trials coke left in the retort was crushed and mixed with the fresh coal, making a coke-coal charge of 24 to 28 percent volatile content.

The regenerators were preheated by gas burners before gasification. After the regenerators had reached 1,500° F., an air blast of about 1,000 c.f.h. was passed through the retort. Combustion took place by contact with the hot air. Airflow was increased by steps, and after the predetermined maximum rate for the test was reached, flow was reversed every 1-1/2 hours.

Analyses showed changes in the air-gas mixture at various points along the channel. At 5 percent along the channel from the inlet the oxygen content was still high; at 20 percent the carbon dioxide content had become high; while at the 50-, 70-, and 95-percent points, there were increasing percentages of carbon monoxide, with a maximum at the 95-percent point and in the product gas.

A "coke pipe" formed around the channel originally built through the charge; most of the ash remaining after gasification of the fuel was deposited on the floor of the retort. Figure 22 shows retort residues found after a successful run, and table 3 summarizes several experiments. These laboratory tests indicated that the "stream method" and a simple air blast should produce a gas having a heating value of 100 or more B.t.u. per cubic foot.

The Second Field-Scale "Stream Method" Experiment

In 1948 construction was started for a field experiment, again using the "stream method" in the Pratt coal bed. An entry and aircourse were driven 1,690 feet from the outcrop, as shown in figure 23, sealed by a firebrick-and-concrete stopping, and the entry and aircourse connected by crosscuts. The 300-foot single entry between boreholes I and II was ignited. A periodically reversed air blast of 7,500 c.f.m. was used. The product gases contained unreacted oxygen and a small quantity of combustible material, indicating inadequate contact between the carbonaceous faces and the air. In an effort to improve contact, sand was fluidized and pumped underground. This was partly successful, but the cross-sectional areas of the mined entries were still too large to eliminate combustion of the gas. Later, a borehole drilled 75 feet east of borehole II was utilized to advance the face farther. Product gases having a heating value of 90 to 100 B.t.u. per cu. ft. were obtained for a time from this new hole.

During one period of operation in the 300-foot underground path the gas produced (mixed with bypassing air) burned underground and in the effluent stack at a temperature that approached 2,000° F. During another period an aircraft-type turbo-supercharger was operated by effluent hot gases and used for pumping air underground.

For one period the reaction path was increased to 600 feet; this materially increased the rate of coal consumption. The quantity of excess oxygen decreased; however, the cross-sectional area of the underground passage was apparently still too large for sufficient contact between reactants.

