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Underground Coal Gasification

Technology Status Report

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From 1972 to 1979, Laramie Energy Technology Center of the U.S. Bureau of Mines (subsequently part of the Energy Research and Development Administration and DOE) conducted a series of UCG experiments in a 30-ft thick subbituminous coal seam near Hanna, Wyoming (Schrider and others 1984; Brandenburg and others 1975; Brandenburg and others 1976; Brandenburg and others 1977; Covell and others 1980). The overburden varied from 160 to 400 ft. These experiments pioneered reverse combustion linking in the United States. Gasification was by air injection. The tests consumed substantial amounts of coal and produced gas with good heating value.

Attempts by the Laramie Energy Technology Center to use hydraulic fracturing and forward combustion were unsuccessful during the Hanna I test. Hanna II, Phase II, was one of the most successful air injection tests ever attempted. The Hanna III test suffered from a deficiency of water in the formation (there was no steam injection) and product gas quality was low. Undetected faulting in the Hanna IV series of tests caused problems with linking and gas flow. In retrospect, proper site characterization could have prevented those problems.

From 1976 to 1979, Lawrence Livermore National Laboratory (LLNL) conducted three UCG experiments at a site near Gillette, Wyoming, known as the Hoe Creek site (Thorsness and Creighton 1982). Linking for the first test (I) was by explosive fracturing, for the second test (II) was by reverse combustion linking, and for the third test (III) was by directional drilling. Test I used air injection, and Tests II and III used combinations of air and a steam-oxygen mixture.

Explosive fracturing did not produce sufficient permeability to sustain gasification. The linking techniques used for the other two tests were successful, but combinations of operational problems precluded complete success of the experiments. Loss of a well casing in the reverse combustion link test (II) caused much of the gas flow to override the coal seam and bypass the gasification cavity. In addition, overburden collapsed into the cavity. Similar problems occurred with the test that was linked by directional drilling (III). All of the Hoe Creek experiments had problems with excessive water influx. The most valuable insight gained at the Hoe Creek site was that the best solution to the problems of water influx and weak overburden is to avoid them by proper site selection.

In 1979, DOE/METC conducted a UCG test in a 900-ft deep, 6-ft thick seam of highly swelling bituminous coal near Pricetown, West Virginia (Martin and Liberatore 1980). Air was the injection gas. Reverse combustion linking was used, but 106 days were required to obtain sufficient permeability to attempt gasification. The test was terminated after 12 days of successful gasification because the product-well casing separated. Decreased gas flow and lowered product-gas temperatures caused tar to condense and plug the production well.

From 1979 to 1981, Gulf Research and Development Company conducted two UCG tests for DOE in a steeply dipping coal bed near Rawlins, Wyoming. The seam was 23 ft thick, dipped 63°, and outcropped at the surface. Linking for the tests was essentially by drilling. Figure 4 shows an idealized picture of a UCG cavity in a steeply dipping bed. The first Rawlins test used a combination of air, steam, and oxygen as injection gases (Singleton, Noll, and Allen 1980). The cavity was about 400 ft below ground level. The injection pressure was varied from about 70 to 115 psig, and product-gas heating value varied from about 150 Btu/scf with air only to 250 Btu/scf with steam and oxygen. The second Rawlins test was conducted at about 600-ft depth, and peak injection pressures were nearly 160 psig (Ahner, Bencini, and Bloomstran 1982). Steam and oxygen were the only injection gases used. During one 19-day period of operation, product-gas heating values averaged 356 Btu/scf, making this the highest-quality product gas from any UCG test conducted in the United States. The reasons given for the success of this test are that the higher cavity pressure increased methane production (to concentrations as high as 24 percent), and that a UCG cavity formed in a steeply dipping bed uses coal more efficiently.

In 1983, LLNL conducted a UCG test for DOE in a 35-ft thick, high-ash, subbituminous coal seam near Centralia, Washington (Hill and others 1984). The top 20-ft section of the seam was used to test a new concept in UCG technology called the controlled retracting injection point (CRIP). The CRIP technique replaces an exhausted UCG cavity with a new cavity by moving to a new injection

4.1 SITE SUITABILITY

One of the primary problems confronting a contemplated commercial UCG venture is whether the target resource is suitable for recovery by UCG. The site and its surroundings must be thoroughly characterized to detect any potential problems that may impact on the UCG process, the site, or its surroundings. Factors such as site geology and hydrology, coal and overburden properties, surface topology and future use must be addressed. At the current level of development, criteria for site suitability are very restrictive and the technology for properly characterizing a site is limited and costly.

The complete relationship between site characteristics and the UCG process is not defined. For instance, when coal is removed in situ by UCG, the void weakens the structural integrity of the overlying strata (overburden), and, thus, overburden collapses into the cavity. This inert material significantly reduces product gas quality because of increased heat losses. If the collapse extends to the surface, the surface subsidence (sinking) occurs. If this condition is severe, it may be environmentally unacceptable as well as operationally unsafe.

