

based on a pressure that does not require x-ray and stress relieving. This sets the top pressure at approximately 350 p.s.i.g., depending upon the diameter of the vessel.

New Morgantown Experiment Station

Construction has been under way over 6 months on the Bureau's new \$2,600,000 Morgantown Experiment Station (see fig. 60). Begun in June 1952 the station, is scheduled for completion early in the calendar year 1954. Research on gasification of coal for producing synthetic liquid fuels will be carried on in this station which also will provide laboratories and a research staff assigned to petroleum studies in the Appalachian field, now conducted in Franklin, Pa., and personnel of the Accident Prevention and Health Division of the Morgantown area, now headquartered at Fairmont, W. Va.

Buildings for the station were designed by Tucker & Silling, architects, Charleston, W. Va., and the Bureau's Morgantown staff prepared preliminary designs for several buildings, including a pilot plant to house coal-gasification work, a coal preparation and beneficiation building, an oxygen plant to house 7,000 std. cu. ft. per hr. of generating capacity, and a combined shop and warehouse building. Preliminary sketches of all utility piping required by the Synthesis Gas Branch were furnished, and assistance was given in the electrical lay-out for the new station.

The contract for constructing seven buildings was awarded to the Southeastern Construction Co. of Charleston, W. Va. Eight buildings originally were planned for the station, but the building for a pump house and cooling towers has been eliminated.

The new Morgantown Experiment Station is being constructed on a 45-acre plot outside of the Morgantown city limits donated to the Federal Government by the Morgantown Community Association, an agency of the Morgantown Chamber of Commerce. The site is on the Collins Ferry road, just north of Morgantown.

Underground Gasification Project, Gorgas, Ala.

Since 1946 field-scale experiments on underground gasification of coal have been conducted by the Bureau of Mines and the Alabama Power Co. at Gorgas, Ala., to develop a process whereby either the chemical constituents or the energy of the coal may be brought to the surface in usable form. These products may then be used for synthesis of liquid fuels or other chemical products, or the energy may be applied as heat or used to produce electrical power. Benefits from such a process include utilization of coal seams uneconomical for mining because of high ash content or poor mining conditions.

Field trials between 1946 and June 1951 featured "stream"-type operation, in which a stream of air or other gas-making fluid is swept along an incandescent coal face, prepared by mining entries in the coal bed. It was found that the roof above the coal bed fused and swelled under the action of heat, filling the entries and the space from which the coal had been consumed. This roof action tended to force the reactants to flow along the reaction face or to enter the fissures in coke formed on the face. A portion of the air bypassed the reaction zone through fissures in or above the burned-out area, bringing about combustion or dilution of the gas near the outlet of the system. The proportion of bypass air increased with the age and width of the burned-out area, and the quality of the gas was reduced in consequence. Accordingly, a method was sought in which the air would be forced to flow through rather than parallel to the reaction face.

Experiments have been conducted by the Missouri School of Mines and the Sinclair Coal Co. at Hume, Mo., in which an electric current was passed through the coal bed

between two metal electrodes inserted in the coal at the bottoms of boreholes drilled from the surface. Coal surrounding the electrodes and lying between them was carbonized by the action of the current. The volatile products were driven off, and a pathway of fissured, incandescent coke was formed between the boreholes. This electro-linking-carbonization method made possible creation of a fuel bed nearly ideal for gasification purposes. The boreholes provide inlet and outlet passages through the rock cover. All work is done on the surface, reducing the hazard to personnel and the time required for mining entries.

A cooperative agreement was made between the Sinclair Coal Co. and the Bureau of Mines under which the system was applied at Gorgas to provide an initial passage for gasification of coal with air. Since June 1951 all experimentation at Gorgas has utilized electro-linking-carbonization for preparing an underground system.

Four boreholes were drilled at the locations given as VIII, IX, X, and XI in figure 61. The electrodes were seated in the America bed 180 feet below the surface. The boreholes were cased with 6-inch steel pipe, and during application of the electro-linking-carbonization technique arcing between the casing and the electrode stems prevented proper development. Between boreholes VIII and IX a path was established at the horizon of the coal bed, and it was possible to gasify coal in this area. This unit was operated for 174 days in all, using reversal of flows at irregular intervals. For a 55-day period, the heating value of the product gas varied between 130 and 87 B.t.u. per cubic foot. The resistance to flow was high, and the throughput was small, not exceeding 300 cu. ft. per min. of product gas. The resistance to flow decreased with time. Leakage from the system was high.

