Geothermal technologies

U.S. Department of Energy

Vol.5 Issue 1
February 2000

IN THIS ISSUE:

GeoPowering the West—DOE's New Initiative for the 21st Century

In an effort to tap the vast geothermal resources of the western United States, Secretary of Energy Bill Richardson and U.S. Senator Harry Reid of Nevada recently announced a DOE initiative to expand the production and use of energy generated from heat within the earth. The new initiative is known as *GeoPowering the West*.

During a news conference on Capitol Hill, Secretary Richardson also announced that DOE will award nearly $5 million in grants to support the development of geothermal energy projects throughout the western United States. Over $4.8 million will be awarded for geothermal activities in six western states, including Nevada, California, Texas, Utah, Idaho, and North Dakota. The funding will be used to provide technical assistance to support the design and testing of new geothermal technology.

"Geothermal power is a clean, reliable, and renewable energy source available in all western states; in fact, it is already a significant supplier of electricity in California, with additional resources in Nevada, Utah, and Hawaii," Richardson said. "We are confident that this initiative will help to increase the power produced by this existing resource and make it a major contributor to our clean energy mix."

By expanding the production and use of energy generated from heat within the earth, the goal of *GeoPowering the West* is to provide 10% of the electricity needs in the western states by 2020.

GeoPowering the West will focus on three major goals:

- Supplying at least 10% of the electricity needs of the West by 2020 with 20,000 megawatts of geothermal energy installed
- Supplying the electric power or heating needs of at least 7 million U. S. homes through geopower by 2010
- Doubling the number of states with geothermal electric power facilities to eight by 2006.

GeoPowering the West will be a partnership of organizations from both the private and public sectors, representing suppliers, users, and the environmental community. The initiative will provide Native Americans, the agricultural community, rural America, and federal facilities an opportunity to participate.

For more information about the *GeoPowering the West* initiative, please visit the Web site at: ***http://www.eren.doe.gov/geopoweringthewest/***

A History of DOE-Funded Research: Developing the Salton Sea Geothermal Resource

In the 1970s, the Lawrence Livermore National Laboratory (LLNL) carried out extensive studies at the Salton Sea Geothermal Field, leading to several developments that industry has adopted in the production of power from this resource. These include adding acid to brine to retard the precipitation of silica—a technique that was not regarded as very practical when first proposed by LLNL. But the concomitant developments in corrosion-resistant materials and brine processing techniques have shown that acidification can solve the problems of scaling and reinjection from silica precipitation. As a result, the CalEnergy Operating Company (now part of MidAmerican Energy Holdings Company) is successfully using brine acidification in the operation of several of its geothermal power plants near Niland in Imperial Valley, California.

The Leathers geothermal power plant, located in the Salton Sea geothermal resource area. Photo by Warren Gretz, NREL.

The history of the brine acidification process began in 1971 when the San Diego Gas & Electric Company (SDG&E) through its subsidiary, the New Albion Resources Co., joined with Magma Power Company to begin exploration and development of the Salton Sea geothermal resource. This led to a cooperative project between SDG&E and DOE (then known as the Energy Research and Development Administration) to construct a Geothermal Loop Experimental Facility (GLEF) at the Salton Sea. In 1974, DOE began funding the LLNL Geothermal Program, and in 1975, LLNL began its studies of brine chemistry and materials at the GLEF.

Before power generation could be commercialized, two problems had to be solved: the rapid corrosion of common metal alloys and the high rates of silica scaling (up to 1 mm/day). Silica scaling from geothermal fluids occurs as the brine is flashed and its temperature is lowered. The fluid becomes supersaturated in silica, and solid silica then tends to rapidly precipitate on surfaces and in the bulk fluid. The brine's high salinity (up to 32 % total dissolved solids) and its natural pH of about 5.5 exacerbate the process. Other compounds such as metal sulfides and hydroxides, and iron silicate, also are deposited along with the silica. Amorphous silica is the major component at lower temperatures. The formation of suspended particles of silica in the brine is also detrimental because this interferes with brine reinjection after energy extraction.

Led by Roy Austin and George Tardiff, the LLNL Geothermal Program was a multifaceted effort that also included the design of a “total-flow” impulse turbine, investigations of spent fluid disposal, and studies of the geology and geochemistry of the resource. LLNL earth scientist Larry Owen carefully examined the literature on the complex chemistry of silica, concluding that lowering the pH of the brine by the addition of an acid, such as hydrochloric acid, could decrease the silica’s rate of precipitation from solution. Silica precipitates from solution via the formation of polymeric chains of molecules of SiO_2, and the rate of polymerization slows down as the pH is lowered. From a brief report by Marshall Reed (now with DOE), Owen also noted that extreme acidification (to a pH of 0 - 1) of the geothermal brine at Cerro Prieto before chemical analysis was effective in preventing silica precipitation.