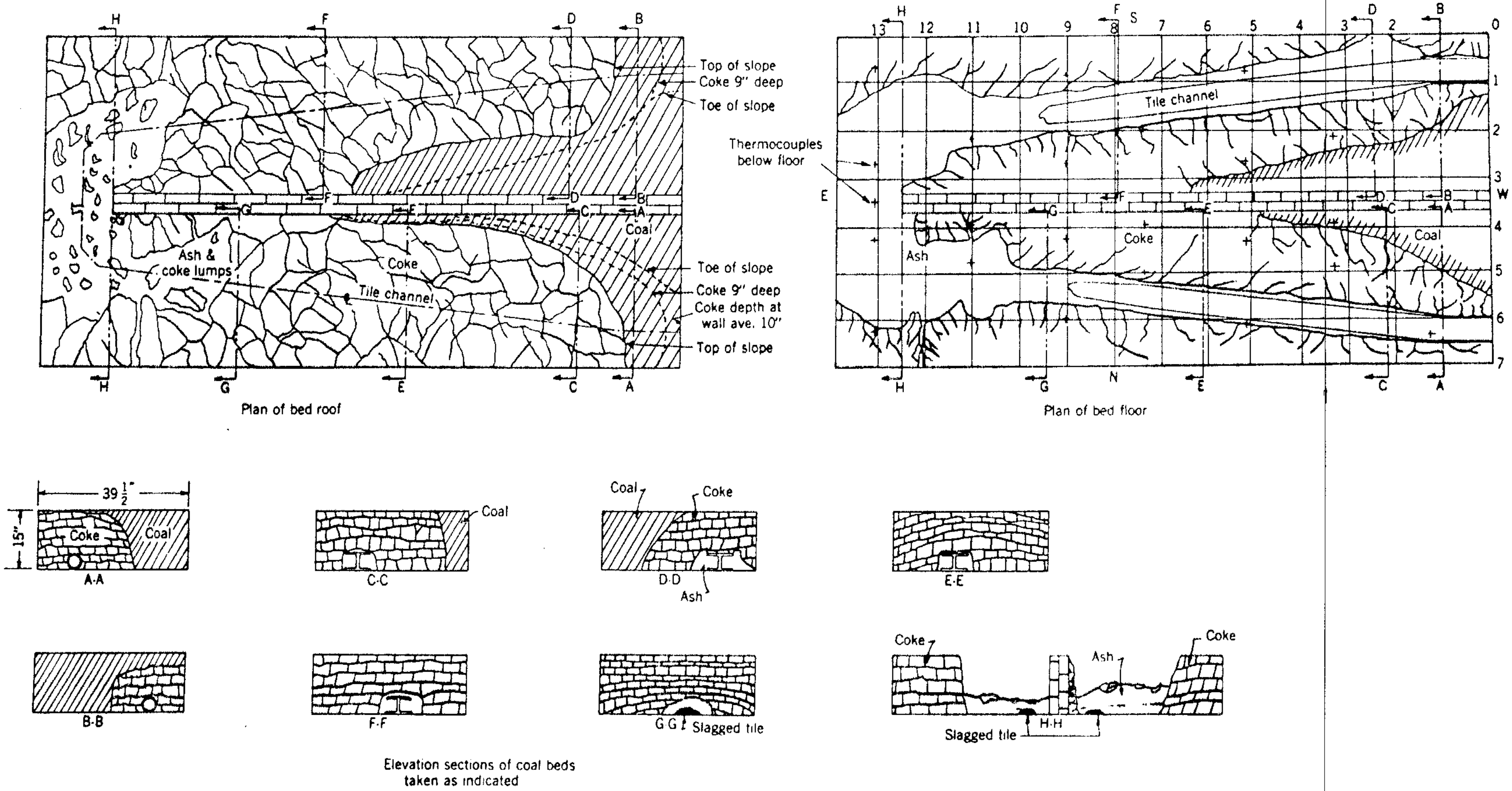

FIGURE 22. - Residue After Laboratory Test Simulating Underground Gasification.

