tar. The most sensitive measures of extent of oxidation of coal were agglutinating value, yield of tar, and coke strength. Correlation of changes in coal and coke properties of the sample oxidized at room temperature with those of samples oxidized at 99.3° C. established simple factors used to express relative rates of oxidation at the two temperatures.

Carbonizing Properties of Chilean Coals

The carbonizing properties of 10 Chilean coals[61/] were determined in an investigation to determine (1) whether metallurgical coke could be made from six high-volatile coals, and (2) whether the quality of four lower-rank coals could be improved. Of two Schwager-mine coals, No. 5 bed was better for coking because it contained less sulfur and coked more strongly than No. 3-bed coal. Of four Lota-mine coals, the Alta bed, Pique Nuevo, had the highest coking power and the most satisfactory composition. These coals contracted during carbonization; they should give no trouble from expansion in coke ovens when blended with as much as 30 percent low-volatile expanding coal. They did not oxidize excessively, as might be expected of coals of similar rank. Four noncoking coals representing (1) Lirquen bed, Lirquen mine, Province of Concepcion; (2) Pupunahue mine, Mulpun, Province of Valdevia; (3) Mina Vulcano, Province of Magallanes; and (4) Mina Elena, Isle de Riesco, Province of Magallanes yielded large volumes of gas at 1,000° C., because much of the inherent water was converted to water gas.

Survey of the Coke Industry

Postwar progress in the coke industry[62/] includes new and improved carbonization plants, upgrading of coal, new sources of blending coals, and improved coke evaluation.

In an evaluation of trends in our creosote-oil supply,[63/] largely derived from coke ovens, the role of basic domestic production imports and other influencing factors was considered, as were the factors that will influence the future supply of wood-preserving raw materials.

German Low-Temperature Coal-Tar Industry

Members of technical fuel missions to Germany, organized under the auspices of the Technical Industrial Intelligence Committee, have written a great many reports describing German developments in mining, preparation, and utilization of coal. These reports are on file at the Bureau of Mines, Washington, D. C., where they are available for public examination. Because of the importance of the subject material, some of the reports or combination of reports were published.

The production and processing of low-temperature coal tars in Germany were not associated with high-temperature tar operations. Investigation disclosed that Germany's increased demands for liquid fuels during the period between 1933 and 1945 had brought about the development of low-temperature coal carbonization industry

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61/ See footnote 17.
62/ Davis, Joseph D., Coal Industry (Coke Industry): Min. Eng., vol. 1, No. 3, sec. 2, 1949, pp. 120-122.
63/ Brown, Ralph L., Creosote Oil Supply: Proc. Am. Wood Preservers' Assoc., vol. 44, 1948, pp. 246-259.

which produced more coal tar than the long-established Germany high-temperature industry.64/ Information on the processes in use was obtained on visits to major plants in the American, British, French, and Russian zones of occupation.

GASIFICATION OF COAL AND COKE

Use of Oxygen in Gas Manufacture

Progress on studies of the reactions, which are of interest in oxygen gasification and in the art of producing tonnage oxygen was reported for the Subcommittee on Use of Oxygen in Gas Manufacture of the American Gas Association.65/ Included in the report were statements on the progress of the design, construction, and operation of oxygen plants prepared by leading manufacturers of tonnage oxygen plants.

The Lurgi Process of Complete Gasification

This process is a method for gasifying fuel (char or noncoking coal) in oxygen and steam at 20 to 30 atmospheres pressure. The work is being carried on in the Central Experiment Station, Pittsburgh, under cooperative agreement with the Southern Natural Gas Co., with equipment designed by O. Hubmann of the Lurgi Co. The process is continuous and designed to consume 3,000 pounds of fuel per day (24 hours), the grate area of the present generator being 1 square foot.

Three coals have been tested in the continuous generator. They are: Corona coal from Alabama, Pittsburgh coal from northern West Virginia, and Hiawatha coal from Utah, the latter being weakly coking. The rate of gasification has ranged from 4,500 to 5,000 cubic feet per square foot per hour, the make gas containing about 28 percent CO_2. After scrubbing out the CO_2, the yield is about 57,000 cubic feet of 420 B.t.u. gas per ton of fuel gasified. The fuel used was low-temperature char in all cases, it being impossible to gasify a caking coal in the generator. It was found practical to use virtually all the CO and H_2 in the gas to synthesize CH_4, using a nickel catalyst, and produce a gas of 900 to 950 B.t.u.