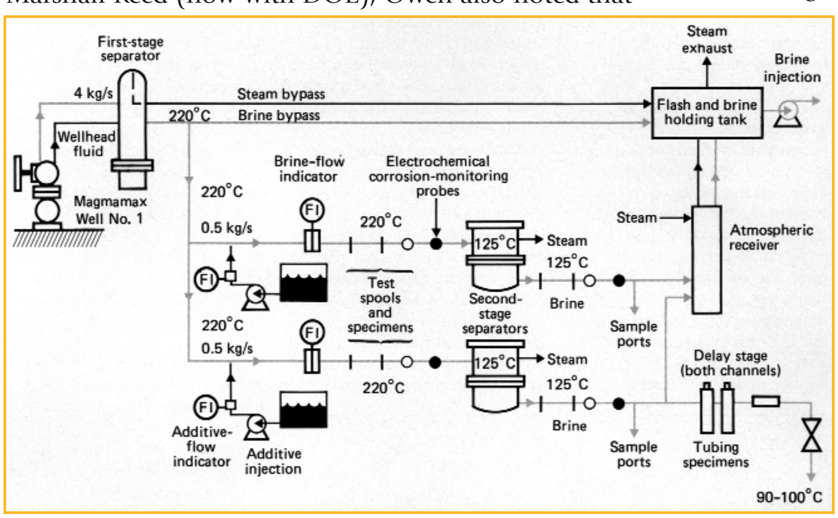


Figure 1. A simplified schematic drawing of the dual-channel, brine-treatment system LLNL operated at Magmamax Well No. 1 in the Salton Sea geothermal field.

LLNL, during the geothermal program, performed almost all of the brine chemistry and corrosion tests on-line or in the field, rather than at LLNL’s laboratory because of the fluids’ instability, as well as the great difficulty of simulating their chemical and physical characteristics. However, corrosion and scaling, the very problems the tests were trying solve, also made experimentation in the field quite difficult. Nevertheless, Owen and John Grens performed a series of short-duration tests at the GLEF using expansion nozzles and wear blades, which clearly demonstrated that the addition of hydrochloric acid to the brine did indeed lower the rates of scaling and the formation of suspended solids in the brine.[1] As expected, the acidification’s effectiveness was in direct proportion to the amount of acid added and, hence, the lower the brine pH. A significant retardation was found with only a slight reduction in brine pH to 5.0, and virtually complete inhibition in the flow system could be achieved at a pH of about 3.

From 1977 to 1979, under the direction of Jack Harrar, LLNL performed further tests of brine acidification, as well as the use of organic compounds alone and in combination with acid, using a new flash test system located at the Magmamax No. 1 well. Pipe sections and test coupons yielded additional quantitative data on the rates of silica scaling and corrosion, and the effects of potential organic chemical inhibitors.[2] The LLNL group also measured the rates of precipitation of silica in the brine as a function of pH, using brine at atmospheric pressure and a reinjection temperature of about 90°C (194°F). These studies confirmed that brine acidification was by far the most effective chemical method of brine stabilization and scale control.[3] Acidification of the brine naturally meant increased metallic corrosion rates, but this was expected to be ameliorated eventually by subsequent advances in materials selection.

Beginning in 1979, John Featherstone, formerly with the DOE Geothermal Energy Program, directed pilot studies at the GLEF for Magma Power. He discovered an alternative method of silica control using a flash crystallizer system and deliberate precipitation of the silica by seeding. The technique, which was very promising as a basis for power plant design, became known as the Crystallizer- Reactor-Clarifier (CRC) Process.[4]

In the 1980s, both Magma Power and Unocal continued to develop the Salton Sea and North Brawley hypersaline resources in the Imperial Valley. At Unocal, John Jost and Darrell Gallup demonstrated a successful power plant design based on brine acidification, which utilized cement-lined steel and high-nickel alloys for the acidic brine handling components.[5] CalEnergy now operates power plants that use both the CRC design and the pH modification design for silica control. Through additional experience and refinement of the acidification process, Featherstone and coworkers at CalEnergy have shown that brine acidification has a number of economic advantages compared to the CRC process.[4]

Geothermal power generation from the hypersaline brines evolved into a successful industry during the 1990s. The Salton Sea resource now generates 280 MW: about 40% through the brine acidification process and 60% through the CRC process. However, research is still underway to improve the economic viability of this resource. Techniques are being studied for the precipitation and purification of silica from the power plants using both the brine acidification and CRC processes. A pilot-scale process involving ion-exchange separation and electrodeposition has been proven for the production of high-purity zinc, and a full-scale production plant is under construction. Integrating mineral recovery with energy extraction promises to greatly improve the economics of these geothermal operations.

