Geothermal *technologies*

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Geothermal Technology Advances Win *R&D 100* Awards

The editors of *R&D 100 Magazine* have selected two projects from Sandia National Laboratory that were sponsored by the Department of Energy's Geothermal Technologies Program as among the 100 most technologically significant products introduced into the marketplace during the past year.

The first, a family of atmospheric geothermal separators known as LEAMS, was developed by Two-Phase Engineering and Research with fabrication by Drill Cool Systems Inc. and with support from the U.S. Department of Energy and Sandia National Laboratories.

The second, acoustic telemetry technology, was developed at Sandia in cooperation with Extreme Engineering Ltd. of Calgary, Alberta, and with support from the U.S. Department of Energy.

The R&D 100 Awards—sometimes referred to as "the Nobel Prizes of technology"—were first awarded in 1963.

The LEAMS (Low Emissions, Atmospheric, Metering, Separator) technology's primary use is to safely contain and clean atmospheric vented steam of polluting solids, liquids, and noxious gases. This system is designed to be environmentally friendly, intrinsically safe, and relatively easy to transport and assemble. LEAMS has a wide operating range and can be used in drilling, well testing, and plant start-up. Currently, no atmospheric cyclone separator can perform all these functions as well using a single system.

The acoustic telemetry technology uses the well-drilling tubing as the data transmission medium and sound waves as the data carrier. Among its advantages compared to existing techniques are a 10-fold improvement in data rates and no blocking of the fluid flow path.

Existing measurement-while-drilling (MWD) communication methods are based on mud-pulse techniques, which were revolutionary when they were introduced in the early 1980s. But mud-pulse is slow and has become a bottleneck to the precision drilling needs of the 21st century.

Doug Drumheller, Sandia project lead in developing the technology, says that although the acoustic telemetry concept has been around for more than 50 years, trial-and-error approaches to solving technical problems led nowhere.

LEAMS in the Field

In geothermal power development, a well must be drilled deeply into the earth where hot water and steam are found under high pressure and temperature. The fluids produced, along with drill cuttings, must be safely brought to the surface to be measured and cleaned before being discharged into the environment. LEAMS is designed to reduce the solid and liquid pollution of the drilling process by up to 99 percent over current cyclone separator technology discharging to the atmosphere. The vented steam is cleaned of formation cuttings, abatement chemicals, and toxic waste, virtually eliminating environmental pollution.

(continued on page 2)

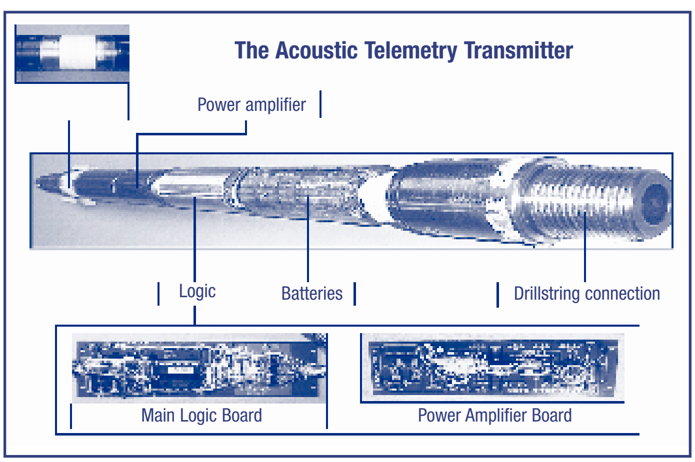
LEAMS also can internally abate hydrogen sulfide gas for secondary treatment, meter two-phase flow without unnecessary drilling-rig down-time, and be shipped in containerized components and erector-set assembled. Its design allows the system to dissipate high-energy slugs that otherwise might launch conventional equipment off the location.

A variety of LEAMS configurations are available. Recent improvements include a diffuser stack that ejects vapors high into the sky to dissipate residual hydrogen sulfide and protect personnel against injury from a potential gas excursion during startup.

LEAMS III Separator at a California geothermal field.