Gasification of Lignite and Subbituminous Coal

Research work of the Bureau of Mines on the gasification of lignite and subbituminous coal was reviewed.66/ Two pilot plants were built to develop a retort-type system of gasification - a small plant at Golden, Colo., and a larger commercial-scale plant at Grand Forks, N. Dak. These two pilot plants have demonstrated that lignite and subbituminous coal can be gasified or carbonized at relatively high speed and efficiency.

64/ Rhodes, E. O., German Low-Temperature Coal-Tar Industry: Bureau of Mines Inf. Circ. 7490, 1949, 84 pp.

65/ Newman, L. L., Report of Subcommittee on Use of Oxygen in Gas Manufacture: Proc. Am. Gas. Assoc., New York, 1948, pp. 302-307.

66/ Parry, V. F., Developments by the Bureau of Mines on Gasification of Lignite and Subbituminous Coal: Skillings Min. Rev., vol. 37, 1948, pp. 1, 4, and 15.

Gasification of Lignite for Preparation of High-Hydrogen Water Gas

Investigations of the gasification of lignite in the externally heated, continuous, annular retort were continued at Grand Forks, N. Dak., during the past fiscal year. Table 13 summarizes this work.

TABLE 13

Run	Retort tube	Hours operated	Lignite used, pounds	Gas made, cu. ft. S.G.C.
9	Cast HK alloy	98	28,400	640,000
10	Cast HK alloy	53	1/	1/
11	Rolled plate 310 alloy.	694	344,760	7,303,773
		845	373,160	7,943,773

1/ Tube failed.

This additional operational experience has contributed to the perfection of the process and equipment. The heart of the gasification unit is the retort tube, and attention has been concentrated on three major points.

The first point deals with the material out of which the tube may be made. Four tubes have been used so far, and their pertinent characteristics have been determined. Table 14 summarizes this information.

TABLE 14. - Comparison of tubes

Tube No.	Material	Construction	Service
1	Metcolized steel	Welded rolled plate	Unsatisfactory.
2	Pluramelt 446	Welded rolled plate	Failed through distortion.
3	HK alloy	Centrifugally cast one-weld seam	Surface too rough weld failed.
4	310 alloy	Welded rolled plate	Satisfactory.

From an operating experience of more than 4,600 hours with four tubes, it is concluded that coated or sandwich-type tubes are unsatisfactory because of blistering and physical distortion due to difference in coefficients of expansion; as-cast tubes are unsatisfactory because of the roughness of the surface and the eccentricity of the tube; rolled-plate construction with the minimum length of welds is desirable; and 310 alloy apparently is satisfactory.

The second major point is the life of the retort tube. Tube 4 has been operated 694 hours with no sign of serious corrosion. In addition, a flame guard of the same 310 alloy has been in service for more than 4,000 hours and is still in excellent condition. There is no sign of mechanical or physical distortion. A very conservation estimate of the life of this tube is 10,000 hours.

The third major point is the determination of limiting operating conditions for this process and this generator. During this fiscal year it has been determined that (1) the minimum operating temperature should be 1,000° F. at the gas off-take to prevent the formation of tars; (2) the maximum operating temperature should be 1,900°

F. in the combustion chamber to prevent excessive corrosion and mechanical and physical deformation; and (3) the maximum capacity of the retort is 375,000 cubic feet of dry gas per day, determined by the area of the gas off-take.

Underground Gasification

The gases produced by this process offer a potential source of energy for electric-power generation and for raw materials for synthetic liquid-fuels manufacture. The method holds promise of utilizing coal veins now difficult or uneconomic to mine or recovering the energy yet remaining underground in regions where only part of the coal has been mined out. This latter possibility would entail burning coal pillars that have been left underground in old, worked-out operations.

Laboratory-scale experiments were carried on at Morgantown, W. Va., and the construction and operation of the second field-scale project was undertaken at Gorgas, Ala.

Laboratory Experimentation

In a horizontal rectangular retort, a simulated segment of a coal bed was placed on a hearth constructed of fire brick and insulating brick.67/ The simulated overburden was composed of fire brick adjacent to the coal segment and covered with a thick layer of diatomaceous earth. Inlet and exhaust openings to the retort were fitted with regenerators and suitable equipment for handling blast air and product gases. During experimentation, the retort was altered repeatedly in size and construction, remaining, however, an essentially horizontal and rectangular unit.

