UNDERGROUND GASIFICATION PROJECT, GORGAS, ALA.

Since 1946 the Bureau of Mines and the Alabama Power Co. together have conducted a group of field-scale experiments on the underground gasification of coal. The objective of this work has been to determine the feasibility of procedures whereby either the chemical constituents or the energy of coal may be brought to the surface in a gaseous form usable in the synthesis of liquid fuels, synthesis of organic chemicals, or production of electric power. Another objective has been either to materially reduce or eliminate underground mining operations.

Processes for underground gasification require preparation of an inlet passage from the surface to the coal bed, a passage through the coal bed, and an outlet passage from the coal bed to the surface. The coal is then set afire, air, oxygen, or steam is passed through the bed, and the products of the reaction are obtained above ground at the outlet from the system.

In the first experiment conducted during 1946-47, a U-shaped passage was mined in the coal bed and connected to the surface at the outcrop by means of stoppings at the portals. In the second experiment conducted during 1948-51, an entry and an aircourse were driven to a point 1,600 feet from the outcrop. These underground passages were connected to the surface by large-diameter boreholes drilled on 300-foot centers. A suitable stopping was erected across the passages approximately 140 feet in from the outcrop. The gasification operations during these two experiments showed that it was possible to ignite coal, maintain combustion, and gasify coal in place. The products obtained were often of poor quality but at times indicated that it was possible to produce useful combustible gases by gasification of coal in place. In general the cross-sectional areas of the passages within the coal bed were too large, and poor contact between the gasmaking fluids and the coal faces resulted. All of these experiments were conducted in the Pratt coal bed, which at Gorgas is almost flat. Experiments have been conducted elsewhere, using mined passages in steeply pitching coal beds with more success.

These first two experiments indicated the need for developing other methods for opening up a passage within the coal bed, preferably methods that would eliminate underground mining work. A procedure known as electrolinking-carbonization had been tried by the Sinclair Coal Co. of Kansas City, Mo., working in cooperation with the Missouri School of Mines. In this process, holes were drilled to the coal bed to serve as an inlet or outlet, and metal electrodes were seated in the coal bed and insulated from the walls of these holes. A current then was passed between the electrodes, a good electric circuit was ultimately developed, and enough coal was carbonized along the path so that the permeability increased to a point where gas-making fluids could be forced through the passage. This process was tried at Gorgas, finally using electrode spacings of approximately 150 feet, and 3 systems were operated satisfactorily. The quality of the gasification products was vastly improved as compared to those obtained in using mined passages, for contact between the reactants was maintained much more satisfactorily. The process of electrolinking-carbonization is of great importance in underground-gasification procedures, and it appears probable that it will become practical after further development. The 150-foot electrode spacing used at Gorgas represents, not the maximum obtainable, but rather the practical limit imposed by the capacity of the equipment available. Although electrolinking-carbonization shows promise for use in underground gasification, two limitations are apparent. At 150-foot spacing of electrodes, the tonnage of coal that may be gasified between a pair of electrodes (inlet and outlet) is limited, and the site-development and installation costs are greater than the system operating cost, which tends to indicate a high-cost gaseous product. It appears likely that further development of the process will result in the use of greater electrode spacings, an increase in available coal tonnage, and a decrease in site-development cost, thus eliminating this objection. Further, the use of electrolinking-carbonization to develop a passage in the coal bed often results in a path of limited permeability, which, in turn, causes high compression costs during operation. It is quite possible that this objection, too, can be overcome by further improvements; however, development of additional methods for opening passages within the coal bed is desirable for processes of underground gasification.

Stanolind Oil & Gas Co. has developed a hydraulic process for increasing the productivity of oil wells which is called Hydrafrac. In this process, a viscous liquid, usually containing granular material, such as sand, for a propping agent is injected into an oil-bearing formation at high pressures to fracture or part the formation. The initial fracturing step is customarily followed by introducing a second fluid that will mix with the first and result in a fluid of relatively low viscosity so that the mixture can be displaced from the formation. The formation of these fractures or passages within an oil-bearing horizon generally increases the well productivity. The Hydrafrac treatment was first applied commercially in the oil industry about 1949, and since that time a large number of wells have been treated successfully.