The success of brine acidification for silica control illustrates that DOE's early support of the geothermal industry and LLNL's pioneering investigations greatly benefited the development of the Salton Sea geothermal resources.

Today, DOE is still significantly involved with other Salton Sea projects. It is cost-sharing the development of the Salton Sea Unit #5 power plant; the National Renewable Energy Laboratory and Brookhaven National Laboratory are working with CalEnergy on heat exchanger linings; and LLNL and CalEnergy are working together to better understand silica chemistry at the site.

REFERENCES

1. Grens, J. Z.; Owen, L. B. *Transactions of the Geothermal Resources Council Meeting, San Diego.* Vol. 1, May 1977; p. 119.

2. Harrar, J. E.; Locke, F. E.; Otto, Jr., C. H.; Lorensen, L. E.; Monaco, S. B.; Frey, W. P. *Soc. Pet. Eng. J.* 22(1), 17, 1982.

3. Harrar, J. E.; Otto, Jr., C. H.; Hill, J. H.; Morris, C. J.; Lim, R.; Deutscher, S. B. *Lawrence Livermore National Laboratory Report UCID-17596*. September 1977.

4. Featherstone, J.; Butler, S.; Bonham, E. *Proceedings of the World Geothermal Congress, 1995, Florence, Italy.* Vol. 4, p. 2391.

5. Jost, J. W.; Gallup, D. L. U. S. Patent No. 4,500,434 (1985).

For more information, contact Jack Harrar, consultant, at 510-538-4559 or jharrar@mindspring; or John Featherstone with CalEnergy Operating Company at 760-348-4032 or john.featherstone@calenergy.com.

The use of 2-D seismic reflection for geothermal reservoir definition has proven marginally successful in some cases, but because of the extreme heterogeneity in many geothermal areas, it has not been cost-effective. Under DOE's Geothermal Energy Program, Lawrence Berkeley National Laboratory (LBNL)—in cooperation with The Industrial Corporation and Transpacific Geothermal, Inc. (TGI)—has been evaluating and applying modern, commercially available 3-D seismic imaging methods to determine if they might be successfully applied, and if not, if they could be modified to derive useful information on reservoir structure.

In 1997, TGI proposed a 3-D seismic survey to determine the geologic structure on the (hypothesized) fault-controlled, geothermal reservoir in Rye Patch, Nevada. Initial exploration efforts during the late 1980s and early 1990s at the reservoir resulted in only one successful well; the other wells were either too cold or had insufficient fluid flow. Even though the 3-D seismic method has become an integral part of modern oil and gas exploration, the heterogeneous and hydrothermally altered nature of geothermal reservoirs makes all seismic imaging more difficult.

LBNL's previous work has shown that Vertical Seismic Profiling (VSP) surveys can be very useful in geothermal fields.[1,3] However, VSP studies cover a relatively small volume of the reservoir in which the seismic response can be consistent despite larger-scale heterogeneity in the reservoir.

A 3-D surface seismic survey was conducted in 1998 to explore the structure of the Rye Patch reservoir. It included the mapping of structural features, which may control geothermal production in the reservoir. The survey covered an area of 3.03 square miles with 12 north-south receiver lines and 25 east-west source lines. Both the receiver group interval and source interval were each 100 feet. The receiver lines were spaced 800 feet apart, while the source line spacing was 400 feet. The sources comprised 4 vibrator trucks arranged in a box array.

Seismic processing involved, among other steps, selecting more than 700,000 of the possible 1 million traces to determine first arrival travel times, normal move-out correction, 3-D stack, deconvolution, time migration, and depth conversion. The final data set represented a 3-D cube of the reservoir's subsurface structure. To support the findings of the surface seismic imaging, travel times were used to perform tomographic inversions for velocity estimates.

The results suggest the presence of at least one dominant fault responsible for the migration of fluids in the reservoir (Figure 1). Furthermore, it is suggested that this feature might

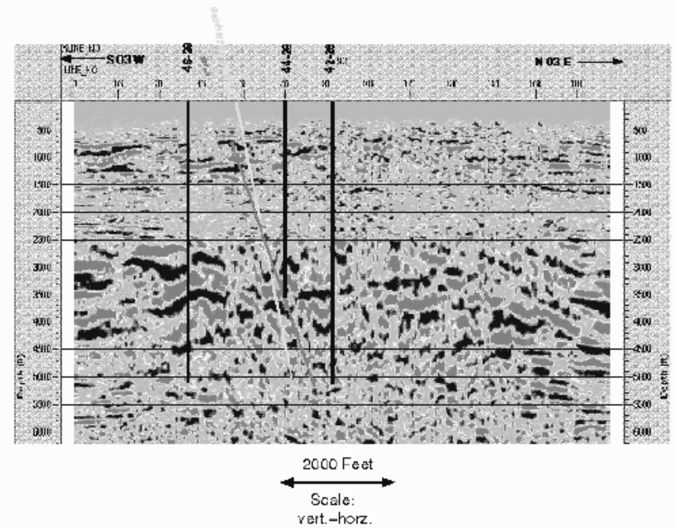


Figure 1. A north-south cross section through the Rye Patch 3-D seismic results with fault interpretations.

be part of a fault system that includes a graben structure. The 3-D seismic reflection data provided interpretable results for a depth range below 500 feet, whereas the tomographic travel-time inversion produced reliable results only down to 500 feet.