Eleven experiments were carried out with this retort. During the first runs, a gas having a heating value of approximately 50 B.t.u. per cubic foot was produced. Marked improvement in gas quality was noted as experimentation continued. Table 15 gives the results of four of the latter test runs made in this retort. The calorific value of the product gas ranges from 92 B.t.u. to 112 B.t.u. per cubic foot. The gas qualities given are the average for the gas-making parts of the several test runs.

During the test runs, the relationship between length of passage and the concentration of oxygen, carbon dioxide, and carbon monoxide in the blast or product gas was determined. Gas analyses were made after the air-gas had traveled 5, 20, 50, 70, and 95 percent of the length of the channel. These analyses clearly showed, first, the decrease in oxygen and an increase in carbon dioxide; then, a decrease in carbon dioxide and an increase in carbon monoxide as the percentage of travel through the channel increased. The 5 percent point was characterized by high oxygen, the 20 percent point by high carbon dioxide, and the 50-, 70-, and 95-percent points by increasing percentages of carbon monoxide with a maximum percentage of carbon monoxide at the 95-percent point. The laboratory tests indicated that it should be possible to use a simple air blast and produce a gas with a heating value of approximately 100 B.t.u. per cubic foot by the underground gasification process.

Second Field-Scale Experiment at Gorgas, Ala.

This second field-scale experiment in underground gasification at Gorgas, Ala. is being conducted in the Pratt coal bed in an area isolated from the main bed of

67/ See footnote 6.