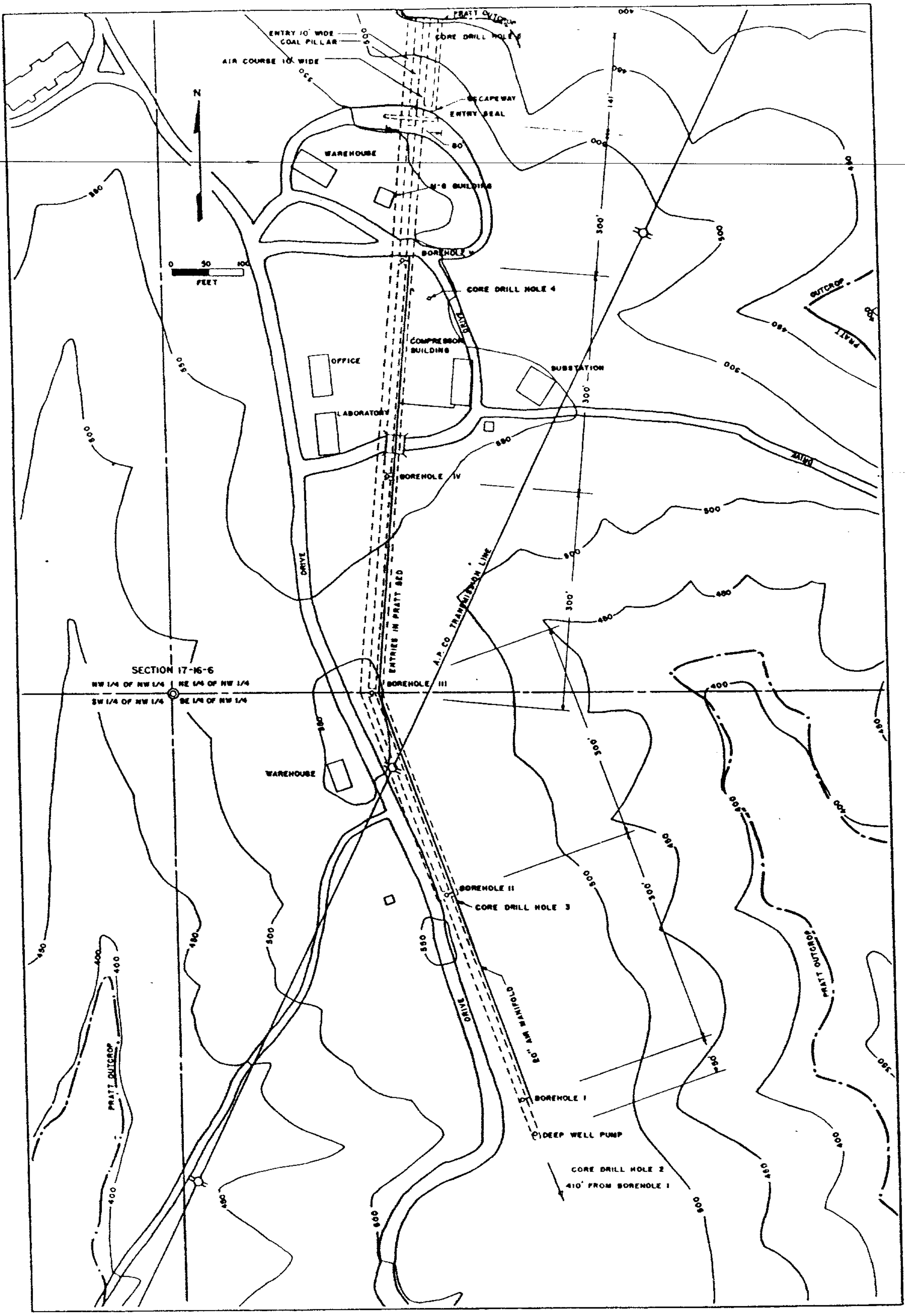

FIGURE 23. - Plan of Second Underground Gasification Project.

TABLE 3. - Results of laboratory experiments simulating underground gasification

Experiment No.	7	9	10	11
Wt. of coal charge..........lb.	5,180	8,738	8,185	8,030
Wt. of residue..........do.	1,453	4,920	4,717	2,002
Coal consumed..........percent	72	44	43	75
Max. air flow..........c.f.h.	2,350	3,640	4,600	2,940
Length of run..........hr.	109	84	46	125
Gasification period..........do.	32	52	20	23
Average gas analysis, percent:				
CO_2	8.7	10.2	7.7	7.7
Illuminants	.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

Leakage from the underground system increased gradually to about 50 percent of the air input, and the 50-percent figure was exceeded when higher pressures were placed upon the system by throttling the gas outlets. Long exposure to heat, with subsequent drying of overlying strata, might have increased leakage. Similarly, pressure may have forced moisture from adjacent strata and reduced its sealing effect.

Various types of equipment and construction were tested. A water jacket between the borehole casing and the concrete surface seal was very effective for handling hot gases, and exit boreholes were operable for long periods. Refractory-lined boreholes were not superior to unlined boreholes for handling hot gases, and the extra cost did not appear justified. Pressure grouting of areas surrounding an outlet/inlet appeared advantageous to decrease porosity of the strata traversed.

During continuous operation for 22-1/2 months, an estimated 10,500 tons of moisture- and ash-free coal had been consumed, under an area of 1.9 acres adjacent to the original entry.