Two additional boreholes (XII and XIII) were drilled as shown in figure 61. Their purpose was to extend the reaction zone already set up between borehole VIII and borehole IX and to explore further the potentialities of electro-linking-carbonization. The holes were drilled 14 inches in diameter to 35 feet in depth and cased with 12-inch I.D. pipe, cemented in. Drilling was then resumed with a 10-inch-diameter bit, which was allowed to penetrate the coal bed slightly. The 10-inch section of the hole was not cased. A section of hole 4 inches in diameter and 17 inches in length was prepared for the electrode in the coal bed. The electrodes were similar to those used in the previous trial, but standard 4-inch, schedule 40, steel pipe was used to supply current to the electrodes through the boreholes. The lengths of pipe were carefully aligned and joined by welding as they were lowered in the hole. The welds were ground flush, so that the pipe presented a smooth exterior for its entire length. To prevent the pipe from touching the walls of the borehole, it was maintained under tension by a counterweight connected by a cable passing over pulleys on a frame support. The pipe was centered in the borehole, and the top of the 12-inch casing was left open. The air gap between the inside pipe and the borehole wall provided the only insulation.

The installation at boreholes XII and XIII was satisfactory during the electro-linking-carbonization phase, and this system was adopted in preparing two additional systems which were operated later in the year.

Table 25 gives operating data pertaining to the electro-linking-carbonization of the section between boreholes XII and XIII, as well as those obtained during the two later trials. The initial high resistance in each instance was a function of the contact between the electrode and the coal. Immediately after current was applied, the coal adjacent to the electrode coked and swelled, enclosing the electrode tightly, and in approximately 1 hour decreased the initial resistance to the range 7.3 to 11.2 ohms. After the initial rapid change in resistance, the rate of decrease was slow. This period ranged from 20.5 to 155 hours for the three trials and constitutes the electro-linking phase of the process - establishment of a good electrical