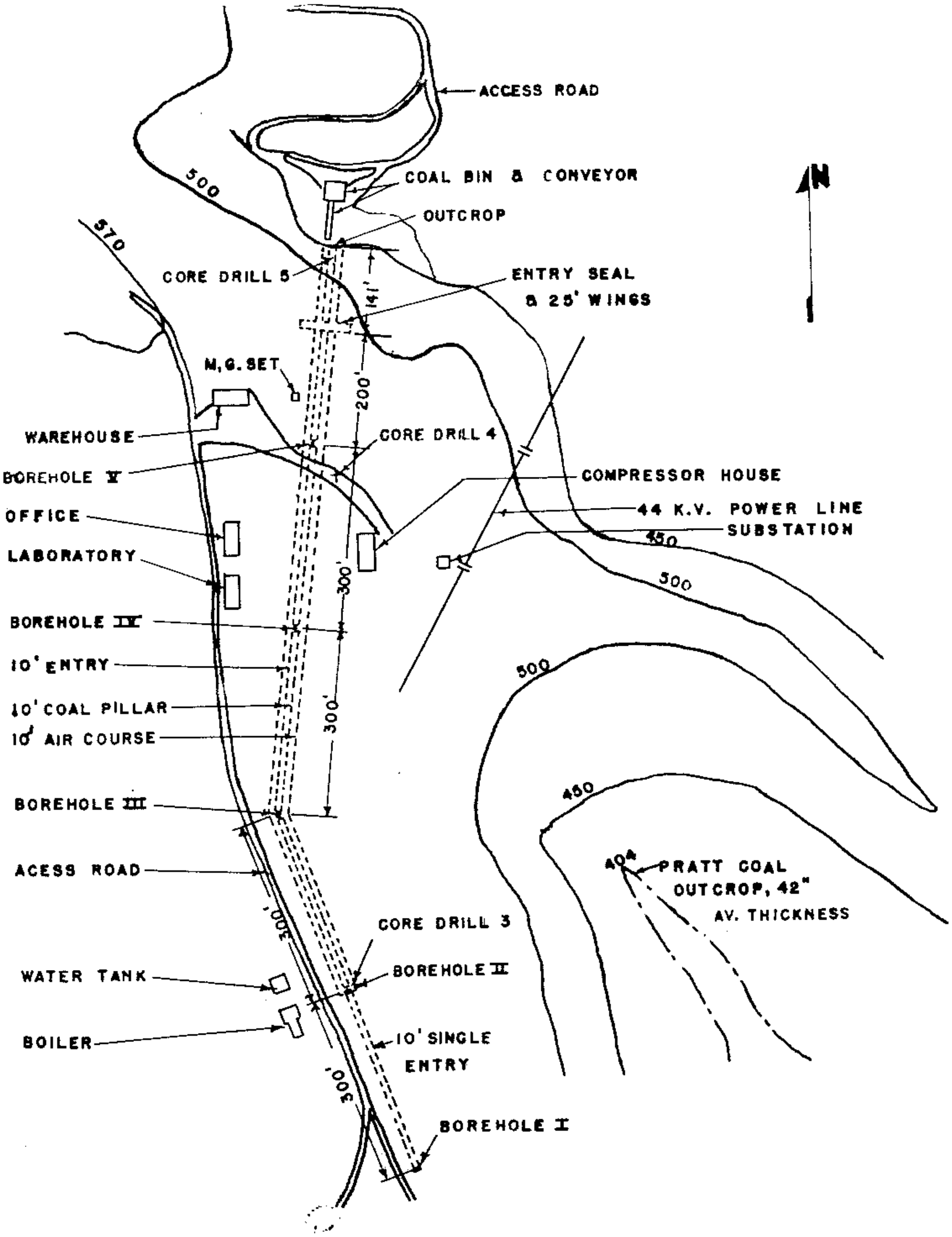

Figure 19. - Plan of underground gasification project.

coal by nature and consisting of approximately 100.[68] [69] The coal bed is 42 inches thick and relatively level; it lies under an average over-burden of 150 feet. One of the purposes of this second experiment at Gorgas is to study the characteristics of a unit installation for underground gasification. Such a unit consists of (1) a gasification chamber that is a passageway in the coal bed; (2) inlet and exhaust channels for blast and product gases, respectively; and (3) machinery and piping necessary to operate the system. The installation for the second experiment at Gorgas, Ala., is shown in the schematic diagram (fig. 19).

TABLE 15. - Results of laboratory experiments

Experiment	7	9	10	11
Weight of charge ... lb..	5,180	8,738	8,185	8,030
Weight of residue ... do..	1,453	4,920	4,717	3,002
Percent consumed	72	44	43	75
Maximum air flow ... cu. ft. per hr..	2,350	3,642	4,600	2,940
Analysis of charge, percent:				
Hydrogen	4.6	4.2	4.2	4.5
Carbon	75.9	75.6	78.2	76.6
Nitrogen	1.2	1.3	1.3	1.4
Oxygen	6.1	5.6	4.7	6.2
Sulfur	.9	1.3	.9	.9
Ash	11.3	12.0	10.7	10.4
Heating value ... B.t.u. per lb.	13,220	13,010	13,390	13,250
Length of run ... hr..	109.25	83.5	46.3	124.5
Gasification period ... do..	31.5	52.0	20.3	22.5
Average gas analysis, percent:				
CO_2	8.7	10.2	7.7	7.7
Ill	.2	.6	.5	.3
O_2	.2	.2	.5	.4
CO	19.9	12.1	14.7	20.9
H_2	4.3	9.5	10.7	4.5
CH_4	1.0	2.4	2.0	2.3
N_2	65.7	65.0	63.9	63.9
Heating value ... B.t.u. per cu. ft..	92	106	112	111
Cold-gas efficiency ... percent.	55.6	75.0	80.9	64.5

The experimental unit consists of a straight-line passage in the coal bed with surface connections at one end through an outcrop seal and at various points along its length by vertical boreholes. The passage is divided into five sections, four of which are 300 feet long and the fifth 200 feet. Each section may be used separately as a gasification unit, or several sections may be combined to form a major unit. The passage in the coal bed consists of two parallel entries 10 feet wide separated by a solid pillar of coal 10 feet wide. Boreholes have been drilled at 300-foot intervals from the surface to the coal seam, opening at the bottom into crosscuts connecting the two entries. The southernmost 300-foot section consists of a single entry 10 feet wide.

[68] See footnote 6.
[69] Fies, M. H., Elder, J. L., Graham, H. G., Montgomery, R. C., and Jernigan, J. M., The Second Underground Gasification Experiment at Gorgas, Ala.: Descriptive pamphlet of the Gorgas Project, 1949, 19 pp. Issued by Bureau of Mines.

The objectives of this second field scale experiment are:

1. To determine the quantity of coal that can be gasified from the given initial combustion zone and the shape and extent of the burned-out area formed during this gasification.

2. To test the design and construction of types of product gas outlets, including the seals required.

3. To determine the operational characteristics of the experimental installation under such variation of conditions as the nature of the installation and progress of work indicated to be desirable; for example, the length of passage required, the optimum rate of flow, and the pressure drop.