Another notable result of the 3-D seismic processing: conventional processing, such as refraction and reflection static corrections, did not help to increase the data quality. This was due to weak arrivals and incoherent reflections from the heterogeneous structure. The more unconventional, tomographic approach was of limited use, even with the far offset data designed to capture deeper structure.

LBNL has issued a detailed report on this work.[2] Overall, 3-D imaging shows promise for geothermal applications. Clearly, processing used for petroleum exploration cannot be directly transferred to the geothermal case. However, much of the technology can be modified and adapted for geothermal applications.

REFERENCES

1. Daley, T.M.; McEvilly, T.V.; Majer, E.L. "Analysis of P- and S-Wave Vertical Seismic Profile Data from the Salton Sea Scientific Drilling Project." *J. Geophys. Res.* 93, B11,1988; pp.13025-13036.

2. Feighner, M. A.; Gritto, R.; Daley, T. M.; Keers, H.; Majer, E.L. "3-Dimensional Seismic Imaging of the Rye Patch Geothermal Reservoir." *LBNL - 44119.* 1999.

3. Majer, E. L.; McEvilly T. V.; Eastwood, F.; Myer L. "Fracture Detection Using P-Wave and S-Wave Vertical Seismic." 1988.

For more information, contact Ernie Majer, LBNL, at 510-486-6709.

ransfer Enhancement

Two DOE-funded research projects are underway to evaluate heat transfer enhancement strategies for air-cooled condensers. Both the Idaho National Engineering and Environmental Laboratory (INEEL) and the National Renewable Energy Laboratory (NREL) are performing key research on air-cooled condensers that are used for heat rejection in binary cycle geothermal power plants when there is no available supply of make-up water for evaporative cooling systems. These two national laboratories will be holding a joint stakeholders meeting with industry during this fiscal year to share their findings.

INEEL R&D

Air cooling poses challenges different from evaporative cooling. Air cooling involves lower heat transfer coefficients and rejection of heat to the dry-bulb temperature, which is often significantly higher than the wet-bulb temperature. In both heat rejection schemes, the working fluid (typically a hydrocarbon such as isobutane) is condensed in a heat exchanger having numerous tubes. In a water-cooled condenser, this condensation typically occurs on the outside of the tube, with the heat of condensation rejected to water flowing through the inside of the tube. In the air-cooled condenser, condensation occurs on the inside of the tube, with the heat of condensation transferred across the tube to the environment (airflow past the outside of the tube).

Because of the low heat transfer properties, air-cooled condensers require very large surfaces to reject all of the heat of condensation. To offset this requirement, the air-cooled condensers have fins and fans on the outside of the tubes to increase the effective heat transfer area. Despite the use of the fins, air-cooled condensers are much larger and more costly than water-cooled units; the capital cost of the air-cooled condensers can be 25% or more of the total project cost. Furthermore, the power that drives the fans to induce airflow through these condensers represents a significant parasitic load, reducing net power production and increasing costs.

INEEL researchers are investigating an improvement in condenser performance that can be achieved by using tubes with an oval rather than circular cross section and by placing small raised "winglets" on the fin surfaces. The oval tubes are streamlined to reduce the pressure drop through the tube bundle for a specified airflow, while the winglets are designed to improve fin-surface heat transfer coefficients by generating vortices of turbulent air to minimize the stagnant regions in the airflow past a tube. The improved heat transfer coefficients are expected to reduce plant capital costs by decreasing the required size of the condenser units by about 15% and may also lead to reduced operating costs.

INEEL researchers have divided the combined experimental and numerical research effort into four phases. The initial phase has been completed. It focused on the measurement and prediction of local heat transfer coefficients in two baseline configurations: single circular tube and single oval tube. The researchers developed a novel heat transfer visualization and measurement technique for experimental assessment of various tube and winglet geometries, and for code validation. Heat transfer measurements were obtained using a transient technique in which a heated airflow is suddenly introduced to the test section. High-resolution local fin-surface temperature distributions are obtained several times using an imaging, infrared camera. Corresponding local fin-surface heat transfer coefficient distributions are then calculated. A sample experimental result is presented in Figure 1.