Acoustic Telemetry Technology

Acoustic Telemetry Technology communicates through the metal piping used to drill wells into the Earth. Why is this important? When you stand next to a well project used to produce natural resources such as oil, natural gas, and geothermal energy, the well-casing strings, production tubing, and other drilling equipment typically extend several miles into the subterranean formation. Because many wells often reach out from the drilling platform more than they reach down, communication between the driller and the drill bit is crucial to accurately steer the drill bit towards the target.



The Acoustic Telemetry Transmitter.

Acoustic Telemetry Technology is a wireless communication method. Here's how it works. Where a television station communicates by broadcasting pictures and audio signals with radio waves that travel through the atmosphere, Acoustic Telemetry Technology communicates by broadcasting data with sound waves. These travel through the well's steel tubing. Acoustic Telemetry Technology provides the drilling industry with an unparalleled increase in bandwidth in virtually every drilling environment. That's important because the price of energy—be it electricity, heating fuel, or gasoline—is a critical part of doing business.

A large part of our nation's energy comes from wells, which are expensive to drill and maintain. Acoustic Telemetry Technology will lower these costs by accelerating drilling and production rates, and by reducing investment risks. Knowing what is going on "down there" is key to achieving these goals. Industry understands the economic, environmental, and safety benefits of communication technologies: it already invests more than $3 billion annually in old measurement-while-drilling telemetry services have been pushed to their practical limits. The new Acoustic Telemetry Technology opens the door to future technology with an unlimited two-way communication range and increased communication rates at lower costs.

DOE Announces SEP Grants for Geothermal Projects

DOE announced July 9th it would award almost $300,000 in competitive grants to 5 western states to conduct geothermal energy outreach projects in partnership with GeoPowering the West geothermal energy projects. The funds were awarded as part of DOE's State Energy Program (SEP). Altogether, DOE awarded $12.6 million for 138 energy efficiency and renewable energy projects in 47 states and 3 U.S. territories.

Funds for geothermal projects will support general geothermal outreach and information sharing, state-based agricultural and rural efforts, and updating resource assessments. These projects will support both direct-use and electricity production applications from geothermal resources.

In announcing the grants, Energy Secretary Spencer Abraham said, "These special energy projects will help conserve energy, provide jobs, increase our national energy security and reduce the need for new electricity generating plants."

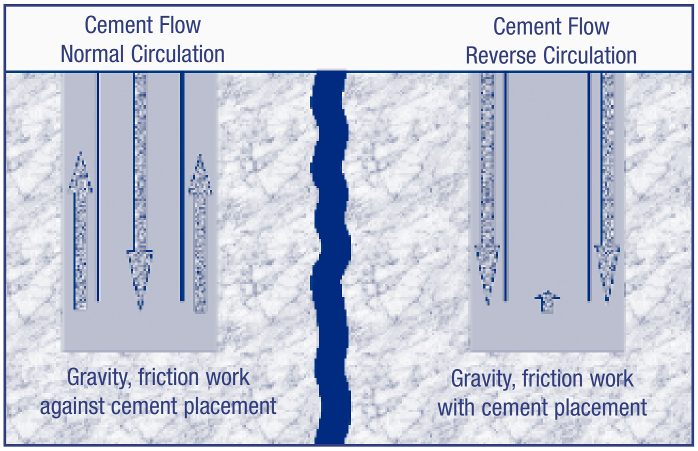


Figure 2: Direction of cement flow during conventional and reverse circulation cementing.

Twin streaming sodium silicate and cement was successfully applied recently to a top-hole primary cement job at Puna Geothermal Venture, (Figure 3) [Livesay, 2003]. To cement in the casing shoe, cement was circulated conventionally up to the point it was lost to the formation. The top-hole job was done by pumping sodium silicate down a tremmie pipe while pumping cement down the annulus. There was no room for a second tremmie pipe. The top job was completed in 12 hours—previously as many as 4 days were required. About one-third the amount of cement was used.

