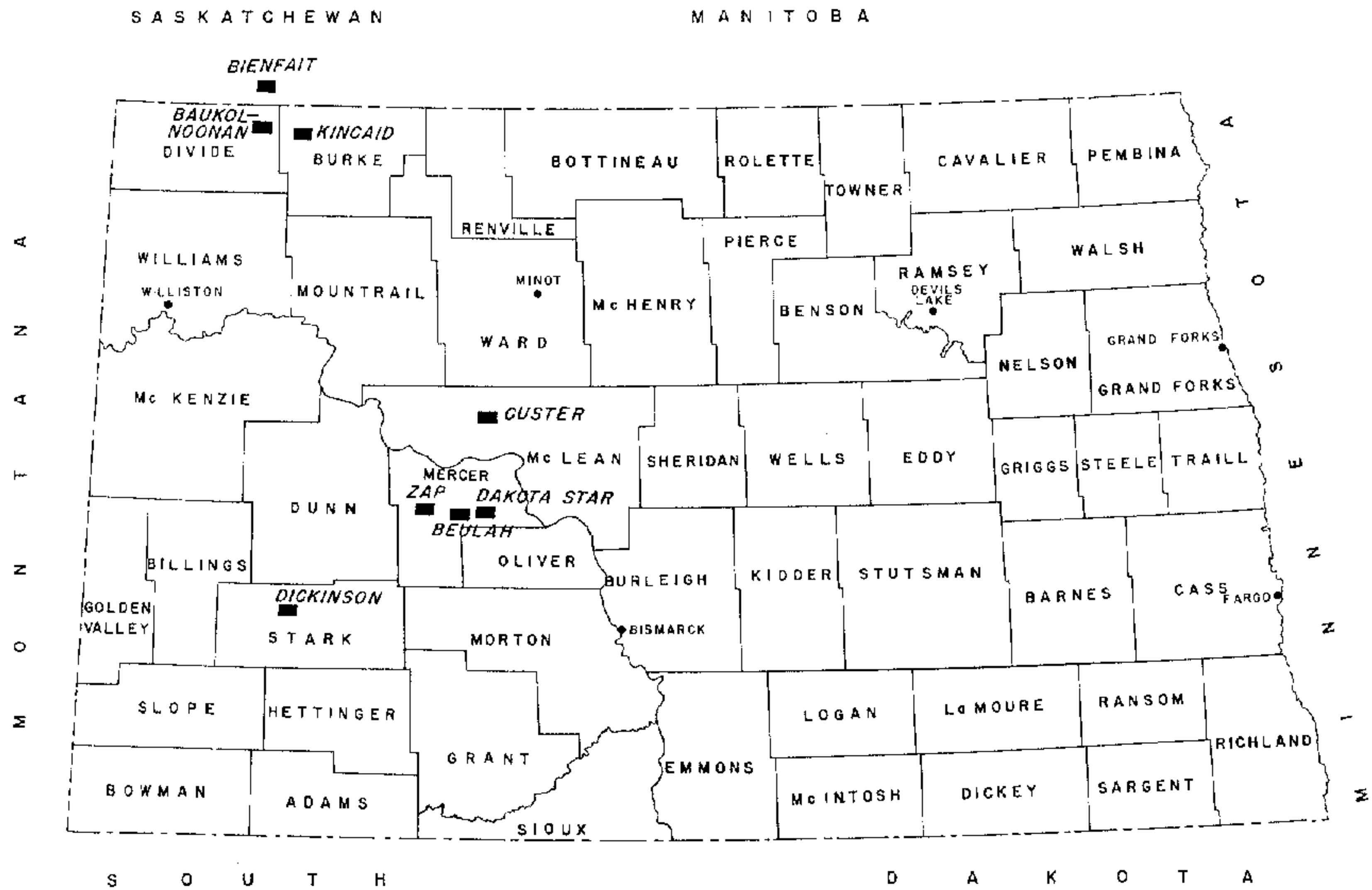

Figure 3. - Source of lignites gasified during runs 14 through 17.

Analysis and Size Distribution

All lignite obtained from the mines was nominal 1-1/2- by 1/2-inch stoker size. In each case the as-received product was rescreened at the plant to obtain a 1-1/2- by 3/8-inch double-screened cut for charging to the gasifier. Representative data for size distribution of the rescreened lignite as charged to the gasifier during individual test periods in runs 14 through 17 are given in table 1.

Proximate and ultimate analyses of the lignites as charged for the same test periods are given in table 2.

Complete data on ash composition and fusibility of ash were also obtained for each of the eight lignites tested. These data are listed in table 3.

