CHAPTER 4. - UNDERGROUND GASIFICATION OF COAL

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Since 1946 field-scale experiments have been conducted by the Bureau of Mines and the Alabama Power Company at Gorgas, Ala., to develop a method by which either the chemical constituents or the energy from coal in place underground may be brought to the surface economically for use as synthesis gas, or as gas fuel for operating powerplants.

Status of Underground Gasification of Coal to 1944

The suggestion that coal might be gasified in place is attributed to Sir William Siemens in 1868 (11) and to Mendeleev in 1888. A British patent was granted in 1909 to A. G. Betts for a method of gasifying coal in the bed, at the base of shafts or boreholes, by supplying air and steam through a pipe and withdrawing the gas formed through the same or other shafts.

In 1912 Sir William Ramsey advocated underground gasification and likened it to retorts in the bowels of the earth. Preparation of an experimental unit was begun; but with the outbreak of World War I and the subsequent death of Ramsey, the installation was not completed.

The Soviet Government subsidized preliminary experiments on underground gasification in 1931, and 2 years later a state trust, Podzemgaz, was formed to carry out such work. Podzemgaz set up experimental stations to investigate gasification of coal in place, and meanwhile conducted chemical and physical laboratory studies of the process.

In the first experiments gasification of unbroken panels of coal was attempted. The panels were isolated from the rest of the bed by brickwork walls, and headings were constructed on opposite sides of the panel for conveying an air blast and for withdrawing the product gas. Unbroken panels were ignited, the air blast was applied at the center of one wall, and product gases were taken from the center of the opposite wall. Combustion was slow, since it depended on natural fissures and the porosity of the seam for the passage of air or gas.

Later the "chamber method" was employed. Chambers filled with broken coal were connected in parallel to common air-inlet and gas-offtake headings. An unsteady flow of combustible gas was obtained.

Next was the "borehole producer method," which involved constructing two parallel headings within the seam, 300 to 360 feet apart, as air-blast-inlet and gas-offtake manifolds. The galleries were connected at right angles by a large number of parallel 4-inch boreholes about 15 feet apart. Boreholes were ignited in succession or in small groups. Operating with air blast or with alternate steam and air blast produced gas of the following compositions (12):

	Analysis, percent	
	Air-blow gas	Steam-blow gas
Carbon dioxide	11.0	23.8
Oxygen	.2	.0
Carbon monoxide	12.0	14.0
Hydrogen	12.0	44.5
Methane	5.0	5.8
Nitrogen	59.8	11.9
Heating value, B.t.u. per cu. ft., 60° F., 30 in. Hg dry	128	248

The "stream method" was subsequently tried in steeply pitching coal beds (2, 6, 19). Air and gas passages 300 to 600 feet apart, connected to the surface by shafts, followed the pitch of the bed for approximately 120 feet. At the bottom the passages were connected within the coal bed by a horizontal heading in which the coal was ignited. The coal roof burned away, and the fire zone advanced upward along the bed; the ash collected below the fire zone. The burning coal face was kept free from accumulation of ash, and the air flow was limited to near the burning coal. Flow was reversed periodically to obtain symmetrical burning of the panel outlined by the passages. Air or oxygen-enriched air in the blast produced gases containing 12 to 28 percent carbon monoxide, 14 to 30 percent hydrogen, and 2.5 to 10.0 percent methane and heating values of 109 to 289 B.t.u. per cubic foot. When the blast was operated intermittently, a gas with 60- to 70-percent hydrogen content was evolved.

The "percolation method," as suggested by the Power Institute of the Moscow Academy of Sciences, depended on heating the coal bed to produce shrinkage cracks and fissures in the bed and thereby make it permeable to gas flow (4, 9, 15). A borehole to the coal bed was fitted with concentric inlet and outlet pipes; the coal was ignited; and combustion was maintained by blasting air or oxygen through the inlet pipe while the products were discharged through the outlet pipe around it. Additional boreholes were drilled in concentric rings around the initial opening. After a time permeability between boreholes increased so that flow between them was feasible.

In the Russian work a number of technical problems appeared. Much of the experimentation required excessive underground labor. Drilling horizontal boreholes or shafts following the pitch of an inclined coal bed required specialized techniques to keep the bit within the bed. Among suggested substitute methods were the hydrolinking of boreholes by high-pressure water jets; the linking of boreholes by burning a path between them with an oxygen jet; and electrolinking by passing an electric current between electrodes embedded in the coal and carbonizing a path (18).