In phase 2, local fin-surface heat transfer will be measured with winglet vortex generators in various configurations added to the single-tube geometries. Phase 3 will involve measurement of local heat transfer and pressure drop in single-channel, multiple-tube geometries with winglets. Overall heat transfer and pressure drop performance will be measured for a multiple-channel, multiple tube-row, prototype heat exchanger during phase 4.

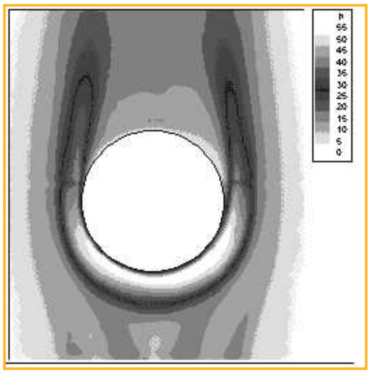


Figure 1. The contours represent measured values of local fin-surface heat transfer coefficient in W/m² K for flow around a circular tube in a simulated fin/tube flow passage. Flow is from bottom to top in the figure with a mean velocity of 2.8 m/s.

INEEL researchers will work closely with industry partners during the final phases to develop a high-performance, cost-effective prototype design.

NREL R&D

NREL research currently focuses on innovative fin geometries that increase the ratio of heat transfer to fan power. To accomplish this, NREL researchers have increased the overall heat transfer coefficient by reducing the average boundary layer thickness, and also increased the effective heat transfer area. Computer models have been developed, and one prototype was built and tested. A patent application has been filed.

In conventional finned-tube condensers, as the air passes between the fins and flows parallel to them, the thermal boundary layer thickens along the fins, resulting in increasing heat transfer resistance. Also, the tube itself tends to block flow over the portions of the fins downstream of the tube, reducing heat transfer in the wake region. NREL designs currently under development use perforated fins in which the airflow is forced *through* the fins, instead of along the fins. NREL refers to these as *transpired* designs. Although perforated fin designs have been used before, virtually all of these have used the holes simply to disrupt the parallel flow and have not taken advantage of transpired flow.

Using the most applicable heat transfer and pressure drop correlations available, NREL developed a spreadsheet model to optimize performance. Small-scale samples were built and tested to provide refinements. Based on these results, a 1-ft x 2-ft prototype was built. To allow a direct comparison with conventional technology, a reference test unit was also constructed using conventional finned tubes with fins spaced at 10 fins per inch (typical in industry). For both the conventional and the prototype units, NREL researchers measured heat input and air temperature rise over a range of air velocities. When the face velocity was adjusted on the prototype unit until the fan power was the same as for the conventional unit, *the prototype delivered 30% more heat transfer than the conventional unit.* Recent analysis indicates that considerably greater improvement can be obtained by going to higher fin porosities.

The advantage of the advanced designs can best be seen when costs are taken into account. Figure 2 shows cost results for the conventional 10 fin-per-inch finned tube design, the prototype (labeled as 7 fins per inch), and another perforated fin design in which the tubes lie in the plane of thick fins. (The latter is not an experimental result, but was generated using the computational fluid dynamics code, FLUENT.) In Figure 2, the y-axis is the capital cost per unit watt of heat duty, and the x-axis is the total present value of fan power cost (over a 20-year plant life) per unit watt of heat duty. Thus at any point on the plot, the total cost is the sum of the x-coordinate (fan power cost) and the y-coordinate (capital cost of the equipment). The straight dotted lines represent constant total cost (i.e., the sum of x and y). Each curve was generated from a range of air velocities. The optimum velocity would be that for which the curve reaches the minimum total cost line.

The two advanced concepts show significantly lower total costs over the entire range. The minimum total costs (capital plus parasitic) are as follows: \$0.20/W for the conventional design, \$0.15/W for the transpired 7 fin-per-inch, tube-through-fin design (the tested prototype), and \$0.12/W for a transpired tube-in-fin design. These results do not account for potential differences in fabrication costs, since the fabrication methods have not been determined yet. However, the results are conservative from a performance standpoint, because NREL researchers believe there is considerable room for improvement of the designs, as better correlations are developed for the many degrees of freedom. Interestingly, this analysis showed that the minimum-cost air velocity for all designs was about 1.5 m/s. A typical design

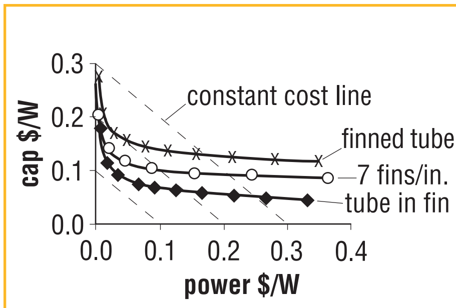


Figure 2. Capital and fan power costs per unit of heat duty for the conventional finned-tube design and two advanced transpired fin designs.

velocity for air-cooled condensers is 3.5 m/s. While this may be appropriate for many applications, the analysis suggests that this may be too high for a binary-cycle geothermal power plant, resulting in excessive fan power costs.