The two experiments using mined entries in a flat-lying coal bed emphasized the difficulty in maintaining sufficient contact between reactants. Roof action apparently helped but was insufficient to force adequate contact. The U-shaped path used in the first experiment was superior to the straight path in the more extensive second test. Both tests indicated that a path forcing intimate contact between reactants is required to produce gas of adequate quality.

Experimentation Using Electrolinking to Form a Passage Through a Coal Bed

Laboratory and field-scale trials were conducted from 1947 to 1951 by the Missouri School of Mines and Metallurgy and the Sinclair Coal Company, with a technique known as "Underground Electrocarbonization" (8). During these trials it was possible to seat a pair of electrodes within a coal bed, pass an electric current between them, and carbonize a path permeable enough to permit passage of air or other gasmaking fluid. The results suggested that electrolinking of boreholes in a coal bed could eliminate underground mining by producing a suitable path for initiating gasification, as well as one likely to enforce maximum contact between reactants.

In 1951 and 1952 the Bureau of Mines, Alabama Power Company, and Sinclair Coal Company conducted at Gorgas, Ala., one unsuccessful and three successful experiments using electrolinking-carbonization in the America coal bed of high-volatile A bituminous coal of 36 to 42 percent volatile content. Borehole pairs were drilled to the coal bed, 180 feet below the surface, electrodes were seated in the coal, and an electric current was passed between them. Electrode spacings of 67 to 200 feet were tried; three gasification systems were established successfully during 1952 by electrolinking-carbonization, using a spacing of 150 to 155 feet. This spacing represented a practical maximum with the available equipment. A plan of the electrolinking installations is given in figure 24.

Electrical data for three successful electrolinking-carbonization trials are given in table 4. The electrolinking established a good electrical path between the electrodes, and electrocarbonization then prepared a porous coke path through the bed, suitable for passage of a gasmaking fluid. Gasification with an air blast followed electrolinking-carbonization of the three systems and produced approximate totals of 92.8, 99.6, and 65.8 million cubic feet of producer-type gas, with an average heating value of 71, 86, and 83 B.t.u. per cubic foot, respectively (see fig. 25). The total amounts of underground coal utilized for the three systems were calculated at 1,022, 1,009, and 564 tons, respectively.

TABLE 4. - Electrical characteristics of electrolinking-carbonization systems

Electrolinking-carbonization trial No.	2	3a	3b
Distance between boreholes...feet	152	155	150
Resistance, after first application of power...ohms	36.7	31.25	15.8
After drop in initial contact resistance...do	11.2	7.30	7.31
Before breakthrough...do	3.85	2.70	3.24
After breakthrough...do	0.95	0.88	1.24
End of electrocarbonization...do	0.30	0.22	0.72
Total power for electrolinking...kw.-hr.	40,500	146,800	20,080
For electrocarbonization...do	30,100	24,160	39,744
Time for reduction of initial contact resistance...hours	1.0	0.75	1.0
Total for electrolinking...do	56	155	20.5
Total for electrocarbonization...do	64.5	51.8	133.5