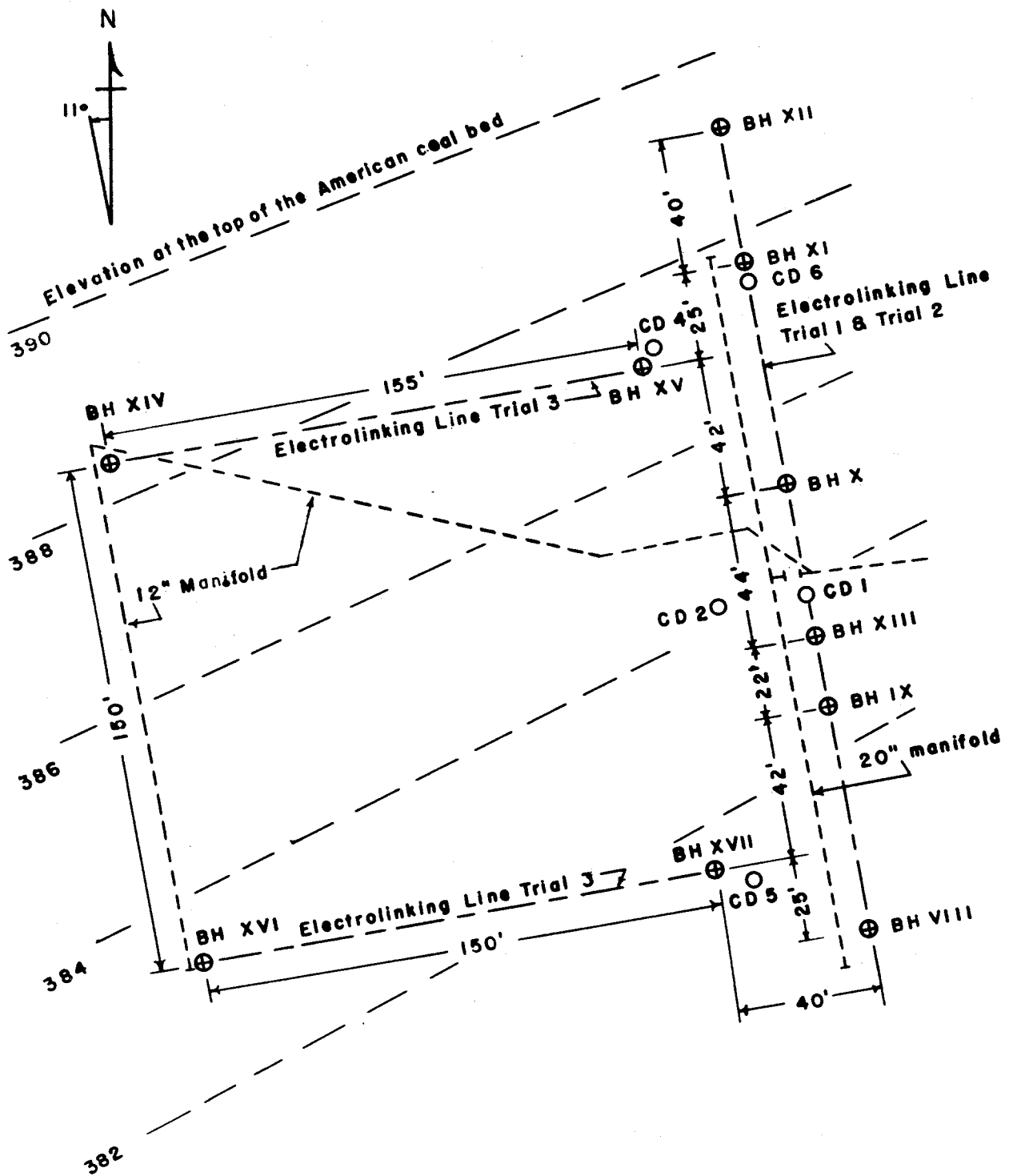


Figure 61. - Plan of electrolinking gasification trials.

circuit between the electrodes. The resistance of the systems during the electrolinking phases of the trials decreased to the range 2.7 to 3.85 ohms at the breakthrough. The power applied during this period is in part applied usefully to the coal and in part dissipated through adjacent strata.

TABLE 25. - Summary of electrolinking-carbonization

Electrolinking-carbonization trial No.....	2	3a	3b
Boreholes.....	XII-XIII	XIV-XV	XVI-XVII
Distance.....feet	152	155	150
Date.....	12/28/51- 1/2/52	8/19/52- 8/28/52	8/28/52- 9/4/52
First determined resistance after application of power.....ohms	36.7	31.25	15.8
Time for reduction of initial contact resistance.....hours	1.0	0.75	1.0
Resistance after drop in initial contact resistance.....ohms	11.2	7.30	7.31
Resistance just before breakthrough.....do.	3.85	2.70	3.24
Resistance just after breakthrough.....do.	0.95	0.88	1.24
Resistance, end of electrocarbonization.....do.	0.30	0.22	0.72
Total time for electrolinking.....hours	56	155	20.5
Total time for electro-carbonization.....do.	64.5	51.8	133.5
Total time for electrolinking-carbonization.....do.	120.5	206.8	154
Total power for electrolinking.....kw.-hr.	40,500	146,800	20,080
Total power for electro-carbonization.....do.	30,100	24,160	39,744
Total power for electrolinking-carbonization.....do.	70,600	170,960	59,824

In each instance a very rapid decrease to approximately 1 ohm resistance occurred at the breakthrough. Following the electrolinking, current was passed through the system for varying lengths of time to carbonize enough coal to provide a satisfactory path underground for flow of air and gas. Changing coal into coke provides a mass of hot, porous, carbonaceous material that acts as the initial fuel bed for the gasification processes applied later. This phase is called electrocarbonization. Large volumes of carbonization gases are produced together with quantities of tar and light oil. The production of these materials reduces the cost of this method of preparing a system for gasification. During the carbonization period nearly all of the power was applied usefully in carbonizing coal.

Despite the fact that the electrode spacing is approximately constant, these three successful applications of electrolinking-carbonization show entirely different power requirements. These differences are influenced by the proximity of coke formed during previous operations and possibly by variation of location of electrodes with respect to the pitch of the coal bed. The operating data also indicate that increased rates of power application probably will materially reduce both the time and power required for successful electrolinking.