NREL plans to conduct additional simulations to develop correlations for use in a spreadsheet model to develop improved designs. NREL researchers will then build and test a second prototype. Once the researchers have determined the best design, they will then conduct a field test at an operating binary-cycle plant that will allow a side-by-side test with a conventional unit. NREL staff will also cooperate with industry to address manufacturing issues. NREL believes that the advanced air-cooled condenser designs will reduce the cost of electricity from binary-cycle geothermal power plants by about 0.5 cent per kWh.

For more information about INEEL R&D, contact Jim O'Brien, INEEL, at 208-526-9096 or jzo@inel.gov.

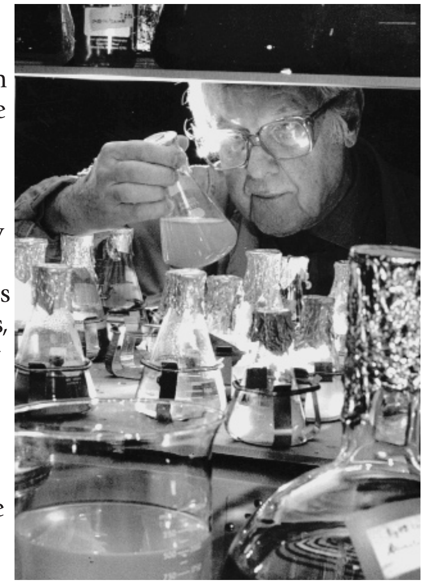
For more information about NREL R&D, contact Chuck Kutscher, NREL, at 303-384-7521 or chuck_kutscher@nrel.gov.

. Premuzic

Dr. Eugene "Gene" Tomislav Premuzic—a long-time geothermal researcher—recently retired from Brookhaven National Laboratory (BNL) after making major scientific contributions to DOE's Geothermal Energy Program and industry. He left BNL late last year as head of its Energy Science and Technology Division in the Department of Applied Science, where he was a key principal investigator for DOE's geothermal research and development programs.

Gene's a true internationalist; his education and extraordinary career span Europe, Canada, and the United States. He was born in Zagreb, Croatia, where he graduated from high school soon after World War II. After undergraduate study in Czechoslovakia and Yugoslavia, he completed graduate work in chemistry in Britain, where he met and married his English wife, Brenda. It's not surprising then that he speaks five languages: Croatian, English, Russian, German, and Czech.

In 1976, after a 20-year career in chemistry and biochemistry in both industry and academia, Gene began his long association with BNL. The laboratory soon called upon his intellect to help solve a costly problem in the commercialization of geothermal energy: how to deal with the high levels of toxicity found in some geothermal brines? Environmental regulations require the special handling of toxic metals—such as mercury, zinc, arsenic, and chromium—substantially increasing the costs of power generation from these resources.



Eugene T. Premuzic. Photo courtesy of BNL.

Gene's highly innovative solutions involved bioremediation techniques never before applied in geothermal power generation. He identified and isolated microbes with an affinity for these and other pollutants. The microbes could detoxify the wastes, eliminating the need for disposal in high-cost waste sites. He then went even further, developing processes for using some of these wastes in commercial products, thereby turning liabilities into assets. These processes can also yield commercially marketable quantities of various metals found in the brines. They hold the promise of significantly improving the economics of geothermal power generation.

While practicing chemistry, Gene shared his love of science and great enthusiasm for his work with many young people. Gladys Hooper, his DOE program manager, said Gene spent a great deal of his own time mentoring high school and college students, especially minority students, in the sciences. He brought students into the lab and exposed them to new ideas, research techniques, and equipment they might not otherwise have encountered. Even with very limited resources, Gene found ways for BNL's Minority Institutions Program to collaborate with Howard University in training graduate chemistry students. Gladys acknowledges a large debt to Gene in her own development as a scientist. "I was one of his best students," she said.

Allan Jelacic, DOE Geothermal Team Leader, was also enriched by his long association with Gene. "Gene has been an important contributor to the department's geothermal research activities for many years," he said. "He brought an enthusiasm to his work and a desire to contribute that few could match."