Investigation of Process Variables

In operating the annular retort gasification process, two primary variables that can be controlled and adjusted directly are the feed rates of steam and of lignite. The bed of fuel undergoing gasification moves slowly down through the annular reaction space at a rate determined by the rate of gasification and by the rate of removal of ungasified residue or char at the bottom of the retort. The char contains the ash in the original lignite, together with carbon not gasified. Both the lignite feed rate and the char-removal rate are subject to direct control by mechanical devices; thus, either one can be chosen as control variable and the other adjusted to maintain steady-state operation and keep the retort filled with fuel.

In addition to steam and lignite feed rates, a third principal variable affecting the gasification process is temperature and temperature distribution in the annular reaction space. This temperature can be controlled and adjusted, within limits, by adjusting rate and distribution of heat release in the external heating furnace surrounding the annular retort. In the pilot-plant gasification runs, temperature in the annular reaction space was not measured directly because of mechanical problems involved in such measurement. Instead, temperatures in the furnace heating space about 3 inches from the outer wall of the gasifier were recorded and used as control temperatures.

In the process variable study, groups of experiments were made at predetermined values of the three principal control variables - lignite feed rate, steam feed rate, and temperature distribution in the combustion space - in order to evaluate the separate influence on the gasification process of each of these variables. Performance of the gasifier was evaluated primarily in terms of quantity and composition of gas generated and also in terms of the percent carbon gasified, net steam decomposition, and other dependent operating variables.

Other factors that were varied during the present series of experiments were mechanical arrangement of the retort (see previous section on design) and source of lignite fed to the gasifier. In the final run of the series, run 17, lignite from seven different mines was gasified at closely similar lignite and steam feed rates and combustion-space temperatures.

TABLE 1. - Size distribution of lignite as charged during representative test periods, runs 14 through 17

U. S. mesh No. 1/	Run and period / Lignite / Screen opening, inches 2/	14-A Dakota Star	14-G Dakota Star	14-O Dakota Star	15-A Dakota Star	15-H Dakota Star	16-E Dakota Star	16-H Baukol-Noonan	16-L Baukol-Noonan	17-A Kincaid	17-C Baukol-Noonan	17-E Zap	17-H Beulah	17-J Dickinson	17-L Custer	17-N Bienfait
		Percent retained														
	1.050	15.0	24.8	47.0	41.1	17.4	41.1	38.3	42.3	38.1	4.8	23.7	1.0	23.1	41.9	50.6
	.742	40.7	42.2	36.5	21.3	37.2	34.4	24.3	31.0	31.9	38.9	44.9	24.9	24.7	29.2	26.9
	.525	30.9	25.7	13.2	27.1	33.0	17.3	20.7	16.7	17.5	41.2	24.3	39.7	21.7	17.8	13.8
	.371	10.4	5.8	2.6	9.4	9.6	5.3	10.4	6.3	8.5	11.3	5.3	25.0	16.0	6.7	6.3
4	.185	2.5	1.1	.5	.8	2.1	1.4	5.4	3.2	3.4	3.2	1.6	9.0	12.0	3.5	1.8
8	.093	.2	-	-	.1	.2	.1	.3	.2	.3	.1	.1	.2	.9	.1	.2
16	.046	.1	-	-	-	.2	.1	.2	.1	.1	.1	-	-	.6	.1	.1
Not retained		.2	.4	.2	.2	.3	.3	.4	.2	.2	.4	.1	.2	1.0	.7	.3
Ave. size, inches 3/		0.81	0.89	1.02	0.93	0.81	0.97	0.90	0.96	0.93	0.73	0.89	0.62	0.76	0.95	1.01

1/ Mesh numbers are U. S. Standard series.
2/ Standard square mesh openings.
3/ Average size of material calculated as sum of fractions retained between two screen sizes multiplied by average of retaining screen opening and the one preceding.

TABLE 2. - Representative analyses of lignites charged to gasifier, runs 14 through 17