Other operational problems included handling high-temperature gaseous products, which was partly solved by lining outlets with steel casing (6, 14, 19), and the effect of high temperatures on strata adjoining the coal bed. According to reports, elevated temperatures caused disintegration and fusion of the adjacent strata, resulting in a blockage of reaction paths; this might be controlled by limiting reaction temperatures. If strata adjacent to the reaction zone were porous, special methods had to be adopted to confine the reactants (13).

Accounts of the Russian work stated that heat losses were not important (3). Heat transfer through layers of soil or coal was negligible, but water in strata adjoining the reaction zone might lead to serious heat losses. The heated layer of coal adjoining the reaction zone was only 3 to 5 feet thick, suggesting that lateral heat losses were small.

In 1937 the Russians started industrial operations at Gorlovka using the stream method, and installation of at least two other industrial stations was begun by 1939-40.

Underground Gasification, 1944-55

Following World War II, experimentation in underground gasification was begun in several countries. In the United States the Bureau of Mines and the Alabama Power Company have cooperated since 1946 in the field-scale experiments to be discussed below (5, 7), and at least two companies have conducted their own experimental programs in underground gasification since 1944.

In 1947 the Belgian Government-subsidized Socogaz started two short experiments in Italy in relatively flat-lying deposits of brown coal having a volatile content above 50 percent. Socogaz initiated an experimental program at the Bois-la-Dame mine near Liège in 1948, in a steeply pitching coal bed with a volatile content of 12.3 percent (10). In 1948 Charbonnages de France joined in the work at Bois-la-Dame, and later Charbonnages de Pologne also cooperated with Socogaz. Charbonnages de France began an experimental program at Djerada in French Morocco in 1949 in a steeply pitching bed of anthracite having a volatile matter content of 5.6 percent (16). The field-scale experimentation in Italy, at Bois-la-Dame, and at Djerada, has been by the "stream method."

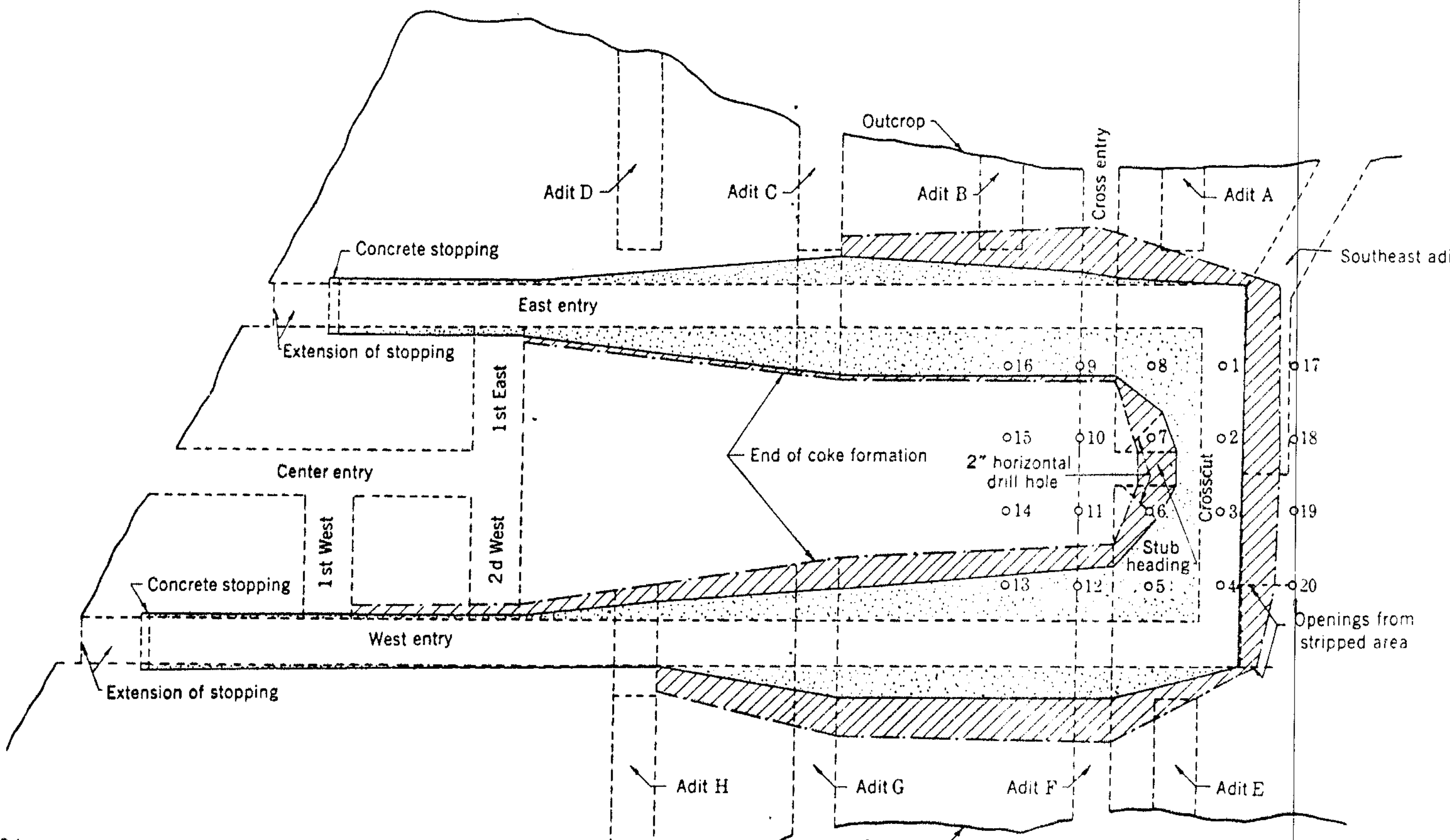
The British Ministry of Fuel and Power began extensive underground gasification tests in 1949 (17). These tests have been in flat-lying coal beds and have been concerned with modification of the "borehole producer method," utilizing horizontal directed drilling within a coal bed; or with modifications of the "percolation method," wherein high-pressure fracturing of the coal or electrolinking of boreholes in the coal has been used to form a passage through the bed.