Gene recently expressed appreciation for his long association with the DOE geothermal program and the geothermal industry: "I have had an opportunity to meet some outstanding people whose broad view of geothermal resources has helped me and my group develop novel biochemical and chemical strategies for processing several by-products generated in the production of geothermal power. They have helped me demonstrate that geothermal formations are a multipurpose, environmentally acceptable resource, providing valuable products such as high quality amorphous silica and rare metals, as well as feedstocks useful in many applications. I have been fortunate to be associated with a community of talented people, and I thank my colleagues and co-workers for this wonderful opportunity."

With retirement, Gene has more time to indulge his several hobbies: gardening, drawing, painting, traveling, history, wine tasting, and cooking. He also considers himself an amateur rock hound. Gene and Brenda recently had the great joy of seeing their only daughter, Arianne, married.

ermeability

ault-Hosted

Researchers from the U.S. Geological Survey, Stanford University, and the Oxbow Geothermal Corporation are developing conceptual models for stress and permeability heterogeneity within a fault-hosted geothermal reservoir in Dixie Valley, Nevada. Their investigation includes trying to determine if and in what manner massive hydraulic fracturing or other reservoir stimulation techniques might be used to turn a well with insufficient permeability into a viable production or injection well.

To determine tectonic controls on the permeability of the fracture-dominated reservoir, the researchers have been conducting borehole televiewer logs, temperature/pressure/spinner logs and in-situ stress measurements in wells drilled at depths of 1.24–1.86 miles into and near the Stillwater fault zone (SFZ). The SFZ is a major, active normal fault in the northern Basin and Range province, which comprises the main reservoir for a 62 MW geothermal electric power plant. Previous results from wells within the Dixie Valley geothermal field (DVGF), and from wells 5 and 12.43 miles to the southwest, indicate that fault-zone permeability is high only when individual fractures, as well as the overall SFZ, are favorably oriented and critically stressed for frictional failure (see Figure 1).

To understand the causes for more localized variations in fault-zone permeability, similar measurements were recently taken in well 82-5, located within the DVGF, but which failed to encounter sufficient permeability to be economically viable. The well was re-drilled three times despite being only 1967 feet southwest of one of the field's most permeable production wells. The most recent (open-hole) leg drilling encountered abundant, sealed fractures starting at about 8990 feet, which is inferred to be the top of the SFZ, before passing through the main range-front fault and into the footwall at a depth of 9295 feet.

Unfortunately, during a routine work-over to clear a blockage and to condition well 82-5 for testing, the drill pipe became stuck and had to be severed at a depth of 8937 feet, preventing further access to the SFZ. Thus,

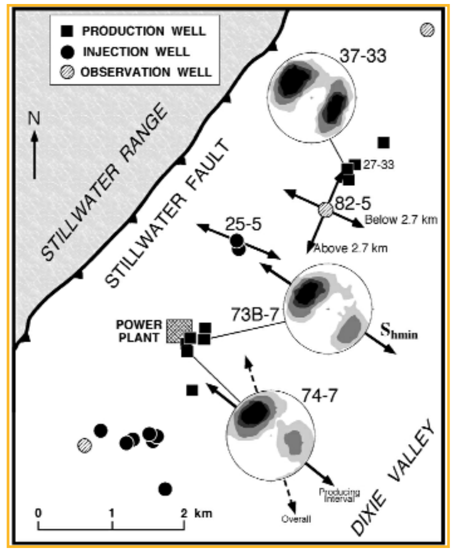


Figure 1: Map of the Dixie Valley Geothermal Field.

although excellent quality logs and a hydraulic fracturing test were conducted in the open-hole interval from 6795 feet to 8924 feet, these data could not be used to determine the causes for the low fault-zone permeability.

However, numerous stress-induced borehole breakouts and drilling-induced tensile cracks were observed. They reveal dramatic perturbations to the regional stress field at this location, manifest both as gradual rotations in the azimuth of the least horizontal principal stress (S_h-min) over depths of several meters and as a sudden 90° shift in stress orientation that occurred at a depth of about 8760 feet. The 90° permutation in the horizontal principal stress directions, similar to stress permutations observed in producing wells 27-33 and 37-33 located about 0.37-0.5 miles to the north-east, is most readily explained by one or more moderate- sized, normal faulting earthquakes that have recently occurred in the northernmost part of the DVGF on faults subparallel to the SFZ. The mean azimuth of S_h-min above 8760 feet in well 82-5 is anomalous in that it is roughly parallel to the SFZ, whereas the orientation of S_h-min below 8760 feet (i.e., directly above the fault zone) is perpendicular to the strike of the fault, agreeing with stress orientations observed in the central and southern parts of the DVGF (Figure 1).

Figure 2: Rigging up to begin bore-hole televiewer logging in well 82-5.

