Dry Geothermal Wells: Promising Experimental Results

Assessments of the prospects for geothermal energy have tended to put the highest emphasis on hot water deposits such as those now being used to produce electricity at Cerro Prieto, Mexico. Estimates of the amount of electric power that could be generated in the United States with heat from geothermal wells—132,000 megawatts by 1985 and 395,000 megawatts by the year 2000, according to one widely accepted study (*1*)—are based primarily on the postulated exploitation of such resources. But the development of known hot brine fields in California's Imperial Valley and elsewhere has been delayed pending granting of leases for drilling on federal lands and the establishment of procedures for environmental review of proposed wells. In the meantime, results from a successful hydrofracturing experiment in crystalline rock and new ideas about how to extract energy from hydrofractured geothermal wells appear to have improved the prospects for tapping deposits of dry, hot rock. Since these dry geothermal deposits are believed to constitute a resource at least ten times as large as deposits permeated by groundwater, the potential for geothermal power may be even greater than the estimates above suggest.

The experiment in question was conducted in a test well drilled 780 m into the rock at one edge of a huge volcanic caldera in the Jemez Mountains of northern New Mexico by researchers from the nearby Los Alamos Scientific Laboratory (LASL), an Atomic Energy Commission facility.

Water was pumped under pressure into a section of the well to open cracks in the rock surrounding the borehole. This hydrofracturing technique is widely used in the petroleum industry to increase the permeability of oil-bearing sedimentary rocks and improve oil recovery, but the technique had not been demonstrated in granite and other crystalline rock formations.

According to M. Smith and D. Brown of LASL, the experiment showed not only that crystalline rocks can be hydraulically fractured, but that modest pressures are required. Water in the test well began penetrating the rock when pressures at the wellhead reached 8 to 12 million newtons per square meter, depending on the character of the rock being fractured. Study of the cores obtained from the well showed that, although the rock ranged in composition from granite to more basic materials such as amphibolite, the pressure at which fracturing began depended primarily on the presence or absence of preexisting cracks in the rock. These cracks were found to be cemented closed with minerals—calcite and silica in the granite, chlorite in the amphibolite—deposited over a long period of time, the researchers believe, by circulating groundwater. Hence rock with an abundance of preexisting cracks was only slightly easier to fracture than intact rock.

Perhaps more important for potential geothermal applications, the cracks leaked very little water. As long as the pressure in the well was maintained within a suitable range, the cracks were held open by fluid pressure alone and did not grow with time, nor did measurable amounts of water escape. This result contrasts with predictions by many geologists that subsurface rock would be highly fractured and hence very permeable, making it impossible to circulate water through the cracks to collect heat and transport it to the surface without continually adding water. The results of the LASL experiment thus suggest that crystalline rock geologic formations, at least in this one area, are readily hydrofractured, yet tight enough to make extraction of geothermal energy feasible.

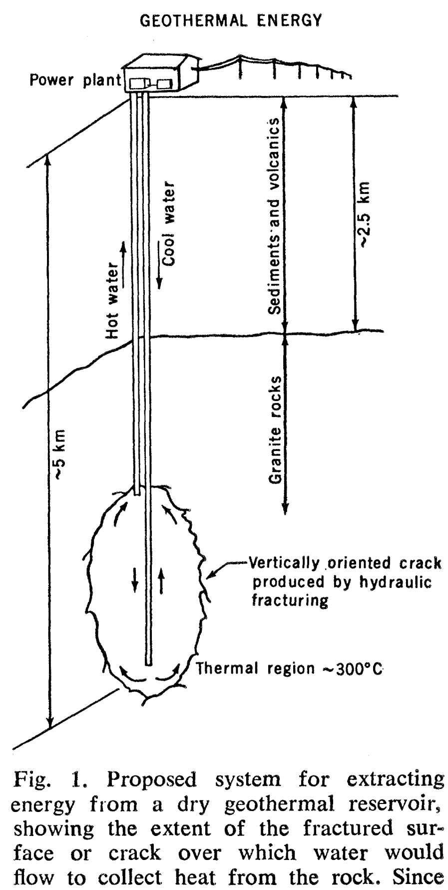

Fig. 1. Proposed system for extracting energy from a dry geothermal reservoir, showing the extent of the fractured surface or crack over which water would flow to collect heat from the rock. Since the crack is not a three-dimensional cavity but lies within a vertical plane, a view at right angles to the view portrayed would show the fractured surface as a vertical line. [Source: Morton C. Smith, Los Alamos Scientific Laboratory]

The LASL team had calculated that cracks should form preferentially in the vertical direction, and they found this to be true when pressures were increased gradually during the hydrofracturing process. They were also able to detect seismic signals from the fracturing process at the surface, a result that the experimenters believe will allow the orientation and extent of the crack away from the well bore to be determined in future experiments. Other facets of the experiment were directed toward measuring the minimum principal stress (that which must be overcome to hold the cracks open) and related mechanical parameters of the rock adjacent to the well.