After electrolinking-carbonization of the system between boreholes XII and XIII it was gasified, using air during the period from January until May 1952. For the major part of the time the air input was at either borehole XI or XII and the outlet at VIII (see fig. 61). Flow was reversed occasionally for short periods to attempt to decrease the resistance to flow or, in effect, to clean the underground passages. Table 26 gives the operating data during the major part of the gasification. During the 2,068 hours of unidirectional operation 95.3 million cubic feet of gas was produced. The greater portion of this gas had a heating value of 83 B.t.u. per cubic foot or more. Generally, the system was operated at an air-input rate ranging

from 1,150 to 1,770 cu. ft. per min. Leakage from the system was high and averaged 48 percent. During a period of good operation gas was produced having an analysis as follows:

TABLE 26. - Gasification of section between boreholes XII and XIII, using XI and XII as inlets and VIII as an outlet, unidirectional flow

Inlet borehole	Time of operation, hours	Total air input, 10 ⁶ cu. ft. _{1/}	Pressure drop of system, range, p.s.i.g.	Total gas produced, 10 ⁶ cu. ft. _{1/}	Average heating, value of gas produced, B.t.u. per cu. ft. _{2/}
XI.....	313	13.6	30-7.4	6.0	99
XI.....	643	44.5	6.1-10.2	26.0	94
XI.....	440	46.7	7.7-11.8	26.9	69
Total.	1,396	104.8		58.9	83 weighted average
XII.....	181	9.6	4.8-5.4	7.5	96
XII.....	168	15.5	5.9-8.1	14.5	56
XII.....	323	27.1	4.5-8.1	13.4	38
Total.	672	52.2		35.4	58 weighted average

1/ At 60° F., 30 in. Hg, dry.

2/ Gross heating value at 60° F., 30 in. Hg, dry.

	Percent
Carbon dioxide.....	8.9
Illuminants.....	.3
Oxygen.....	.3
Hydrogen.....	11.6
Carbon monoxide.....	13.4
Methane.....	2.5
Nitrogen.....	63.0

Heating value
B.t.u. per cu. ft.... 112

The original plan of operation was to introduce air at borehole VIII and pass the mixture of gas and hot products of combustion through the reduction zone between boreholes IX and XII. Repeated attempts were made to operate in this manner, but each attempt indicated that gas made with flow in a reverse direction was far superior in quality and the system itself much more operable.

Observations during operation of the gasification phase of the project indicated that the coal near the inlet borehole was consumed at the highest rate. This is at the point of maximum oxygen availability. As gasification continued the dimensions of the area of complete coal gasification increased in nearly all directions, with the downstream dimension increasing at the greatest rate. When the area of complete coal gasification reached the outlet from the system, the gas quality deteriorated owing to loss of the necessary contact between hot products of combustion and coal or coke. This finally resulted in unreacted oxygen appearing in the products.

Operation from January until May 1952 clearly demonstrated that gasification with unidirectional flow was advantageous and that air-input rates of 1,500 std. cu. ft. per min. could be utilized in a two-borehole unit system. Leakage from the system was high, and steps to eliminate it were necessary.

Two additional systems were prepared during the year by drilling boreholes XIV, XV, XVI, and XVII at the locations shown in figure 61. These provided two parallel systems, each of which ultimately would discharge into the old system between boreholes VIII and XII. Test holes first were drilled to obtain the optimum location of boreholes XV and XVII, as these should be in fresh coal for the electrolinking-carbonization phase and very close to the old system in order to use it ultimately for product collection.

The boreholes were drilled and prepared in a manner similar to that used for boreholes XII and XIII. To diminish leakage from the system, a chemical grout was pumped into these four boreholes to seal fissures that existed between the bottoms of the casing and the coal bed. The grout was a clear liquid when placed in the borehole but formed a gel within a predetermined time, during which it was pumped into adjacent strata. Electrodes were placed at each of the four locations, and the electrolinking-carbonization was carried out as shown in table 25. The sections between boreholes XIV and XV and boreholes XVI and XVII have been operated, using unidirectional flow, with air admitted at boreholes XIV and XVI. The system between boreholes XIV and XV was developed first, and air-input rates ranging from 220 std. cu. ft. per min. at 38 p.s.i.g. to 2,040 std. cu. ft. per min. at 10 p.s.i.g. have been employed. The system between boreholes XVI and XVII was operated simultaneously during part of the time at air rates ranging from 180 std. cu. ft. per min. at 56 p.s.i.g. to 530 std. cu. ft. per min. at 48 p.s.i.g. The operating data are summarized in table 27.