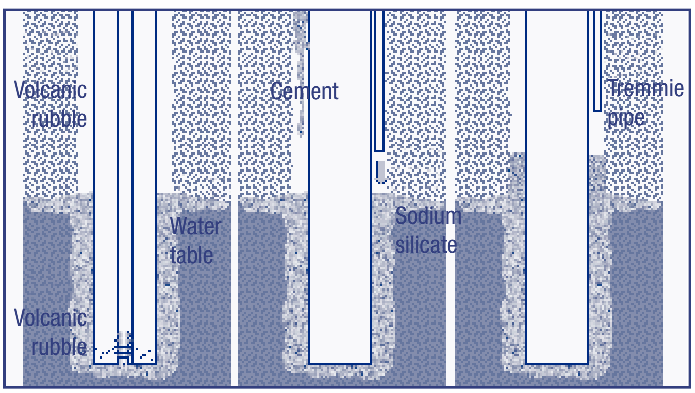


Figure 3. Top-hole tremmie pipe cementing job at Puna Geothermal Venture. Left: conventional inter-liner cement placement back up to water table. Cement cannot be circulated conventionally above this level. Center: simultaneous pumping of one part sodium silicate down tremmie pipe and five parts cement down annulus. Pumping was stopped once the cement volume equaled the hole volume below tremmie pipe. Right: at that time tremmie pipe was raised for next lift.

Decision Making

Making appropriate decisions is key to drilling. Decisions are based on experience, expected economic outcomes, and risk management. New technologies will have no effect until they can be incorporated into the decision making process. While this cannot be done until they have been tried and proven in the field, it is useful to examine how the new technologies discussed above may be applied.

Suppose proper use of standard drilling, mud program, and lost-circulation materials or bridging agents procedures have been applied and yet there is total loss of returns. Then a cautious use of the new technologies described above can be depicted as in Figure 4. If there is cross flow and it is not plugged off, then subsequently applied cement will be washed away. Thus, the conservative action is to stop and plug the cross flow. If there is no cross flow, there are options for drilling ahead. If one drills ahead and problems only get worse to the point where it is unlikely the primary cement job will be successful—cross flow back up hole is detected at a later time—then restoring wellbore integrity is required (fill and re-drill). If one drills ahead and restoring wellbore integrity is not required, there are three primary cement job options: conventional cementing (unlikely to work based on past experience that has driven the industry to plug each zone as it is encountered), tremmie pipe (if there is adequate space in the annulus), and reverse circulation.

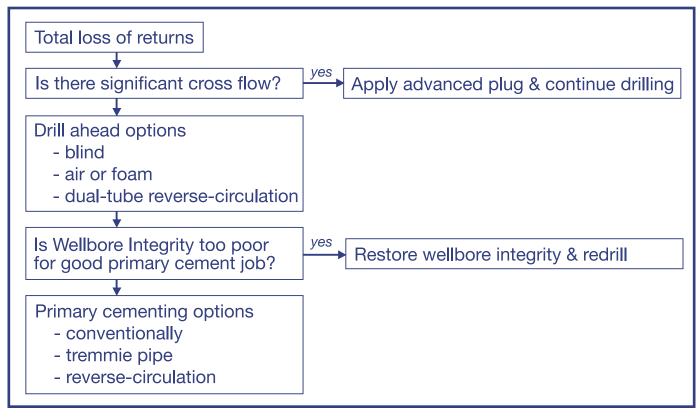


Figure 4: Coordinating the use of new Wellbore Integrity technologies.

The fact that tremmie pipes require extra space in the annulus does not necessarily preclude their use. Often the surface casing is one size larger to allow for a contingency string, or the production string ends up one size smaller because of a contingency string. It may be better to do a tremmie pipe primary cement job in the string that fits rather than use a contingency string.

A primary cement job that includes both twin streaming sodium silicate and cement using a tremmie pipe may allow a less cautious approach than that described by Figure 4. Assuming it can be demonstrated that cross flow does not wash away the sodium silicate and cement mixed downhole, the primary cement job can be done in the presence of cross flow. This is an advantage because it is difficult to predict if there is cross flow in the wellbore.

Conclusions

A new paradigm for wellbore integrity is possible, but requires the use of emergent technologies that are today being demonstrated in geothermal drilling.

problems including sloughing, caving, washouts, or bridging. Lost circulation-related phenomena are expensive—accounting for 10% to 20% of the total cost of drilling a typical geothermal well—and cause drilling problems such as stuck drill pipe, damaged bits, slow drilling rates, and collapsed boreholes.

Cross flow occurs when the wellbore encounters permeable zones whose pore pressures are not hydrostatically balanced (Figure 1). This often occurs when alluvial deposits are separated from underlying volcanics by an impermeable layer. During seasonal runoff, lost circulation is usually not encountered while drilling the alluvium. However, the fluid level in the borehole may fall hundreds of feet below the surface (significant lost circulation/cross flow) when drilling penetrates the volcanics. Therefore, if the surface casing shoe is not set in the impermeable zone, the well may have cross flow from one zone to another sufficient to wash away all cement plugs and primary cement.

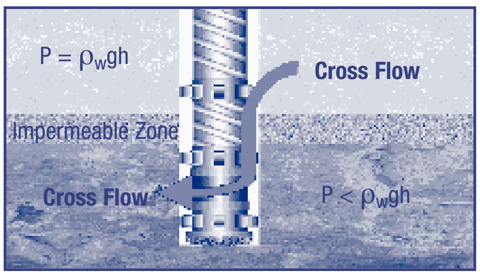


Figure 1: Cross flow occurs when the wellbore encounters permeable zones whose pore pressures are not hydrostatically balanced. P = pore pressure, and $\rho_w gh$ is weight column of water back to surface.

The Wellbore Integrity Program at Sandia National Laboratories began with the development of polyurethane grouting as an advanced lost-circulation/cross-flow plug mitigative measure. While a technology specifically focused on plugging lost-circulation zones may be the only sure way of mitigating the effects of severe cross flows and minimizing overall drilling costs, a broad system perspective is needed that considers how lost circulation affects well design, drilling ahead, casing, primary cementing, and related issues. The ultimate goal is not controlling lost-circulation, but rather maintaining wellbore integrity.

Several factors are key to successful wellbore integrity:

- Using standard drilling and cementing procedures properly (mud program, lost-circulation materials or bridging agents, cement plugs, and so on)
- Distinguishing between ordinary lost circulation and cross-flow, and if required, using a cross-flow plugging technique that does not wash away
- Being able to drill ahead trouble free even in the worst lost-circulation zone
- Being able, if required, to restore wellbore integrity up-hole after drilling ahead, and
- Applying alternative placement techniques, if required, for the primary cement job.

If the proper use of standard drilling procedures and primary cementing are inadequate (including the use of cement additives and nitrogen foamed cement), a number of emerging technologies can be applied. These include polyurethane grouting, dual-tube reverse-circulation, reverse circulation, and tremmie pipe twin-streaming sodium silicate and cement.

Polyurethane grouting at the Rye Patch geothermal field in northern Nevada proved this technology's applicability to plugging geothermal cross-flow zones. This grouting used materials and emplacement techniques borrowed from mine dewatering. The Rye Patch grouting success begs the question, "Can the same success be achieved with traditional drilling materials and emplacement techniques?" Yet polyurethane grout remains the standard by which to judge other advanced cross-flow plugging material.

After the successful Rye Patch grouting, InstanSeal™ Cement was identified as a new commercial material potentially capable of plugging severe cross flows. Twin streaming sodium silicate and cement is another possible technology for plugging geothermal lost-circulation zones.

Dual-tube reverse-circulation, developed for minerals and water well drilling, has significant potential to allow drilling ahead in incompetent wellbores without caving or stuck pipe [Mackay, 2003]. This technique has been used at the Rye Patch [Rickard, et al., 2001], Soda Lake, and Dixie Valley geothermal fields in northern Nevada.

Reverse-circulation cementing and sodium silicate tremmie pipe cementing offer alternatives for primary cement jobs, for example, cementing in the casing. Reverse-circulation cementing reduces equivalent circulating densities (ECD) and allows better timing of the cement setting. If nitrogen is added, bubble expansion is better controlled through the cementing interval.

Tremmie pipe twin-streaming sodium silicate and cement allows cement to be placed into a formation that will not hold the cement column pressure. This method allows the cementing of zones where cementing normally sloughs into the formation, requiring an unacceptable number of lifts or top jobs.

Finally, the development of these solutions necessitates careful decision-making. The options discussed will not be useful unless they are utilized in the proper context.

Past Work: Polyurethane Grouting

Polyurethane grouting was developed to stop cross flows because polyurethane grout:

- Will not be diluted by nor mixed with water,
- Forms a rigid plug of sufficient strength to withstand primary cement job pressures,
- Displaces rather than fingers through drilling mud, and
- Sets up fast enough (between seconds and minutes) that it is not easily washed away by cross flow.

These facts are best validated by the use of polyurethane grout to stop cross flow in dams where it has become the grout of choice [Bruce, et al., 1998]. The applicability of polyurethane grout to geothermal drilling has been demonstrated at the Rye Patch geo-thermal field [Mansure, et al., 2001]. A rigid plug is preferred over a stiff gel because a rigid plug only has to penetrate a short distance (~1 foot) into a 1" to 2" crack to form a plug strong enough to withstand primary cement job pressures. Typical polymers have low yield strengths and require hundreds of feet of penetration into such cracks to form an adequate plug.

Success at Rye Patch depended upon much more than using proper materials. One step leading to the field test was development of best practices, which were incorporated into the job planning process. Mansure and Westmoreland summarize these:

- "Squeeze Job." The grout must be placed in the formation, not the borehole. This normally requires a packer. Placing grout into the borehole and coating the borehole wall are not sufficient. Subsequent drilling will remove the grout, re-exposing the loss zone.
- "Use Excess Material." The grout should be pumped until significant back pressure is achieved—pumping should continue until grout diverts into all the loss zones, not until a predetermined volume is displaced.
- "Pump for Longer than the Gel Time." When grout is pumped for longer than the gel time, the process becomes self-diverting and compacts the polyurethane to form a strong impermeable plug.

Significant parallels exist between these polyurethane grouting practices and the best practices for successful cement squeeze jobs.

Wellbore Integrity Vision

New wellbore integrity technologies are needed to facilitate change in the ineffective standard practice of fixing each lost-circulation zone as it is encountered. Drillers should be focusing on the question, "How do we get the next casing string cemented in with minimal lost time and low additional cost?" To facilitate the new paradigm, we focus on the following needed technologies:

- Advanced methods for plugging lost circulation/cross-flow zones (for example, polyurethane grout, twin-streaming sodium silicate and cement, and InstanSeal™)
- Adequate options for drilling ahead to the next casing point (dual-tube reverse-circulation drilling)
- Methods for reestablishing wellbore integrity after drilling ahead (for example, fill and re-drill, wellbore lining, and so on), and
- Alternative methods for primary cement placement (reverse-circulation and tremmie pipe cementing).

The areas discussed here illustrate how wellbore integrity problems will be solved in the future rather than proven/validated best practices. Many ideas discussed have not been field proven, but are ideas for future testing.

Advanced Plugging Methods

Polyurethane grouting proves the practicality and economic viability of advancing methods for plugging lost circulation zones. Work continues to transfer polyurethane grouting from the civil engineering methodologies applied at Rye Patch to standard drilling service company practice. Other advanced plugging technologies in line with current service company practice are also being evaluated.

The deployment of polyurethane grout at Rye Patch used a two-part formulation. Plans to adapt this work to more standard drilling service company practice and allow deeper deployment (Rye Patch was ~700 feet) have focused on using a one-part prepolymer activated by water. The one-part prepolymer requires only one "tubing" rather than the two hoses used at Rye Patch.

The development of high temperature polyurethane formulations has not progressed as rapidly as hoped. Prior to Rye Patch, laboratory testing was done by baking samples in an oven, measuring compressive strength at ambient and elevated temperature, and measuring permeability at ambient temperature. A plug test was performed at 200°F and 500 pounds per square inch (psi) differential pressure—comparable to conditions at Rye Patch. After a week, during which leakage through the polyurethane plug was negligible, the temperature was increased to 300°F and the plug leaked excessively.

Based on the results obtained in oven tests, it was assumed that changing to higher temperature polyurethane formulations would allow application temperatures in excess of 300°F. Unfortunately, subsequent tests demonstrated that combining temperature, pressure, and water introduced a new failure mechanism: hydrolysis, or reversing of the polymerization reaction. So far, results of subsequent testing have not been intuitive. The one-part formulation has the best stability and appears usable up to about 200°F to 250°F. The exact temperature depends on how long the plug needs to last.

Though sodium silicate and cement have been used to plug geothermal lost-circulation zones, they have not gained a reputation for success. While they form a rigid plug, set up fast, and, after mixing, are less susceptible to being diluted by water than standard Portland cement, their application still poses a problem in controlling the downhole delivery/mixing process.