A single, hydraulic fracturing test conducted in well 82-5 indicates that the magnitude of S_h-min at about 8038 feet (i.e., within the zone exhibiting the anomalous minimum stress orientation) is near the critical value for frictional failure on optimally oriented normal faults. This suggests, together with the observation that borehole breakouts are common in well 82-5 yet absent in the wells not stress-perturbed in the southern part of the DVGF, that the horizontal differential stress prior to the hypothesized earthquake was quite low (as previously proposed) and that this earthquake was accompanied by a near total relief of shear stress on the causative fault. Finally, if the stress orientation observed immediately above the fault zone in this well persists to greater depths, then a massive hydraulic fracture within the SFZ would propagate toward the highly permeable wells to the northeast. Therefore, well 82-5 may still be a good candidate for massive hydraulic fracturing, although it would require the drilling of a new leg to regain access to the SFZ.

For more information, contact Dick Benoit with Oxbow at 702-850-2223.

urbo-Drill

esting Begins

Maurer Engineering, Inc., with support from DOE's geothermal and fossil fuel research programs, has developed an advanced turbo-drill for use in oil, gas, and geothermal hard rock drilling. The turbo-drill uses high performance turbine blades and a two-stage, planetary gear reducer to produce higher torques and lower speeds than conventional turbo-drills. Laboratory testing of the downhole, mud-driven, turbo-drill was recently completed, making way for the next stage in its development—field testing.

Maurer conducted a field test of the advanced turbo-drill on the PEMEX well, ARCOS 511, located in Mexico approximately 70 miles west of McAllen, Texas, at the Falcon Reservoir near the U.S. border. The 9.62-inch diameter turbo-drill cut down through a hard sandy shale formation from a depth of 526 feet to 3940 feet, drilling at rates up to 207 feet per hour (Figure 1), compared to 76 feet per hour for rotary drilling using a 12.25-inch Baker Hughes PDC bit (ARCOS 46 and 47).

The turbo-drill used 23 stages of high performance turbine blades that produced 7800 foot-pounds of torque at 120 rpm while operating at oil-based mud flows of 500 to 550 gpm and stand pipe pressures of 2800 to 3500 psi. The rotary table was turned at 100 rpm, making the total bit rotary speed 220 rpm. Although PEMEX limited bit weight because of concerns over hole deviation, the high torque turbo-drill allowed bit weights up to 18,000 pounds with no hole deviation.

Crews on PEMEX's rig 316 quickly learned how to operate the turbo-drill. Unlike conventional motors, the equipment is easy to operate because the high torque output helps to prevent stalling. The high torque and low speed make the turbo-drill ideal for use with roller core or PDC bits operated at high bit weights. The absence of rubber in the turbo-drill

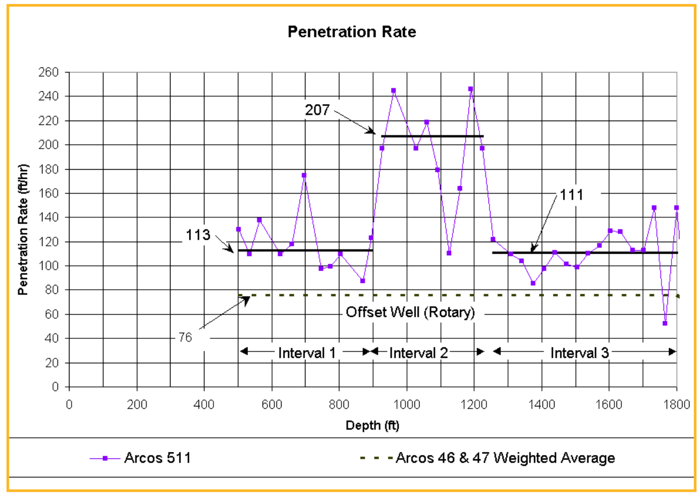


Figure 1. The penetration rate (feet per hour) of the advanced turbo-drill.

allows it to operate in high temperature geothermal wells and with oil-based muds. A flexible coupling between the gear box and the bearing pack permits the use of a bent housing, making the advanced turbo-drill ideal for directional and horizontal drilling.

The advanced turbo-drill represents an improvement in downhole motors that should significantly reduce costs in high temperature and hard rock wells. This tool should facilitate the drilling of horizontal geothermal wells that intersect multiple natural fractures and increase production rates two-to-four fold.

Vector Oil Tool, the manufacturer of the gear box used in the advanced turbo-drill, is expected to market this promising new technology worldwide under license from Maurer when development is complete. Vector currently markets positive displacement motors and other downhole tools.

For more information, please contact John H. Cohen, Maurer Engineering, Inc., at 713-683-8227, ext. 215 or at jhcmaureng.com.

How to Reach Us

U.S. Department of Energy
Geothermal Energy Program
1000 Independence Ave., S.W.
Room 5H-048
Washington, DC 20585
202-586-5340
www.eren.doe.gov/geothermal

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA