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Geothermal Technology Publications and Related Reports: A Bibliography January through December 1983

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Dana L. Cooper, Editor

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GEOTHERMAL TECHNOLOGY PUBLICATIONS AND RELATED REPORTS:

A BIBLIOGRAPHY

January through December 1983

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Abstract

Sandia National Laboratories has done significant research and development for the U.S. Department of Energy to access and utilize geothermal resources. Results of the work from January 1977 through December 1982 were summarized in reports SAND81-0662, SAND82-0993 and SAND83-0492. This bibliography extends the past listings to work reported in the 1983 calendar year.

The reported research was done by personnel at Sandia or at universities or industry under contract to Sandia. The major support of this work was provided by the Department of Energy Division of Geothermal Energy.

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I. GEOTHERMAL TECHNOLOGY

Introduction

The U. S. Department of Energy-sponsored program in geothermal drilling and completion research and development is managed by Sandia National Laboratories. The program objective is to conduct long-range R&D aimed at developing advanced geothermal drilling and completion systems to expand resource utilization. The technical program is organized into four broad categories: 1) Rock Penetration Mechanics, 2) Fluid Technology, 3) Borehole Mechanics, and 4) Diagnostics Technology. In addition to these R&D activities, considerable effort is made to insure that the program is properly focused and emphasizes the most important factors. This effort is broadly classified as systems analysis.

Research in Rock Penetration Mechanics is directed toward a basic description of rock penetration by advanced drilling systems. Ongoing research projects include: studies of the behavior of polycrystalline diamond compact (PDC) cutters in relation to rock fracture and wear mechanisms, improved carbide materials, cavitating jets, and percussion drilling.

The general goal of the Fluid Technology research is to develop drilling fluids specifically tailored to solve the problems encountered in geothermal drilling. The projects include the study of properties of aqueous foams which could be used as drilling fluids and the temperature and chemical effects on drilling clays. Also included are studies aimed at improving the cleaning of the hole and the removal of debris.

The R&D in Borehole Mechanics addresses the problems of lost circulation and lining and cementing the well, as well as problems of production maintenance such as perforating and scale removal. An unique high temperature lost circulation-cementing test facility has been constructed which will provide data on advanced materials and techniques for controlling lost circulation and cementing casing.

Diagnostics Technology research is aimed at developing high temperature capabilities for well-logging equipment and instrumentation. This program element also includes research into areas aimed at increasing the capability to measure and evaluate downhole conditions. The tools and techniques developed as a part of this effort are basic support devices for the other program elements, yielding definition of the downhole environment for better system definition.

The Systems Analysis section lists publication of generic interest which apply to the program planning and program management tasks.

This entire section lists specific reports and technical papers which have been published in support of the Geothermal Technology Development Program. This effort supports one of the important program aspects, namely, technology transfer to private industry.

1 1

A. Rock Penetration Mechanics

SUBSURFACE DAMAGE DEVELOPMENT IN ROCK DURING DRAG-BIT CUTTING: OBSERVATIONS AND MODEL PREDICTIONS, SAND82-2505C, D. H. Zeuch, D. V. Swenson and J. T. Finger, Sandia National Laboratories, Proceedings, 24th U.S. Symposium on Rock Mechanics, June 20-23, 1983, College Station, Texas.

As part of a program to develop new technology for the reduction of well-drilling costs, we have conducted a series of single-cutter drag-bit tests on specimens of Tennessee Marble and Westerly Granite. Despite substantial differences in the mechanical properties of these two rock types, particle morphologies indicate that the same mechanism is responsible for chip formation in each case. Tested specimens were either vacuum-impregnated with dyed epoxy or imbibed with fluorescent dye penetrant, then sectioned, and examined optically to study the development of subsurface damage. The subsurface fracture patterns constitute a characteristic "signature" which can be used to validate numerical models designed to simulate the rock-cutter interaction and the chip formation process. We show that qualitative agreement exists between observed damage patterns and predictions of a two-dimensional finite element code. Surprisingly, however, results of single-cutter tests on "conditioned" (i.e., precut) specimens indicate that the development of subsurface damage has little influence on the strength of the rock in subsequent passes of the cutter.

WEAR MECHANISMS FOR POLYCRYSTALLINE DIAMOND COMPACTS AS UTILIZED FOR DRILLING IN GEOTHERMAL ENVIRONMENTS-FINAL REPORT, SAND82-7213, Louis E. Hibbs, Jr. and George C. Sogoian, General Electric, under contract to Sandia National Laboratories.