4. To determine the quality and quantity of the product gas generated under the experimental conditions. A secondary phase of this objective will be the determination of the quantity of tar and related byproducts obtained.

5. To obtain all possible information regarding the action of heat on the overlying strata.

6. To develop, without interfering with the foregoing objectives, such fundamental technical and economic information as is likely to be helpful in selecting plant sites, plant installation, and operating processes.

Construction work on the Gorgas project was started in the latter half of June 1948 and was completed in March 1949. The underground entries were driven into the coal bed, and conveyors were used to load out and transport the coal to the surface. Two 18-inch-diameter and three 28-inch-diameter churn-drill holes were drilled from the surface to the entry. The strata through which each borehole passed were pressure-grouted by means of four 6-inch churn-drill holes spaced 4 feet from the center point of the large hole. Generally, the first two grout holes took appreciable quantities of cement grout, and the last two refused grout, indicating that the underground crevices intersected by the holes were securely stopped.

The five large boreholes were sealed at the surface by lengths of water-jacketed pipe set in concrete (fig. 20). These seals extend approximately 25 feet below the surface and are seated on hard strata. The two 18-inch boreholes are unlined below the surface seal. It is possible that the natural strata will crumble and slag at high temperatures and block these boreholes. To prevent this, the 28-inch diameter holes were fitted with a refractory lining 4 inches thick.

In addition to the large boreholes, a number of holes 6 inches in diameter have been drilled from the surface to the coal bed. Each of these was fitted with thermocouples to measure the temperature rise in the coal bed. The holes are so placed that the progress of the combustion zone may be traced.

An entry seal was constructed across the two entries 141 feet in from the outcrop. This seal consists of a fire-brick wall backed with concrete extending across and 25 feet beyond the outby ribs of the entries. The wall extends 6 feet into top rock and 2 feet into the bottom. Outlet pipes have been sealed into this stopping, so that it may be used to withdraw gas from the underground system.