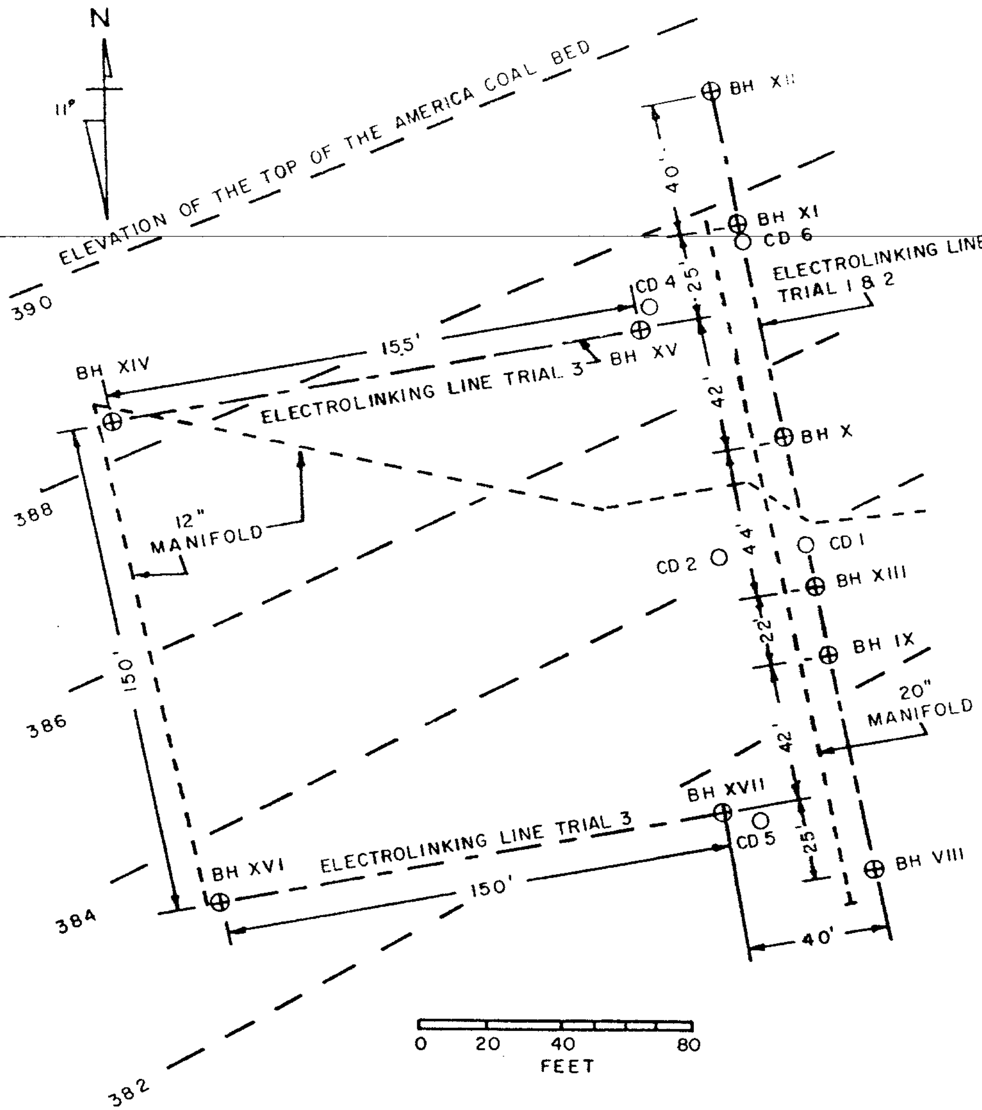

FIGURE 24. - Site Plan of Electrolinking Installation.

Gasification using borehole pair XVI-XVII was started, using first air, and then oxygen (see table 5). Later alternate operation with an air blast and steam produced results as summarized in table 6.

The coal near the inlet borehole (the point of maximum oxygen availability) apparently was consumed at the highest rate. As gasification continued the area of complete coal gasification extended in nearly all directions, increasing at the greatest rate downstream. When the area of complete gasification reached or closely approached the outlet, the gas quality deteriorated, unreacted oxygen appeared in the product, and the temperature rose, partly from combustion in the outlet.

The first objective of this work has been development of a workable unit for underground gasification. Electrolinking-carbonization followed by gasification with air is a workable procedure for producing a producer-type gas suitable for generation of power. (Gases made with oxygen or an air-stream