TABLE 27. - Gasification with air in section between boreholes XIV and XV and boreholes XVI and XVII, using boreholes XIV and XVI as inlets.

Inlet borehole	Time of operation, hours	Total air input, 10 ⁶ cu. ft. <u>1/</u>	Pressure drop of system, range, p.s.i.g.		Total gas produced, 10 ⁶ cu. ft. <u>1/</u>	Average heating value of gas produced, B.t.u. per cu. ft. <u>2/</u>
			BH XIV	BH XVI		
XIV.....	163	3.8	28-39	-	2.9	165
XIV.....	58	.2	41-42	-	.1	118
XIV & XV.....	162	8.0	35-40	51-57	4.9	105
XIV & XV.....	166	14.1	32-34	54-57	9.2	82
XIV & XV.....	57	3.6	32	54-56	2.3	72
XIV & XV.....	104	10.2	43-48	55-57	6.5	105
XIV & XV.....	168	22.2	25-41	53-57	23.5	108
XIV & XV.....	168	25.2	15-24	47-53	29.5	92
XIV & XV.....	168	25.4	10-14	38-49	30	81
Total.....	1,214	112.7			108.9	95 weighted average

1/ 60° F., 30 in. Hg, dry.

2/ Gross heating value at 60° F., 30 in. Hg, dry.

The average gas production as given in table 27 is 2.2 million cu. ft. per day at 95 B.t.u. per cubic foot. The data indicate that immediately after the electrolinking-carbonization phase, leakage from the system was of the order of 45 percent of the input air. The recovery increased rapidly during the early stages of operation. For the greater part of the period covered in table 27, leakage of gas-making fluids varied between 0 and 15 percent. The chemical grout and the relocation of the systems have greatly diminished leakage. The input to a single-unit section was increased to 2,040 std. cu. ft. per min.

During a 21-day operating period with an average input of 2,407 std. cu. ft. per min. to the two sections, the product gas averaged 2,718 std. cu. ft. per min. on a

dry basis. The recovery for this period averaged 93.2 percent on a basis of the air pumped underground. The gas had an average analysis as follows:

	<u>Percent</u>
Carbon dioxide.....	9.6
Illuminants.....	.3
Oxygen.....	.5
Hydrogen.....	9.5
Carbon monoxide.....	13.4
Methane.....	1.5
Nitrogen.....	65.2
 <u>Heating value</u>	
B.t.u. per cu. ft.....	95

Figure 62 shows the product gas burning at the outlet burner when the flow is approximately 2,400 cu. ft. per min. and the quality 94 B.t.u. per cubic foot.

The system between boreholes XVI and XVII was operated at a reduced capacity for the period shown in table 27. It was planned to develop this system to a good operating level and then attempt to produce synthesis gas by substituting oxygen for air.

Liquid oxygen was shipped by tank car to the nearest railroad siding, and vaporized by two pumping trucks; the gas was stored in "Cascade" units as shown in figure 63. A 3,700-foot pipeline equipped with a flowmeter and control valves carried the oxygen from the "Cascade" unit to the underground gasification system.

A borehole, CD 10, was prepared 10 feet east of borehole XVI (see fig. 61) for an oxygen inlet to the system. This borehole was cased with 2-inch standard steel pipe to a depth of 83 feet and the remaining 64 feet to the coal bed with 2-inch stainless-steel tubing. A boiler, necessary steam lines, and a mixing system for oxygen and steam were installed at CD 10.

Approximately 5.25 million cubic feet of oxygen was used during the oxygen-gasification test. The run, using CD 10 as an inlet to the system, lasted for 107 hours, and the oxygen-input rates were varied from 253 to 813 std. cu. ft. per min. with a resulting dry gas output of 533 to 1,390 std. cu. ft. per min. The operating data are given in table 28.

TABLE 28. - Operating data during oxygen gasification

Average oxygen input, cu. ft. per min. ^{1/}	Average gas output, cu. ft. per min. ^{1/}	Ratio, output:input
253	533	2.11
449	1,050	2.34
449	1,037	2.31
602	1,390	2.31
652	1,320	2.03
813	1,387	1.71

^{1/} At 60° F. 30 in. Hg, dry.