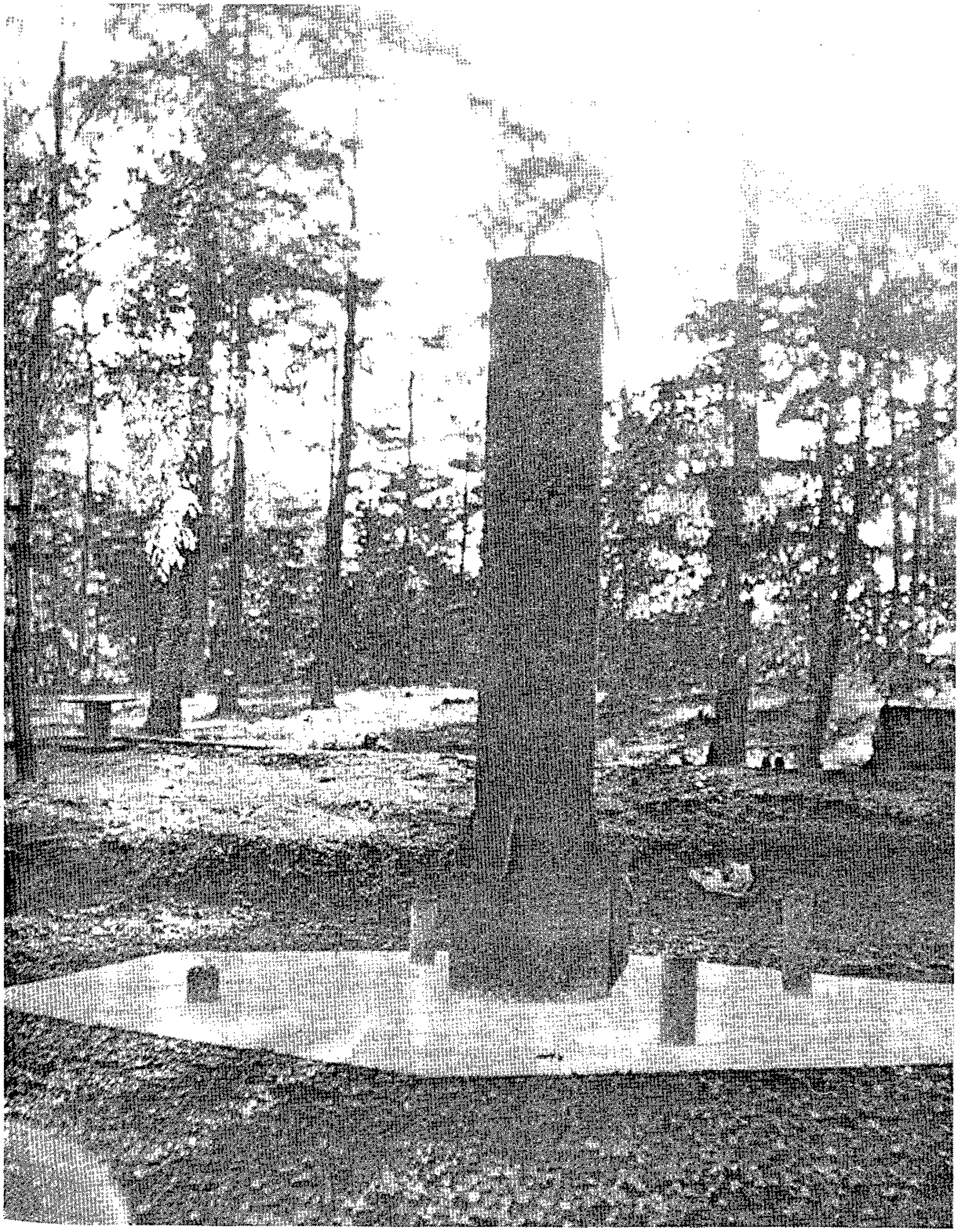

Figure 20. - Water-cooled seal installation at borehole V.