Sodium silicate has failed in past geothermal tests for batch jobs—pumping sodium silicate first, then chasing it with a water spacer followed by cement. Successfully applying this process depends upon in situ mixing of the sodium silicate and the cement. Mixing can be accomplished in two ways, either, turbulent action as the fluids flow through the formation, or contact adhesion between sodium clinging to formation surfaces and subsequent cement flow. Laboratory tests suggest that most geothermal lost-circulation zones have apertures that are too wide for sodium silicate clinging to the rock walls to adequately gel the subsequent cement and then seal voids. In the lab, batch jobs injected through 3/16" tubes (huge pores even for porous media formations) plugged easily, whereas batch jobs injected through 1/2" tubes (representative of a small geothermal formation fracture) did not readily plug.

Eliminating the water spacer significantly increased the chance of plugging open channels by allowing the sodium silicate and cement to mix at the interface. With cross flow, however, the sodium silicate can be sufficiently diluted before mixing or blending with the cement so that the material does not gel, allowing it to wash away. Twin streaming solves this problem by mixing the sodium silicate and the cement downhole within close proximity of the zone to be plugged.

Before work on polyurethane grouting began, review of the state-of-the-art of lost-circulation control failed to identify a product with the attributes needed for cross-flow control. After the demonstration of polyurethane grouting at Rye Patch, however, a product with potential to stop cross-flow was identified: InstanSeal™ Cement. Plans are being made to test this product to determine its applicability to geothermal lost-circulation zones. Thus far, this product has been used to 130°C (266°F).

InstanSeal™ cement is a two-phase emulsion that, when pumped through the bit nozzles, uses shear action to allow the two parts to chemically react [Johnson, et al., 2002]. The resulting material is stiff enough to stand on, but not rigid. When lost circulation is encountered, the material is pumped through the bit into the loss zone. It sets in minutes and is then drilled out. In many applications, the resulting plug allows drilling ahead as if no loss zone had been encountered.

Drilling Ahead Options

Historically, the methods used for drilling ahead with total lost circulation have been to drill blind (that is, all the drilling mud and cuttings are lost to the formation), or to use aerated or foamed drilling mud. These options have often proven inadequate to prevent stuck drill pipe and twist offs. Dual-tube reverse-circulation has been recognized as a superior option, but additional research is required to fully validate this approach and apply it with conventional geothermal drill rigs. Further, water well and minerals rigs are not normally designed for a BOP stack and blowout control [Rickard, et al., 2001].

The proliferation of options, explosion of information, and increasing complexity means many "construction industries" that used to be vertically integrated are breaking up. Industry standard practice continues to vertically integrate drilling using the same rig from top to bottom, except in setting the conductor pipe. This begs the question, "Why not use a special rig to drill and set the top-hole casings through the severe loss zones?" Using a separate top-hole rig would allow existing minerals or water well rigs to be used that may not be suitable for drilling to TD. This concept was carried out at Soda Lake, allowing a "smaller" rig, one not capable of handling surface casing diameters, to drill the deep hole. Using the "smaller" rig for the deep hole saved enough in mobilization to pay for the extra mobil- ization to bring in the top-hole rig. Further, if the well had passed through difficult lost-circulation zones (though it did not) the savings would have been considerable.

Reestablishing Wellbore Integrity

Methods for reestablishing wellbore integrity after drilling ahead to the next casing point have not been demonstrated. Work in this area should begin with simple approaches such as using a tremmie pipe to fill the well and surrounding formation with fast setting, easily drillable, slumpless cement. Once the wellbore is filled, the cement is drilled out, leaving a competent cement-healed wellbore. If such approaches cannot be validated, work will progress to wellbore lining technologies [Finger and Livesay, 2002].

Alternate Primary Cement Placement Methods

Two alternatives to conventional placement of primary cement show promise: reverse circulation and twin streaming of sodium silicate and cement using a tremmie pipe.