Little operating difficulty was encountered in the course of the operation at CD 10. Table 29 gives typical analyses of the product gases. No. 1 is an analysis of a product gas near the beginning of the oxygen test, when the system had not yet reached its best operating level and the oxygen-input rate was low. Nos. 2 and 3

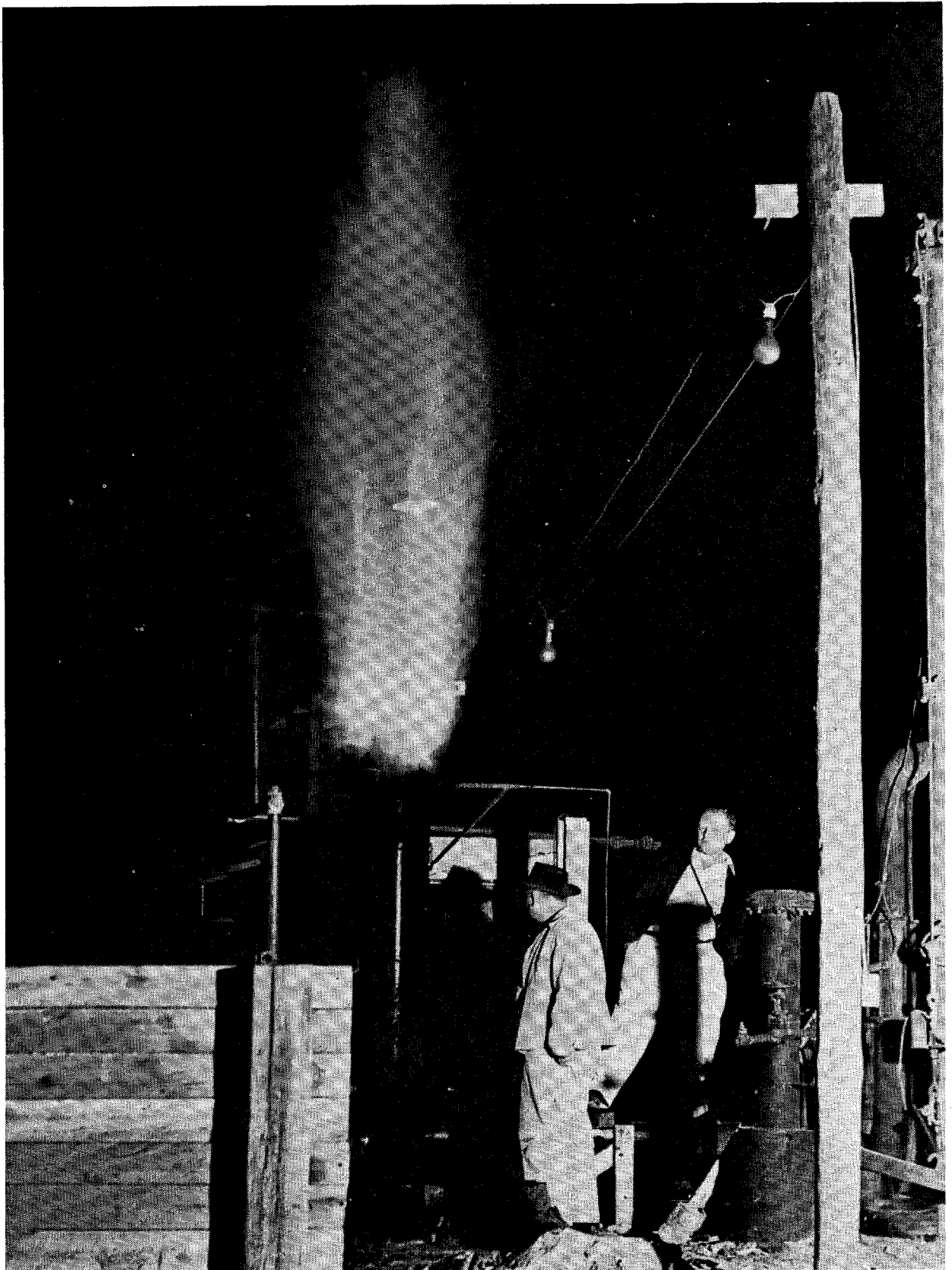


Figure 62. - Producer gas from underground gasification burning at 12-inch outlet burner.