This technical report covers the work performed by the General Electric Company, Corporate Research and Development, for Sandia National Laboratories on Contract Number 13-9406. The work, which was performed in the period from December 6, 1979 to September 30, 1981 included 1) rock cutting experiments with single point polycrystalline sintered diamond compact (PDC) cutters to quantitatively determine cutter wear rates and identify wear modes, 2) PDC rock cutting experiments to measure temperatures developed and examine the effects of tool wear, cutting parameters and coolant flowrates on temperature generation, 3) assisting the Drilling Technology Division, Sandia National Laboratories, in performing full-scale laboratory drilling experiments with PDC bits, using preheated air to simulate geothermal drilling conditions, and in analyzing and reporting the experimental results, and 4) acting in a

consulting role for the Drilling Technology Division to interact with Christensen, Inc., Salt Lake City, Utah, with the purpose of establishing design specifications for geothermal hard matrix PDC bits to be procured by Sandia Laboratories for test purposes.

The supplementary technical report covers the work performed by the General Electric Company, Corporate Research and Development, for Sandia National Laboratories on Contract Number 13-9406 during the period from November 1, 1981 to July 11, 1982. This work consisted of additional experiments added to the program to expand the scope of and complement the polycrystalline diamond compact (PDC) cutter wear and temperature measurements that were part of the original (Phase I) contract. These Phase II tasks included 1) measurements to determine the friction coefficients of preworn PDC cutters on various rock using different fluids (coolants) and 2) expansion of the original PDC cutter temperature measurements to include tests at much higher (5 m/s) rock cutting speeds and the addition of two additional rock types (shale and sandstone) to the original marble tests. The primary purpose of both Phase II tasks was to provide additional experimentally determined information to Sandia Laboratories for support of Sandia's programs to develop models of heat flow and wear of PDC cutter used for drilling applications.

MODELING AND ANALYSIS OF DRAG BIT CUTTING, SAND83-0278, D. V. Swenson, Sandia National Laboratories.

This report documents a finite element analysis of drag bit cutting using polycrystalline diamond compact cutters. To verify the analysis capability, prototypic indentation tests were performed on Berea Sandstone specimens. Analysis of these tests, using measured material properties, predicted fairly well the experimentally observed fracture patterns and indentation loads. The analysis of drag bit cutting met with mixed success, being able to capture the major features of the cutting process, but not all the details. In particular, the analysis is sensitive to the assumed contact between the cutter and rock.

Calculations of drag bit cutting predict that typical vertical loads on the cutters are capable of forming fractures. Thus, indentation-type loading is probably one of the main fracture mechanisms during drag bit cutting, not the intuitive notion of contact between the front of the cutter and rock. The model also predicts a change in the cutting process from tensile fractures to shear failure when the rock is confined by in situ stresses. Both of these results have implications for the design and testing of drag bit cutters.

PROGRAM FOR THE IMPROVEMENT OF DOWNHOLE DRILLING MOTOR BEARINGS AND SEALS - FINAL REPORT, SAND83-7102, P. H. DeLaFosse, Drilling Research Labs.

This report summarizes the work completed during Phase V of the DOE/DGE "Program for the Improvement of Downhole Drilling Motor Bearings and Seals," Sandia National Laboratories Contract 74-6607.

Downhole motors require a bearing system to transfer the applied drilling weight from the non-rotating drill string to the bit. The bearing system must be lubricated with an oil having very good anti-wear properties. Seals are required to retain the oil and prevent drilling fluid from contaminating the lubricant. The seal must also resist the bit pressure drop; high bit pressure drops are desirable because they greatly increase the rate of penetration. In geothermal operation, the seals, bearings, and lubricant must also withstand higher bottomhole temperatures. The specific objectives of this program were therefore established as follows:

1. Develop a lubricated bearing pack with a life in excess of 200 hours;
2. Develop an improved rotary seal which allows bit pressure drops in excess of 1000 psi; and
3. Develop a bearing seal package to operate at 250°F circulating bottomhole temperatures.

In the previous four phases of the program, the test facilities were designed and constructed, and extensive testing and development were accomplished. These efforts are summarized in Appendix C; additional information is available in prior annual reports, listed in the Bibliography.

The Phase V efforts were as follows:

1. The seal test machine was modified to allow testing with mud.
2. A mud pumping system was added to the Bearing Seal Pack Test Facility to enable long-term testing.
3. Tests were run on second and third generation elastomeric seals, second and third generation spring-loaded U-section teflon seals, and two types of face seals.