U.S.S.R. reports (1) indicate that damage to underground gasification installations was severe during the German invasion of Soviet territory. However, restoration of stations and rehabilitation of the underground gasification program appear to have been undertaken soon after liberation of the areas. Research and development continued on an expanded scale, and by 1947 industrial gas was again being produced underground from brown coal in the Moscow Basin. By 1955 industrial production from this station and from two bituminous coal stations - one in the Donets and one in the Kuznetsk Basin - was reported to be 20.3 billion cubic feet annually. Projected production, from these and from three additional stations, was set at 100 billion cubic feet annually by 1960.

Bureau of Mines Contributions to the Underground Gasification of Coal, 1944-55

Experimentation by the "Stream Method" (First Gorgas Experiment)

In 1946 the Bureau of Mines and the Alabama Power Company conducted their first field-scale test on underground gasification. This experiment utilized a "U-shaped" path (see fig. 20) through the Pratt bed of high-volatile A bituminous coal of about 32 percent volatile content, at Gorgas, Ala. The bed was under approximately 30 feet of cover. Twenty holes were drilled from the



Coal in pillar 732 tons

Coal used, tons	In the pillar Completely burned	In the pillar Coked	Outside the pillar Completely burned	Outside the pillar Coked
East portal to cross entry	55	6	27	21
Cross entry to crosscut and beyond	41	14	6	43
West portal to cross entry	46	38	31	42
Total	142	58	64	106

Broken coal originally placed in crosscut	15 tons
Total coal burned	221 tons
Total coal coked	164 tons
Total coal affected	400 tons

FIGURE 20. - Coal Utilization in Underground Gasification (First Gorgas Experiment). Boreholes are indicated by small circles with numbers.

surface to the underground workings so that data and samples could be obtained during the experiment. Combustion was started below borehole 1; after 50 days the fire was extinguished by discontinuing the air blast and cooling with steam and water. New adits were driven, part of the overburden was removed by stripping, and coal utilization as shown in figure 20 was then determined by visual observation.

There had been no difficulty in maintaining combustion of the coal underground. Examining the residue showed that burning had been fairly uniform and that coal in place could be completely gasified. Where combustion had been completed, only ash and clinker remained with no islands of unreacted coal or coke.

Simple air blasting had produced gas with an average heating value of 47 B.t.u. per cubic foot.[7] Short runs using an oxygen-enriched air blast, an oxygen-air-steam blast, and an oxygen-steam blast, produced gas with average heating values of 51, 110, and 135 B.t.u. per cubic foot, respectively. These results may not indicate the maximum improvement possible from use of oxygen under stabilized operating conditions. On several occasions short steam runs following periods of air blasting produced gas with an average heating value of approximately 200 B.t.u. per cubic foot.

The air blast and the oxygen-enriched air blasts produced gases useful for generating power. During air blasting approximately 450,000 cubic feet of gas was piped from boreholes and burned under a boiler. The oxygen-steam-air, the oxygen-steam, and the steam blasts produced gases that might be used for synthesis purposes.

During gasification the high temperature had brought about favorable changes in the overlying strata. The roof rock became plastic, expanded, and settled down on the mine floor, directly behind the reacting coke face, which was a thin, cracked, and porous layer. Settlement of the roof forced the air and gas to flow through this coke face or to pass through the narrow (less than 1/2-inch) opening along the coke-rock interface.