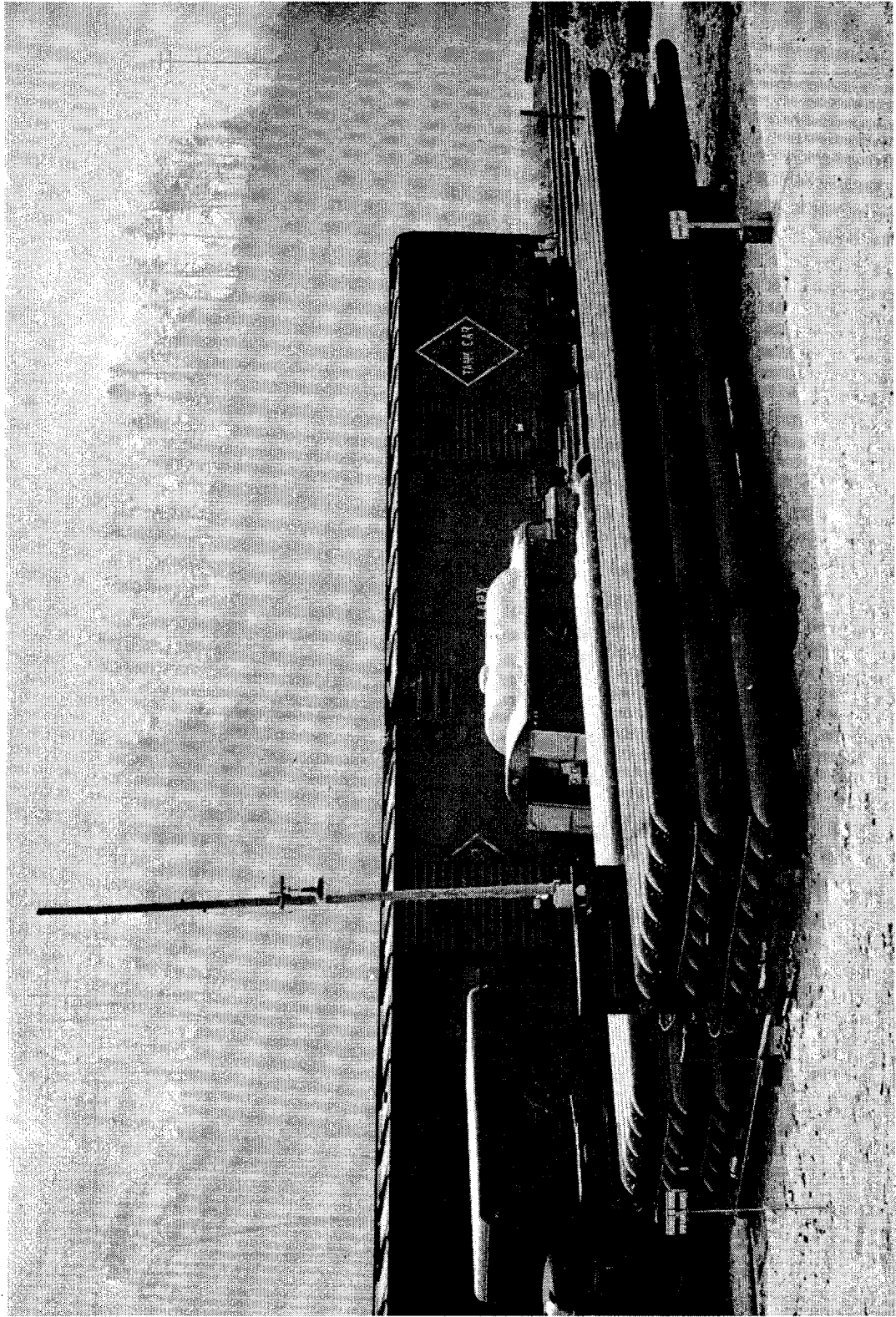


Figure 63. - "Cascade" oxygen-storage units and vaporizing trucks used during oxygen runs.

were taken during periods of the best operation obtained when the input rates were between 450 and 600 cu. ft. per min. Nos. 4 and 5 were obtained when input-oxygen rates exceeding 650 cu. ft. per min. were attempted. In these instances it is questionable that the operating level had become stabilized.