4.2 PROCESS WELL LINKAGE

An essential ingredient to a commercial UCG endeavor is the ability to reliably provide process well linkage of the correct size and location, to assure predictable cavity development. A coal bed is not a uniform, homogeneous mineral deposit. There are fractures, cleats, and faults that commonly create anisotropy and random channels. This causes problems when one is trying to create a high-permeability link between an injection well and a production well. At the present level of technology, there is no guarantee that a link will be obtained. If the link is too high in the coal seam, the coal will not be fully utilized. UCG cavities tend to develop above a link path, while the coal below the link is relatively unaffected. Because the UCG cavity development will more or less follow a link, it is essential that the link be located correctly, laterally as well as vertically.

Reverse combustion processes have been used successfully at times in subbituminous coals, in coal beds that were reasonably free of fractures and faults. There has been limited success with reverse combustion in bituminous coals. A more complete understanding of the physical and chemical phenomena involved in reverse combustion could lead to more reliable applications.

Directional drilling, although used successfully at Hoe Creek and Centralia, suffers from the inherent inaccuracies of the instruments used to guide the drill bit. The state of the art is such that the surveying tools used by drillers have errors larger than the targets at which they are aiming.

More exotic linking techniques, such as explosives and hydraulic fracturing, have been attempted but have met with no success. The lack of mechanical strength and severe anisotropy of coal simply preclude the use of explosives and hydraulic fracturing.

Electrolinking, in which an electric current passes through and heats the coal seam, much as a coil is heated in an electric toaster, offers promise in seams of highly volatile bituminous coal. This technique overcomes the problem of coal swelling. It also heats the link, inhibiting tar condensation and link plugging.

4.3 PROCESS CONTROL

After the target coal resource has been found suitable for recovery by UCG and the required process wells have been successfully linked, the gasification process must be started and controlled to optimize product quality and resource recovery. Burning coal in the ground to produce combustible gas is relatively simple. However, the physical and chemical processes that occur are quite complex and in-results of the two projects are significant, but well bore damage could account for the discrepancies.

5.4.4 Groundwater Monitoring Problems, Hoe Creek and Hanna, Wyoming, Sites

DOE is currently responsible for compliance with the appropriate environmental legislation at both the Hoe Creek and Hanna, Wyoming, UCG sites. Wyoming Department of Environmental Quality (WDEQ) regulations require that groundwater must be returned to its original use (pre-UCG test) quality before the site can be closed. A specific DOE objective is to satisfy the WDEQ regulations. Unfortunately, sufficient pre-UCG test baseline groundwater quality data is unavailable for either the Hoe Creek or Hanna site. Satisfactory scientific methods had to be employed to try to establish the pre-UCG test conditions after the tests had already been conducted, and this was not a trivial effort.

Techniques used to monitor groundwater at all UCG sites are similar. Several wells are drilled around the UCG cavities, and periodically they are pumped and the water is analyzed for suspected contaminants. The procedure appears straightforward, but in reality the results of the effort are often uncertain. The levels of the suspected contaminants are usually in the parts per million (ppm) range and frequently are in the part per billion (ppb) range. Concentrations at these low levels are difficult to measure accurately. Indeed, considerable differences in results are common depending on which analytical procedures are used. In addition, different times of pumping of the sample wells can cause a dilution effect, and care must be taken that drilling and completing the wells does not introduce contamination.

One of the most serious problems involved with an accurate assessment of groundwater contamination is related to the flow of the groundwater through the coal seams and surrounding strata. On a microscopic scale coal is relatively impermeable. Small pieces of coal can have permeabilities as low as 1 millidarcy. However, coal has cleats, fractures, and faults. Flow through a fracture can be several orders of magnitude greater than flow through the coal itself. Therefore, flow of groundwater through a coal seam is controlled by the presence and types of cleats, fractures, and faults rather than by the permeability of the coal itself. This condition is what gives coal seams directional flow properties (anisotropy).

The following example will illustrate some of the problems in determining contaminant flow behavior in coal seams affected by a UCG reactor:

Imagine a monitoring well that is drilled so that it intersects or is near a fracture that intersects or is near a UCG reactor. If the natural flow of groundwater is from the reactor to the well, contaminants can reach the well from the reactor in a matter of days. It will appear that serious groundwater contamination has occurred. If by chance there is a fracture perpendicular to the monitoring well-UCG reactor axis, contamination from the UCG reactor may never reach the monitoring well. This fingering of flow from the reactor makes evaluation of groundwater contamination difficult.

Additional problems can arise if there is overburden collapse into the UCG cavity. It is not uncommon to have several strata above and below the UCG cavity that are aquifers but are normally hydraulically isolated vertically. A significant overburden collapse into the cavity can cause vertical communication between the aquifers. In other words, uncontaminated water from above the reactor can flow into the coal seam or contaminated reactor water can get into the otherwise uncontaminated aquifer above the cavity. Similar problems can arise if great care is not taken when drilling and completing the monitoring wells. It is essential that each hydraulically isolated aquifer is also hydraulically isolated in the well.

5.4.5 Monitoring of Groundwater Contaminant Migration, Western Research Institute

As a first step in evaluating groundwater conditions at the Hoe Creek site in October 1983, WRI drilled 29 wells to locate the contaminant plume around the UCG sites and installed samplers in 20 of the wells in both the Felix 1 and Felix 2 coal seams (McTernan and Davidson 1984). Figure 10 shows