However, satisfactory contact between the reactants apparently was not realized over the entire path. Samples along the reaction path showed that gases of high carbon monoxide content were produced; yet the carbon dioxide content of product gases at the outlets was high and the carbon monoxide content low. The low heating value at the outlet was probably due in part to underground combustion of gas in oxygen that had bypassed the coal-combustion region.

Laboratory Experimentation With the "Stream Method"

Following the first field-scale experiment, laboratory tests were made by the Bureau to study the "stream method" more economically than in field-scale operations. A horizontal, rectangular, retort (fig. 21) was constructed of

7/ Throughout this chapter, volumes of gas were calculated, according to a gas industry standard, as dry gas at 60° F. and 30 in. Hg.

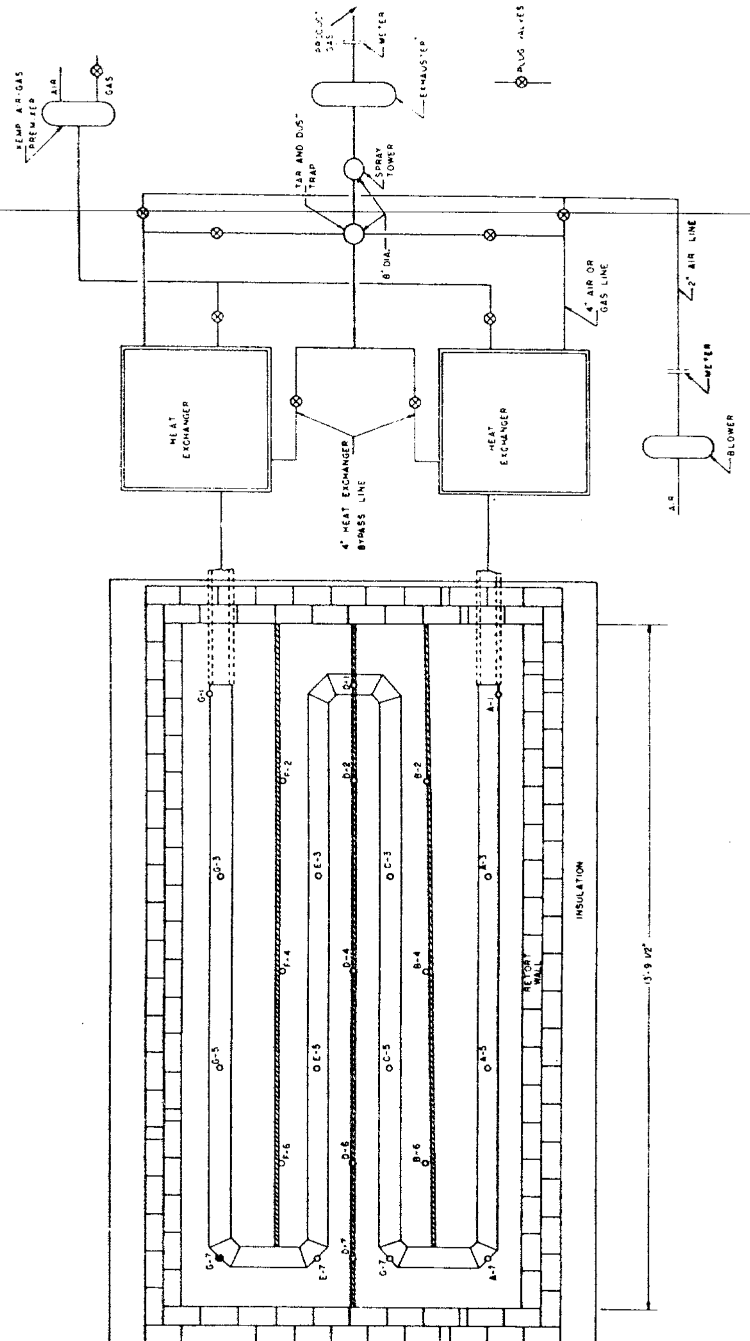


FIGURE 21. - Plan of Laboratory Unit Simulating Underground Gasification.

standard refractory materials, insulated with diatomaceous earth, and contained in a steel jacket open at the top. Inlet and exhaust openings were provided with regenerative heat exchangers. Crushed coal was piled 14 to 24 inches high on the floor of the retort and covered with a roof of firebrick and then a blanket of diatomaceous earth.

A medium-volatile Upper Freeport, W. Va., bituminous coal, containing 28 percent volatile matter, was used in the first experiment. For subsequent