TABLE 29. - Analyses of gas produced during oxygen gasification, percent

	1	2	3	4	5
Carbon dioxide.....	66.4	42.1	40.0	46.4	50.3
Illuminants.....	.3	.4	.2	.2	.3
Oxygen.....	.1	.0	.2	.2	.0
Hydrogen.....	19.4	26.4	27.5	26.3	24.7
Carbon monoxide.....	7.7	25.2	26.2	21.5	18.9
Methane.....	4.2	4.0	4.0	3.7	3.5
Nitrogen.....	1.9	1.9	1.9	1.7	2.3
<u>Heating value</u>					
B.t.u. per cu. ft.....	136	215	218	196	183

This first test using oxygen in underground gasification showed that it is possible to prepare a synthesis gas in this manner. The oxygen usage is high, and the quality of the products lower than can be achieved because of excessive moisture present in the underground system. It is possible that, in a future system, the excess moisture can be eliminated and better operating levels achieved. It was not feasible to do so in the system available at Gorgas.

At the end of the oxygen run, a series of tests was made in an effort to prepare synthesis gas by first blowing the underground system with air and then running with steam in a manner somewhat similar to that employed in a water gas machine. These tests are being continued. Table 30 summarizes the operating data obtained.

TABLE 30. - Average operating data, using air blast followed by steam run

	Group 1		Group 2	
	Air blast	Steam run	Air blast	Steam run
Average length of cycle.....hr.	19.8	4.34(3.83-5.08)	17.75 ^{1/}	4.04
Input air rate.....cu. ft./min. ^{2/}	1,215		1,288	
Input steam rate.....lb./hr.		1,174		2,113
Dry gas produced.....cu. ft./min. ^{2/}	1,808	582	1,779	586
Moisture in product gas.....mol H ₂ O/mol dry gas	0.20	0.60	0.17	0.51
Analysis of product gas, percent:				
Carbon dioxide.....	13.2	21.9	12.0	20.5
Illuminants.....	0.2	0.5	0.4	0.3
Oxygen.....	0.2	0.3	0.5	0.3
Hydrogen.....	14.3	52.5	12.5	54.5
Carbon monoxide.....	10.2	10.9	10.6	13.2
Methane.....	3.5	9.2	2.1	7.0
Nitrogen.....	58.4	4.7	61.9	4.2
Heating value..B.t.u. per cubic foot ^{2/}	119	308	104	297
Specific gravity.....	0.90	0.57	0.92	0.57

^{1/} For 1 air-blast period only.

^{2/} At 60° F., 30 in. Hg, dry.

In the first hour of each steam run, the product gas averaged between 218 and 230 B.t.u. per cu. ft. and contained nitrogen remaining from the previous air-blast period. The analyses of table 30 give the composition of the product gases during the final 3 to 4 hours of each steam run. For the period covered by group 1, 15.1 million cu. ft. of gas averaging 119 B.t.u. per cubic foot was produced by air blast and 1.21 million cubic feet of gas, three-fourths or more of which averaged 308 B.t.u. per cubic foot by steam run. For the period covered by group 2, 6.1 million cubic feet of gas averaging 104 B.t.u. per cu. ft. was produced by air blast and 0.29 million cu. ft. of gas, three-fourths of which averaged 297 B.t.u. per cu. ft. by steam run.

Table 30 also shows that increasing the rate of steam input from 1,174 to 2,113 lb. per hr. had virtually no effect either on the rate of gas production or its quality. The natural inflow of water into the system apparently supplied most of the water reacting. This suggests that elimination of most of the steam and use of an exhauster at the outlet would be the simplest and most efficient type of operation. The physical lay-out of the system unfortunately precluded an experimental trial of this nature.

During each steam run, no deterioration in quality or decrease in output flow was found, and the proper balance between the length of air blast and the duration of steam run has not been determined. Increasing the length of the steam run by 1 hour, as noted in group 1, did not affect either the quality or the output. Further, these tests represent 1.4 weeks operation and do not give the complete picture over the entire life of an installation.

First International Conference on Underground Gasification of Coal

In February 1952 the First International Congress on the Underground Gasification of coal was held in Birmingham and Gorgas, Ala. Representatives of several foreign countries, plus personnel of the Bureau of Mines and representatives of industries in the United States, met and discussed the problems. The meeting was characterized by the free exchange of information and experiences obtained in underground gasification by the several countries represented.

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