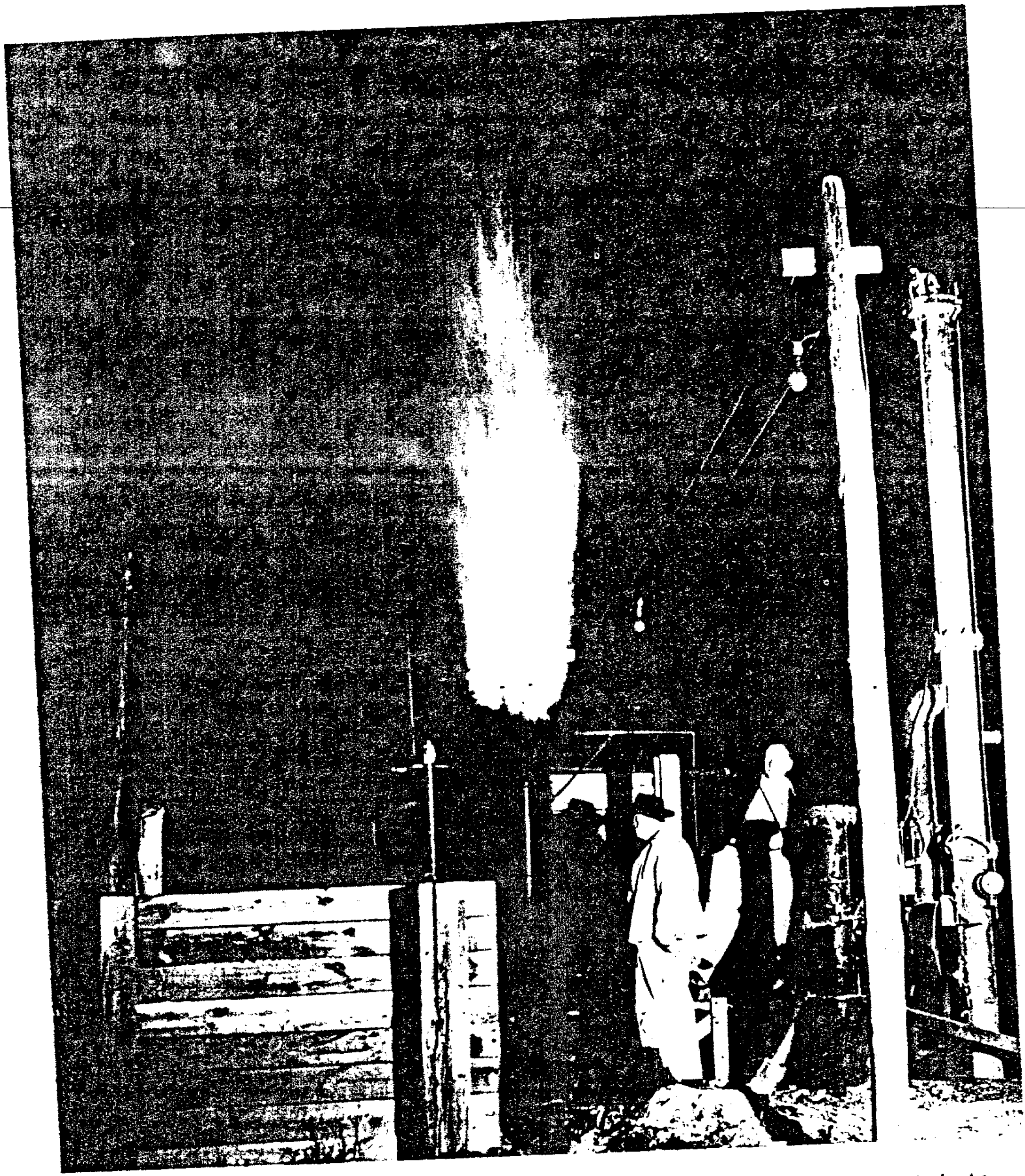

FIGURE 25. - Burning Gases Evolved During Gasification Tests With Air, Following Electrolinking of Boreholes.

cycle might be used for synthesis of organic chemicals or liquid fuels.) With each succeeding experiment, the tonnage from a single, constant-length unit has increased; however there is obviously a practical limit, which cannot be exceeded. With oxygen, the coal is more completely utilized, so increasing the oxygen content of air may eliminate coke residue.

On the basis of overall heat balances, gasification with oxygen was the most efficient of the methods, cyclic water-gas operation second, and air blasting third. These heat balances indicate that approximately 25 to 35 percent of the heat of combustion of the coal was lost underground, probably in heating and fusing surrounding rock strata and in vaporization of water.