Lignite	Run and period	Condition[1/]	Pittsburgh lab. No.	Proximate, percent				Ultimate, percent					Heating value, B.t.u./lb.	Ash softening temperature, °F.
				Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
Dakota Star......	14-A	A	D-50111	36.0	27.9	30.9	5.2	6.9	41.3	0.6	45.4	0.6	6,990	2,520
		B			43.6	48.3	8.1	4.5	64.5	.9	21.1	.9	10,920	
		C			47.5	52.5		4.9	70.2	1.0	22.9	1.0	11,880	
Do.	14-G	A	D-50117	36.3	27.7	29.9	6.1	6.7	41.4	.6	44.3	.9	6,930	2,380
		B			43.4	47.1	9.5	4.2	64.9	.9	19.1	1.4	10,870	
		C			48.0	52.0		4.7	71.7	1.0	21.1	1.5	12,010	
Do.	14-O	A	D-50125	34.6	29.1	31.1	5.2	6.7	42.4	.6	44.5	.6	7,160	2,500
		B			44.5	47.6	7.9	4.4	64.8	1.0	21.0	.9	10,950	
		C			48.4	51.6		4.8	70.4	1.0	22.8	1.0	11,900	
Do.	15-A	A	D-55385	36.3	27.3	31.3	5.1	6.8	41.9	.6	45.0	.6	7,060	2,520
		B			42.9	49.2	7.9	4.3	65.8	.9	20.2	.9	11,090	
		C			46.6	53.4		4.7	71.4	1.0	21.9	1.0	12,050	
Do.	15-H	A	D-55392	36.4	26.8	30.5	6.3	6.8	41.2	.6	44.2	.9	6,980	2,360
		B			42.2	47.9	9.9	4.2	64.8	1.0	18.6	1.5	10,980	
		C			46.9	53.1		4.7	72.0	1.1	20.6	1.6	12,200	
Do.	16-E	A	D-65006	36.8	27.0	30.6	5.6	6.8	41.3	.6	45.2	.7	6,960	2,390
		B			42.7	48.4	8.9	4.3	65.3	.9	19.7	.9	11,020	
		C			46.9	53.1		4.8	71.7	1.0	21.5	1.0	12,100	
Baukol-Noonan....	16-H	A	D-65009	33.4	28.1	31.0	7.5	6.6	43.1	.7	41.5	.6	7,380	2,100
		B			42.1	46.6	11.3	4.4	64.7	1.0	17.7	.9	11,080	
		C			47.4	52.6		5.0	72.9	1.1	20.0	1.0	12,490	
Do.	16-L	A	D-65013	35.2	27.1	32.1	5.6	6.8	42.6	.6	44.4	.4	7,260	2,150
		B			41.8	49.5	8.7	4.5	55.7	1.0	19.4	.7	11,200	
		C			45.8	54.2		4.9	72.0	1.1	21.2	.8	12,270	
Kincaid	17-A	A	D-72726	35.2	26.1	30.5	6.2	6.7	42.0	.7	44.0	.4	7,100	2,150
		B			40.3	50.1	9.6	4.4	64.8	1.0	19.6	.6	10,950	
		C			44.6	55.4		4.9	71.6	1.1	21.8	.6	12,110	
Baukol-Noonan ...	17-C	A	D-72732	36.4	26.5	30.1	7.0	6.8	41.1	.8	43.9	.4	6,950	2,150
		B			41.7	47.3	11.0	4.3	64.6	1.2	18.2	.7	10,930	
		C			46.9	53.1		4.9	72.5	1.3	20.5	.8	12,270	
Zap	17-E	A	D-72821	35.0	27.8	30.5	6.7	6.8	41.9	.6	42.9	1.1	7,090	2,290
		B			42.8	46.9	10.3	4.4	64.5	.9	18.3	1.6	10,910	
		C			44.7	52.3		4.9	72.0	1.0	20.3	1.8	12,170	
Beulah	17-H	A	D-72731	35.8	27.0	28.8	8.4	6.6	40.2	.6	43.2	1.0	6,680	2,340
		B			42.0	44.9	13.1	4.1	62.6	.9	17.7	1.6	10,410	
		C			48.3	51.7		4.7	72.0	1.1	20.4	1.8	11,980	
Dickinson	17-J	A	D-72729	37.8	27.1	27.3	7.8	6.9	38.1	.4	44.5	2.3	6,510	2,340
		B			43.5	43.9	12.6	4.3	61.3	.7	17.4	3.7	10,470	
		C			49.8	50.2		4.9	70.1	.8	19.9	4.3	11,980	
Custer	17-L	A	D-72131	40.4	27.3	28.1	4.2	7.1	39.6	.6	48.1	.4	6,650	2,570
		B			45.9	47.1	7.0	4.5	66.4	1.0	20.5	.6	11,150	
		C			49.3	50.7		4.8	71.4	1.1	22.1	.6	11,980	
Bienfait	17-N	A	D-72736	35.0	28.6	30.7	5.7	6.8	43.0	.8	43.2	.5	7,280	2,520
		B			44.0	47.3	8.7	4.5	66.2	1.2	18.7	.7	11,200	
		C			48.2	51.8		4.9	72.5	1.3	20.6	.7	12,270	

1/ Condition: (A) as received; (B) moisture-free; (C) moisture- and ash-free.