It was believed that it might be possible to apply the Hydrafrac method, or a modification thereof, to a coal bed with the objective of hydraulically fracturing the bed and thus producing a flow path that might be suitable for subsequent gasification. The process was discussed on numerous occasions since 1949. In June 1954 cooperative agreements were drawn up whereby the Bureau of Mines, Alabama Power Co., Stanolind Oil & Gas Co., and Halliburton Oil Well Cementing Co. would cooperate in applying the Hydrafrac treatment to the America coal bed at Gorgas. Work on the project was begun in June 1954 and is being continued at present.

Preparation of Injection Well

A site was chosen at Gorgas some 370 feet west of the last gasification test workings. At this site the America-bed coal lies 155 feet below the surface. A 14-inch-diameter hole was drilled and cased with 12-inch pipe from the surface to a point in solid rock 19 feet below. The hole was continued 10 inches in diameter to a depth of 141 feet. This entire portion of the well was drilled with a churn drill. From a depth of 141 feet to 155.2 feet (the top of the America-bed coal), the hole was drilled 9 inches in diameter, using a rotary bit. The well was extended 18 inches into the America coal bed. A 4-inch steel pipe casing was placed in the well and seated 6 inches above the bottom. At the bottom of the casing, a 4-1/2-inch float shoe was attached, and casing centralizers were placed 21, 63, 107, and 136 feet above the float shoe. The 4-inch casing was swedged to 6 inches in diameter, and the top 23 feet of the casing was made of 6-inch extra-heavy steel pipe. After the casing was placed, a grout of cement and water was pumped through the casing and the float shoe and up the annulus between casing and the walls of the hole to cement and seal the casing firmly to adjacent formations. To insure a good bond at the top of the coal bed (the elevation of the float shoe), only 100 feet of cement was displaced from the casing at the time of cementing. After the cement had set for 5 days, the residual cement in the casing was drilled out with a 3-7/8-inch bit and the hole extended an additional 7-1/8 inches into coal. The portion of the coal bed exposed for Hydrafrac application thus was the perimeter of a cylinder 3-7/8 inches in diameter and 7-1/8 inches high, with the bottom of the cylinder 2 feet below the top of the coal bed. The top bench of the America bed at this location is 37 inches thick.

Hydrafrac Application

After the injection well was completed, the Hydrafrac process was applied by personnel and equipment of the Halliburton Oil Well Cementing Co. The equipment consisted of pumps capable of exerting 12,000 p.s.i., a blender unit for mixing heavy oil and sand, and three transport tank trucks, 1 of which contained 5,000 gallons of kerosine and the other 2 a total of 10,000 gallons of a viscous residual fuel oil. The injection well first was treated with 500 gallons of kerosine containing 5 gallons of an additive used to prevent emulsification of water and oil. During this initial formation breakdown, the kerosine was injected at a rate of 250 gallons per minute, and the pressure at the pumps was 250 p.s.i. Next, viscous residual fuel oil, containing 10 gallons of additive to prevent emulsification, was mixed with Ottowa-flint shot sand, sized through 20- and on 40-mesh screens. Mixing was accomplished in the blender unit as the residual fuel oil was pumped from the tank trucks to the high-pressure pumping equipment. Then 9,550 gallons of residual fuel oil, containing 15,000 pounds of sand (1.6 pounds of sand per gallon), was injected into the formation in 22-1/2 minutes, using a flow rate of 425 gallons per minute. The pressure required during this phase of the treatment ranged from 700 to 900 p.s.i. at the pumps. Following the sand oil, 4,040 gallons of kerosine was injected at a flow rate of 184 g.p.m.