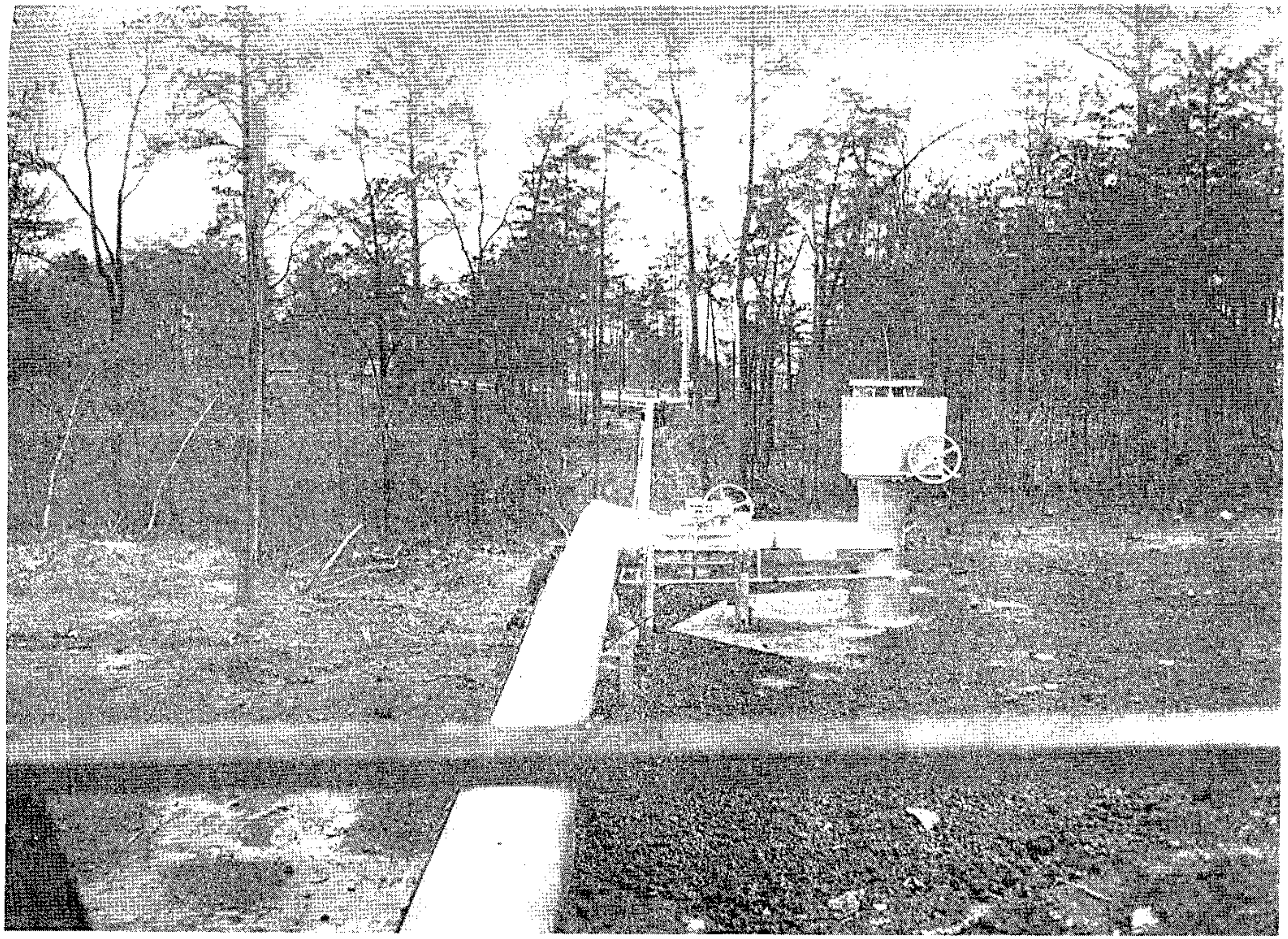

Figure 21. - 20-inch air manifold looking south; borehole IV in foreground.