TABLE 3. - Composition of ash from eight lignites used in gasification experiments

Lignite / Run and period	Kincaid 17-A	Kincaid 17-O	Baukol-Noonan 17-C	Zap 17-E	Beulah 17-H	Dickinson 17-I	Custer 17-K	Bienfait 17-M	Dakota Star 16-A
Carbon gasified .... percent...	86.4	76.6	82.4	80.2	60.7	66.8	72.3	68.4	81.9
Ash as received .... do.	6.2	7.0	7.0	6.7	8.4	7.3	4.5	4.9	6.2
Ash analysis, percent:									
Loss on ignition	0.3	0.3	0.3	0.1	0.2	0.4	0.4	0.3	0.2
Silica, SiO_2	28.0	33.3	30.4	17.5	23.1	11.2	18.1	16.0	11.8
Aluminum oxide, Al_2O_3 1/	19.8	19.5	15.4	9.9	12.3	8.3	10.7	15.0	7.5
Ferric oxide, Fe_2O_3	6.6	4.5	8.5	15.0	8.7	29.8	6.4	6.1	17.0
Calcium oxide, CaO	16.5	16.5	16.5	17.8	18.8	18.6	32.7	29.9	20.4
Magnesium oxide, MgO	3.3	3.8	4.8	5.6	7.3	4.9	7.8	7.6	7.6
Sulfur trioxide, SO_3	14.9	11.5	15.2	28.3	24.8	26.2	17.9	18.5	30.8
Alkalies by difference, $Na_2O + K_2O$	10.6	10.6	8.9	5.8	4.8	0.6	6.0	6.6	4.7
Fusibility of ash, °F.: 2/									
Initial deformation temp. ...	2,080	2,100	2,080	2,030	2,080	2,210	2,540	2,520	2,150
Softening temp.	2,150	2,180	2,150	2,290	2,340	2,400	2,570	2,570	2,490
Fluid temp.	2,210	2,230	2,180	2,310	2,370	2,500	2,590	2,620	2,570

1/ The Al_2O_3 includes any titanium oxide or phosphorous pentoxide that may be present.

2/ Determined by standard procedure as described in Bureau of Mines Bulletin 492, Methods of Analyzing Coal and Coke, by A. C. Fieldner and W. A. Selvig, 1951, pp. 25-29.

In addition, experimental results, particularly during run 17, pointed to gradual buildup of ash deposits on the alloy tube as a probable significant factor in determining gasification rate. Results of run 17 led to a reexamination of data from earlier tests in the process variable series for possible influence of ash deposition on gasification characteristics.

Specific experimental conditions and objectives of individual runs were as follows:

Run 14

The divided annulus arrangement of the gasification retort was used in run 14.

Specific objective of this run was to determine the influence of varying combustion-space temperature on rate of gas generation, gas composition, etc., at each of three feed rates of process steam. Lignite feed rate was maintained approximately constant during the run at about 500 pounds of natural lignite per hour.

The three rates of steam admission and distribution of the added steam were as follows:

Steam admission, percent of lignite feed rate		
To top of retort	To bottom of retort	Total
10	30	40
30	33	63
47.5	57.5	105

At each of these three rates of steam admission, tests were made for five different temperature distributions over the length of the combustion space, as follows:

Thermocouple No.	1	2	4
Temp., °F.	1,925	1,850	1,600
	1,840	1,850	1,600
	1,750	1,850	1,600
	1,840	1,800	1,600
	1,840	1,750	1,600

Location of the thermocouple positions is indicated in figure 1. When predetermined temperatures were established at positions 1, 2, and 4, the temperature at position 3, opposite the upper part of the retort, was subject to some variation, as recorded in the summary tables of experimental data (table 16, Appendix).

As an additional special objective in run 14, data were obtained on variation in composition of gasification residue or char during a stabilized test period.

Runs 15 and 16

Run 15 was terminated before the scheduled experiments were completed because an elevator conveyor in the lignite feed system failed. The uncompleted portion of the program was carried over into run 16.

Specific objective of these runs was to obtain additional data on the operation of the continuous annulus arrangement of the gasification retort for comparison with data previously obtained from operation with a divided annulus. Variables investigated were lignite feed rate, steam to lignite feed ratio, and temperature distribution over the length of the combustion space. In general, two of the variables were held constant while the third was varied.