Planning is now under way for a second experimental well 1.5 to 1.8 km in depth. Cores from this well are to be recovered over its entire depth to provide a continuous section of continental rock for geological and petrographic studies, and measurements of temperature, conductivity, and gases given off by pore fluids are to be made every 9 m. If hydrofracturing experiments also prove successful in this well, the LASL experimenters hope to drill a pair of still deeper wells, the second of which would be directed so as to intersect a large crack hydrofractured in the first, and set up a prototype geothermal power system (Fig. 1). Water circulating down one well, through the crack in the hot rock, and up the other well would carry off heat that could be used to run a power turbine at the surface. Unless the rock fractures further as it cools, making additional hot rock available to the system—a phenomenon that has not been demonstrated—the initial crack must be large enough to supply heat for ten or more years in a practical power system. The LASL team believes that such a crack, extending 1.25 km from the borehole (compared with an estimated 40-m crack in their first experiment), is well within the realm of the hydrofracturing technique, although whether problems will be encountered in scaling up to this size remains to be seen.

The LASL experiment appears to have removed two of the principal concerns over the feasibility of tapping dry geothermal deposits in igneous rocks—it has shown that granite can be hydrofractured and that it is, at least in one region, impermeable enough to hold water tightly. (Even drilling in the granite, the most expensive operation in establishing such a geothermal well, turned out to be not as difficult as had been expected.)

Thinking about the optimum method of recovering heat from the earth is only beginning, however. One concept that could greatly increase the economic life of hot rock geothermal systems (and decrease their cost) is that proposed by B. Rayleigh of the Menlo Park, California, research center of the U.S. Geological Survey. Observing that in many regions the stresses in subsurface rock are reasonably constant over large areas, Rayleigh suggests that geothermal wells be drilled at an angle, in a direction perpendicular to the expected orientation of fractures. Then a series of parallel, vertical cracks could be fractured from a single well, possibly spaced as close as every 30 m. Slant drilling techniques are common in the oil industry, although not yet developed for crystalline rock, and Rayleigh's preliminary cost estimates indicate that such a system could be competitive with existing sources of electricity, even with cracks of relatively modest size. Still other ideas may emerge as more hydrofracturing experiments are performed and the design of geothermal systems moves from the feasibility stage to engineering design.

Assessing the extent of dry geothermal resources and drilling to prove out suspected deposits has also barely begun. Preparations for such assessments are going forward at a site in the vicinity of Marysville, Montana, however, at what may turn out to be the "mother lode" of geothermal deposits, at least in this country. The deposit is an apparent remnant of a geologically recent magma intrusion that very nearly became a volcano and that left what is believed to be billions of dollars worth of heat within 1 or 2 km of the surface. The project, directed by D. Stewart of the Battelle Memorial Institute laboratory in Richland, Washington, and funded by the National Science Foundation, will determine, among other things, whether groundwater is present or whether the deposit is dry.—ALLEN L. HAMMOND

References

1. Panel on Geothermal Energy Resources, *Assessment of Geothermal Energy Resources* (Department of the Interior, Washington, D.C., 1972).

Singlet Oxygen: A Unique Microbicidal Agent in Cells

When the electrons of molecules in living cells are excited to higher energy levels, the process is invariably associated with light. Molecules that can be electronically excited by light serve as light receptors in two fundamental life processes, photosynthesis in plants and vision in animals. Electronically excited molecules generated by chemical reactions serve as light sources in the bioluminescence of certain insects and fish. Until last year, no one ever claimed to have demonstrated the existence in animals of functional excited molecules unrelated to light.

Then, in the spring of 1972, Robert C. Allen, Rune L. Stjernholm, and Richard H. Steele of Tulane University, New Orleans, Louisiana, presented evidence that electronically excited singlet oxygen acts as a microbicidal agent in phagocytosis. Their experimental approach and the evidence for their hypothesis were summarized by Allen at the recent American Chemical Society meeting in Chicago. If that hypothesis is substantiated, the system they have described represents the first demonstration of the capability of mammalian cells to use stored chemical energy for the generation of electronically excited molecules with a role in cellular function.

Phagocytosis is the process in which some types of white blood cells such as polymorphonuclear leukocytes engulf and destroy microorganisms. The mechanism of microbial digestion by these cells has been the subject of intermittent speculation for nearly a century. Intense interest in the system was revived in 1967, however, when Seymour J. Klebanoff of the University of Washington in Seattle showed that the digestion is mediated by a tripartite system consisting of an oxidizing enzyme called myeloperoxidase, hydrogen peroxide, and halide ions. Similar systems have subsequently been found in rat liver microsomes, cellular structures that, among other roles, participate in the detoxification of drugs and other foreign chemicals; in mouse spleen cells; in guinea pig polymorphonuclear leukocytes and bone marrow cells; and in rat alveolar macrophages, phagocytic cells from the lung.

Neither myeloperoxidase nor halide ions exhibit any intrinsic microbicidal activity, and the activity of hydrogen peroxide is much less than that of the complete system. Various mechanisms have thus been proposed to account for the observed microbicidal activity, including halogenation of the microorganism, production of reactive intermediates such as hypohalite anions (OI^-, OCl^-, and OBr^-) and chloramines, and formation of toxic aldehydes. Iodinated microbial substrates have, in fact, been isolated among the products of phagocytosis, but no one has been able to isolate comparable chlorinated or brominated products. Similarly, no one has been able to demonstrate the existence of hypohalites, chloramines, or any other reactive intermediates during the digestion. It is now considered likely that the system operates through more than one mechanism; one of these mechanisms, Allen argues, is the formation of singlet oxygen.

A singlet molecule is one in which the absorption of energy has shifted a valence electron from its normal bonding orbital to an antibonding orbital of higher energy, and in which the electron spins are paired. (Oxygen is an unusual diatomic molecule in that the spins of the two valence electrons of lowest energy are not paired in the most stable or ground state.) The resultant excited molecule is highly un-