The concept of reverse circulation cementing is not new [Marquaire, et al., 1996 and Griffith, et al., 1993] (Figure 2), but has not been widely practiced. However, in the last few years, new supporting technologies, such as downhole monitoring of when the cement reaches the shoe and improved process control, have made the process reliable. Over 20 of these jobs have been completed in the last few years in wells that have defied other approaches to cementing. Unfortunately, they have not been well documented. The first such jobs have recently been tried in geothermal wells [McCulloch, et al., 2003a,b,c].

The five geothermal projects receiving DOE SEP grants are:

Arizona Geothermal Collaborative Outreach Program

This program seeks to increase awareness of and interest in geothermal energy to spur its application for electricity production and direct use. Program goals are being supported with $99,640 in DOE funds and include:

- Collecting, summarizing and making existing data and a resource map available electronically on the Web
- Creating state-specific educational materials for students and developers
- Conducting a series of Geothermal Awareness Forums in rural areas of the state to educate voters, economic development officials, local businesses and citizens about their area resources.

The program plans to use these forums to identify areas where the potential for geothermal energy can be matched with interest in developing the resource.

Assessment of Hawaii's Geothermal Resource

The project will assess the potential of available geothermal resources on the island of Hawaii. The project is supported with $42,753 of DOE funding and includes assessing the potential to use geothermal energy as the primary energy source and identifying possible new markets for it. The state energy office is interested in exploring hydrogen production from geothermal in the future and would like a more accurate assessment of their geothermal resource.

Geothermal Energy Outreach in Rural Idaho

This project will educate rural Idaho communities about their geothermal energy resources and help them develop these resources. It will address those communities that have geothermal development projects in the works. These communities primarily need technical, steering and financial assistance, as well as written project plans.

The project also will use the $59,572 DOE SEP grant to identify rural areas most likely to develop their geothermal resources. In those areas, the project will work to create interest through public forums and educational materials.

Identifying New Opportunities for Direct-Use Geothermal Development

The California Energy Commission Geothermal Program plans to use its $54,310 DOE grant to update and build on an existing resource assessment of geothermal direct use. It will use the assessment to provide information to potential users.

It also will use the updated assessment to identify opportunities for economically viable, near-term generic applications for geothermal direct-use heating in three or more selected regions in California.

New Mexico Geothermal Direct-Use Development

This project, supported with $37,810 of DOE funding, will work to attract agribusinesses to direct-use geothermal applications by conducting outreach, providing resource assessment information and evaluating economic feasibility.

The project includes:

- Identifying the most promising sites in the state for aquaculture and crop drying
- Developing pro forma business plans for selected aquaculture and crop drying market segments
- Conducting two workshops for people interested in entering geothermal agribusiness
- Marketing geothermal direct-use at industry trade shows.

It will build upon and leverage prior geothermal development activities in New Mexico, which spurred significant development of geothermal aquaculture and crop drying with chile and other suitable field-grown crops.

From Plugging Lost-Circulation Cross-Flow Zones to Wellbore Integrity

A.J. Mansure and J.J. Westmoreland
Sandia National Laboratories

Fixing each lost-circulation zone as it is encountered before drilling ahead has been standard practice because of the technologies historically available to drillers. In recent years, however, significant developments have occurred in wellbore integrity technology.

These include reactive and shear-setting plugs for lost-circulation/cross-flow control, the use of dual-tube reverse-circulation rigs to drill severe lost-circulation zones, and alternative emplacement techniques for primary cementing (reverse circulation and "tremmie" pipe).

These and other new techniques are allowing lost circulation mitigation strategies to change dramatically. Instead of fixing each lost-circulation zone as it is encountered, drillers can consider the question, "How do we get the next casing cemented in with minimal lost time and additional cost?"

Understanding Lost Circulation

Lost circulation occurs when pore pressure in the formation is less than the pressure of the fluid column in the wellbore. This causes some or all of the drilling fluid to flow into the formation instead of circulating back up the wellbore annulus. Lost circulation is a persistent problem in geothermal drilling, and is frequently the root cause of other wellbore integrity

With the exception of the contingency tool of restoring wellbore integrity after drilling ahead, significant progress is being made in introducing each of these tools to geothermal drilling. Important to the success of this plan is having more than one tool to mitigate a given problem. Once these additional tools have been demonstrated, the paradigm can change from fixing each lost-circulation zone as it is encountered to asking more important questions such as, "How do we get the next casing cemented in with minimal lost time and additional cost?"

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