Rates of steam admission for run 15 were selected to produce gas with relatively low hydrogen-carbon monoxide ratios, from 2.0 to 3.0. A single combustion-space-temperature distribution was maintained during run 15, as follows:

Thermocouple No.	1	2	4
Temp., °F.	1,925	1,850	1,600

Test periods 15-A to 15-C. - For the first series of experiments, lignite feed rate was increased in hundred pound increments from 450 pounds to 650 pounds per hour. Rate of addition of process steam was 40 percent, by weight, of the lignite feed rate in each case.

Test periods 15-D to 15-F. - For the second series of experiments lignite feed rate was held constant, as closely as possible, at about 600 pounds per hour, and ratio of process steam to lignite was varied. Three tests were made, in which steam feed rates were 30, 20, and 10 percent, by weight, of the lignite feed rate.

Test periods 15-G and 15-H. - Operation of the gasifier without addition of process steam was the object of the third series of experiments. Since only moisture and water of decomposition are available for reaction with carbon, under these conditions, gas yield is relatively low and that of discharged refuse high. Two test periods, at lignite feed rates of 590 and 670 pounds per hour, were completed before failure of the lignite-conveying system made it necessary to terminate the run.

Test periods 16-A to 16-F. - In the first phase of run 16, a series of 6 tests was made at lignite feed rates of 450, 550, and 650 pounds per hour and at each of the following two combustion-space-temperature distributions:

Thermocouple No.	1	2	4
Temp., °F.	1,925	1,900	1,600
	1,850	1,850	1,600

The above temperatures were selected to maintain a uniform temperature over the greatest portion of the externally heated retort to reduce deformation owing to differences in radial expansion. Ratio of process steam to lignite was held constant during the 6 test periods at 0.40 on a weight basis.

Test periods 16-H to 16-L. - Dakota Star lignite had been almost exclusively used in past experimental work on the externally heated gasification process (3, 4). To obtain information on gasification characteristics of another North Dakota lignite, the last five test periods of run 16 were run with lignite from the Baukol-Noonan mine, Noonan, Burke County, N. Dak. Lignite and steam feed rates and combustion-space temperatures were chosen to provide data for comparison with results on gasification of Dakota Star lignite for selected test periods in runs 15 and 16.

Run 17

The specific objective in run 17 was to gasify several lignites from North Dakota and Canada under similar experimental conditions to determine influence of source of lignite on gasification characteristics. Seven lignites were tested. Gasification characteristics of each lignite were determined at 2 feed rates, 450 and 550 pounds per hour. Combustion-space temperatures were held constant at the following distribution:

Thermocouple No.	1	2	4
Temp., °F.	1,925	1,900	1,600

Steam to lignite feed ratio was also held approximately constant. Because there was some variation in moisture content of the different lignites, the rate of admission of process steam to the retort was adjusted according to as-charged moisture content of coal to give nearly equal ratios of total available water to moisture- and ash-free lignite.

Results and Discussion

General

Summary tables of experimental data for the four gasification runs included in this progress report are given in the Appendix. Selected data of principal significance and their interpretation are presented in this section.

A brief summary of operations is given in table 4. The gasification unit has been operated 8,748 hours, 33 percent of which was accumulated during the present series of tests. The 30 million cubic feet of gas produced during the reporting period constitutes 56 percent of the gas made with the 310-alloy reaction tube and 36 percent of the total gas produced since the beginning of the investigation.

TABLE 4. - Summary record of operations from July 1, 1950, to December 31, 1951, Bureau of Mines pilot plant, Grand Forks, N. Dak.

Run No.	14	15	16	17	Summary
Total hours operated1/	802	466	637	974	2,879
Natural lignite charged to gasifier.... tons ...	185.2	129.0	2/153.1	3/219.1	686.4
Average lignite feet rate .... lb./hr. ...	462	553	481	450	477
Total gas production4/ .... M cu. ft. ...	8,220	4,874	6,965	10,210	30,269
(H_2 ≠ CO) production .... do.	6,004	3,818	5,317	7,920	23,059
Average gas production rate....M cu. ft./hr. ...	10.2	10.5	10.9	10.5	10.5
Average gas production per ton of natural lignite .... M cu. ft. ...	44.4	37.8	45.5	46.6	44.1

1/ Operating time from lighting to closing of burners.

2/ Includes 53.3 tons of Baukol-Noonan lignite; balance was Dakota Star.

3/ Breakdown as follows:

Lignite	Tons
Kincaid	44.4
Baukol-Noonan	27.2
Zap	28.2
Beulah	35.7
Dickinson	21.9
Custer	30.9
Bienfait	30.8

4/ Standard gas conditions: 60° F., 30-inches Hg, saturated.