The entire Hydrafrac treatment required 46-1/2 minutes and, during this period, 14,100 gallons of fluid and 15,000 pounds of sand were injected. A short time after the well treatment was completed, the pressure was let down at the casinghead and soon thereafter the casinghead was removed. During the pressure letdown, an estimated 500 gallons of fluid was bled from the well. Approximately one-half hour after the casinghead was removed, the fluid level in the casing had receded about 5 feet and by the next morning had receded 120 feet. At that time fluid remaining in the well bore was removed by an air lift. This was repeated 48 hours later, and a total of approximately 25 gallons was removed in this manner. The rest of the fluid remained underground.

Evaluation of Hydrafrac Treatment

Results of the Hydrafrac treatment have not yet been fully determined or evaluated, but some information is available. After the injection well was completed and before the Hydrafrac treatment was applied, permeability tests were made on America-bed coal in the well with compressed air. Using Darcy's law, as applied to isothermal linear flow of ideal gas through a porous medium in a channel of constant cross section, a function was derived that is a measure of the permeability of the coal bed. This permeability function was evaluated by the air-flow test and had a numerical value of 0.031. A series of arbitrary assumptions can be made and this function roughly expressed as a permeability coefficient. In this case the estimated value of the coefficient was 46 millidarcys. The air-injection test showed that approximately 6 c.f.m. of air, measured at 60° F., 30 inches Hg, and saturated with water can be forced through the coal bed at an applied pressure of 65 p.s.i.g.

After the Hydrafrac test, permeability tests again were applied at the injection well, and it was found that the permeability function had increased to a numerical value of 2.63. This, in turn, can be roughly estimated as a permeability coefficient of 3,900 millidarcys. The air-injection rate at 65 pounds in this case was 520 std. c.f.m. The permeability tests show an 85-fold increase for the coal bed.

Before the Hydrafrac application, it was not known whether a fracture could be kept within the coal bed or whether it would enter adjacent strata either above or below. Another unknown was the area of coal that could be fractured. To determine the horizon followed and extent of the fracture, it was proposed to drill test holes at various distances from the injection well and to apply air pressure at the injection well. Also, the nearest outcrops and old openings to the America-bed coal were to be examined for traces of fracture effects.

The nearest outcrop is 850 feet south, 40° west, of the injection well. When air was injected under pressure at the well, no trace of fracture was found at this outcrop. The old electrolinking workings lie 370 feet east, 20° north, of the injection well. When air was applied at the well, a large percentage of the flow, together with a definite odor of kerosine, was detected at openings from these workings, indicating that the fracture extends to this point. At an old core-drill hole to the America bed, 200 feet north, 14° east, of the injection well, a definite flow of air, oil, and kerosine was evolved. Inby workings of an abandoned mine in the America bed are 670 feet north, 22°-39° west. At the portal of this mine, an odor of kerosine vapor was noted when pressure was maintained at the injection well. The fracture may have intersected these old workings, but more definite evidence is needed.

Test holes were drilled at points 150 feet north, 44° east, and 200 feet south, 44° west, of the injection well. These holes are on the line of the face cleats of the America-bed coal. When the injection well was maintained under air pressure, definite evidence of fracture was indicated at both by the evolution of oil and kerosine and by an air flow. At these two test holes, it was definitely established that the fracture was entirely within the horizon of the America-bed coal.

These tests indicate that a large area of coal bed was affected by the hydraulic fracture process. The shape and extent of the area must be determined by further drilling and permeability studies. Indications are that the fracturing effects were much more extensive than expected.

After the extent and nature of the fracture have been evaluated more completely, it is planned to ignite and gasify at least a section of the coal affected. Probably the injection well or a point beyond it will be used as an inlet to the system, and the existing openings in the old electrolinking project will be manifolded together and used as an outlet.

The hydraulic fracturing of a coal bed may have uses other than for underground gasification. As the area of coal affected apparently is quite large, the process may lend itself to removing gas from coal beds ahead of mining operations. This application could improve safety in coal mining.

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