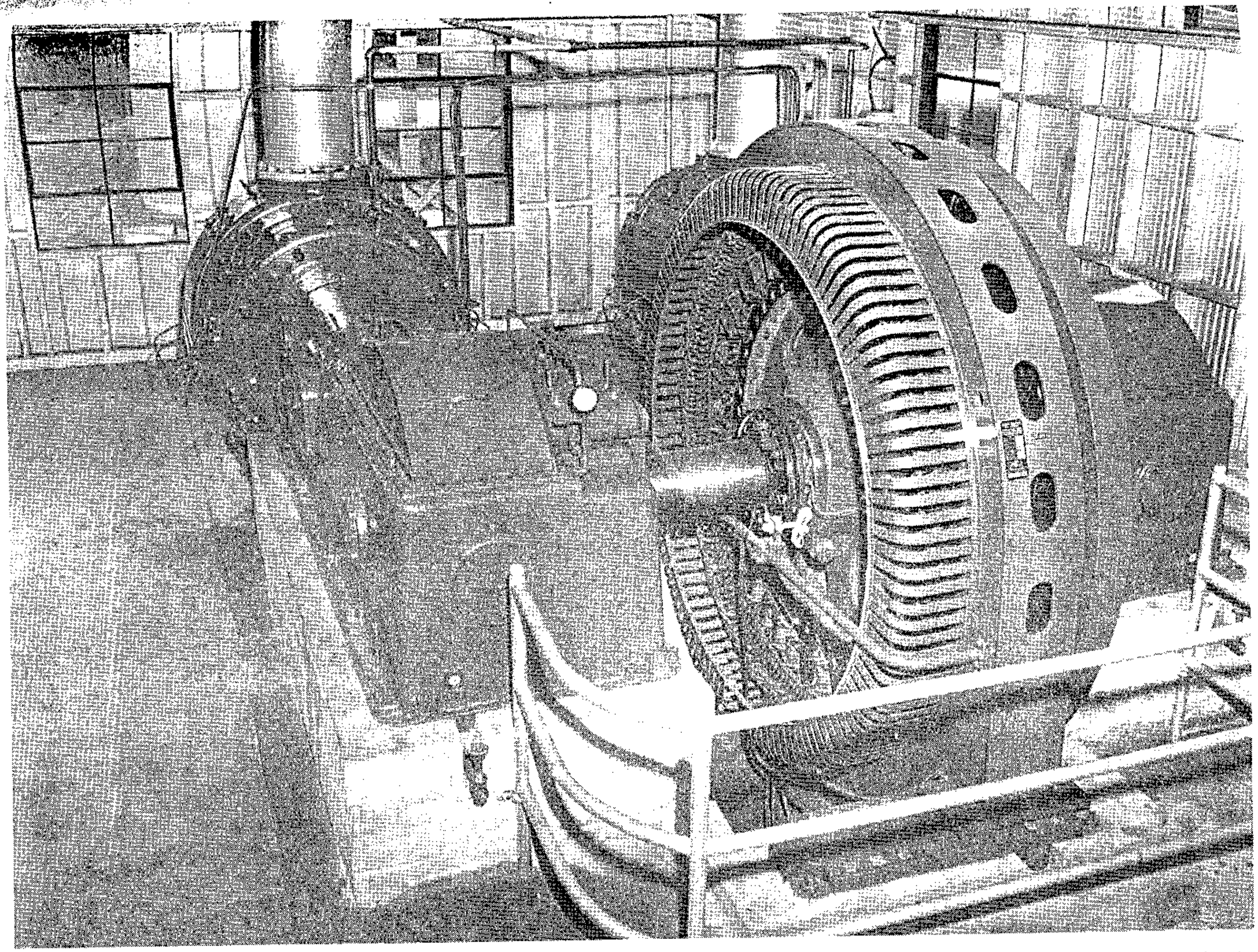

Figure 22. - 800-horsepower reciprocating compressor; capacity, 7,200 c.f.m. free air, 30 p.s.i.g. discharge.

On the surface, a 20-inch air manifold has been constructed along the line of the entry and extending from borehole I to borehole V (fig. 21). This manifold is connected to each of the boreholes in such a way that the borehole may be used either as an inlet or outlet for the system.

Three electric motor-driven compressors were installed to supply air for gasification of the coal. The major compressor unit is a two-cylinder reciprocating compressor designed to compress 7,200 cubic feet of air per minute with a discharge pressure of 30 pounds per square-inch gage (fig. 22). This machine is driven by an 800-horsepower synchronous motor. Two smaller compressors are for stand-by use.

Operation of the project has been confined to the 300-foot section between boreholes I and II. The ribs of the single entry were undercut to a depth of approximately 15 inches, and a pile of broken coal approximately 15 feet long and 2 feet deep was placed adjacent to the bottom of borehole I. Pine wood was stacked on this pile of broken coal, and the mass of combustible was saturated with fuel oil. On March 18, a thermite hand grenade was tossed down borehole I to ignite the coal seam. At this time air was flowing at a rate of 1,600 cubic feet per minute, entering at borehole I and leaving at borehole II. For several days after the initial firing, temperatures underground continued to rise, the oxygen content of the gases issuing from borehole II decreased, and the carbon dioxide content of the gases increased. After 4 days, the oxygen content in the product gas reached a value of 4.1 percent, and the carbon dioxide content reached 13.6 percent. At this time the carbon monoxide content ranged between 1 and 3 percent. After the fourth day, the oxygen and carbon dioxide contents of the product gases respectively increased and decreased from the values given above until, after 11 days, the carbon dioxide content was 4 percent and the oxygen content 12 percent. Also, during this 11 day period the combustion zone moved from borehole I toward borehole II, and it was then necessary to reverse the flow of blast air in order to drive the combustion zone back toward borehole 1. During these first 11 days the air flow was ranged from 1,500 to 6,000 cubic feet per minute in order to find the optimum flow rate.

After this initial period, the project was operated continuously. Flow was reversed periodically in order to raise temperatures underground to the highest possible level, and an estimated 10 feet of coal has been burned from each of the ribs of the single entry. This quantity of coal is approximately 900 tons. There was no difficulty in maintaining a fire in the coal bed, and there is every evidence that the roof fell uniformly as the coal was burned. The pressure drop over the first 300-foot section of entry increased from approximately 1-1/4 inches of mercury to 12-1/2 inches of mercury with a blast rate of 7,200 cubic feet per minute. Test observations indicate that the pressure drop is very nearly proportional with the length of the entry, indicating a uniform fall of roof. Oxygen is still present in the product gases, but as the resistance to flow has increased the oxygen content has decreased. Good contact between the coal face and the air blast has not yet been achieved, as a by-pass exists through the broken rocks that have fallen into the original entry. A system is being developed whereby this air by-pass through the broken rock will be choked off and the contact between the air blast and the coal face will be improved. At this time the rate of consumption of coal averages 15 tons per day, with a blast rate of 7,200 cubic feet of air per minute. The carbon dioxide content of the product gases ranges between 7 and 8 percent and the oxygen content between 12 and 11 percent. The product gases now always contain carbon monoxide, hydrogen, and methane in amounts ranging from 0.2 to 1.0 percent each. Combustible gases appear to be forming on the coal-coke faces but are being burned by the air by-pass before they can be withdrawn from the system.