4. High-temperature load-capacity tests were run on a second generation lubricating oil with reduced viscosity.
5. New floating pistons were designed and fabricated, and tested in conjunction with Bearing-Seal package tests.
6. Shaft materials and finishes for radial seals were evaluated.

The report contains four major sections: Seal Testing and Evaluation, Bearing-Seal Package Testing and Evaluation, Lubricant Testing and Evaluation, and Bibliography.

THE THERMAL RESPONSE OF POLYCRYSTALLINE DIAMOND COMPACT CUTTERS UNDER SIMULATED DOWNHOLE CONDITIONS, SAND83-0489C, D. A. Glowka and C. M. Stone, Sandia National Laboratories, SPE Annual Technical Conference, San Francisco, CA, October 5-8, 1983.

A numerical-analytical method is developed to predict temperatures in polycrystalline diamond compact (PDC) drag cutters under steady state and transient downhole conditions. The method is used to determine mean wearflat temperatures for cutters under conditions used in previous experiments to measure cutter wear. A correlation between wearflat temperatures and cutter wear rates is demonstrated, and it is shown that, for the particular rock type tested, cutter wear rates increase significantly above 350°C. The concept of critical weight-on-bit, above which wearflat temperatures exceed this value, is introduced. The effects of several parameters on the critical weight-on-bit are examined, including cutter thermal conductivity, diamond layer thickness, rock properties, convective cooling, bit balling, and transient events such as bit bounce. Preliminary results of thermal stress modeling show that yielding of the cutter structure can occur under certain downhole conditions.

DEVELOPMENT OF A NEW FAMILY OF CEMENTED CARBIDES FOR GEOTHERMAL DRILLING, SAND 83-7435, D. J. Rowcliffe, SRI.

This project was a screening study to fabricate and evaluate a range of cemented carbides based on niobium carbide, NbC_x , and tantalum carbide, TaC_x , (where x is 0.83 to 1) with cobalt and nickel binders for use as rock-bit inserts in geothermal drilling. A major goal was to explore the influence of

carbon content on selected mechanical properties of the cemented carbides. Most test materials were made by hot pressing, but exploratory work indicated that these cemented carbides could also be produced by cold pressing and sintering. Processing variables that were studied included milling conditions, hot pressing time, pressure, and temperature. The fabrication studies showed that the lowest porosities and most uniform microstructures were obtained in the $\text{NbC}_x\text{-Co}$ System, and much of the study focused on these materials.

Hardness, fracture toughness, and abrasive wear resistance were measured and compared with data for cemented WC bit materials. For a given weight fraction of binder, stoichiometric NbC-Co was harder than the other experimental stoichiometric cemented carbides, and the substoichiometric material $\text{NbC}_{0.8}\text{-10Co}$ was substantially harder than the equivalent stoichiometric alloy. The most significant toughness result was that, for a given hardness, the fracture toughness of $\text{NbC}_{0.83}\text{-Co}$ was greater than that of stoichiometric NbC-Co . From these data, it was concluded that carbon content exerts a strong influence on the properties $\text{NbC}_x\text{-Co}$ materials and that, by adjusting the carbon content of the carbide, it is possible to obtain simultaneous improvements in hardness and toughness in this system.

Abrasive wear tests showed that the wear-resistance of $\text{NbC}_x\text{-Co}$ lies within the range of wear resistance of grades of WC-Co commonly used for rock cutting. Examination of wear surfaces indicated that both phases in $\text{NbC}_{0.83}\text{-10Co}$ wear at a relatively even rate and that material is removed by a process primarily related to plastic flow, rather than microfracture.

INVESTIGATION OF THE POTENTIAL FOR USING ELECTROCHEMICAL TECHNOLOGY TO REDUCE DRILL BIT WEAR, SAND 82-0896, Thomas E. Hinkebein and David A. Glowka, Sandia National Laboratories.

Recent work has shown that an important drill bit wear mechanism in aqueous environments is electrochemical in nature. The synergistic effects of corrosion and abrasion are responsible for a large percentage of bit wear in laboratory studies. It has been shown that measured wear rates can be reduced by factors of two to five with the application of a voltage potential which opposes and exceeds the galvanic potential generated by the corrosion cells existing downhole. The present study investigates the potential for applying this technique in the downhole environment. The results demonstrate that a downhole generator sub powered by drilling fluid is a possible electrical power source. Graphite is chosen as the optimal nonsacrificial anode material for this application.

Steel is also shown to be a possible anode material, but the anode would be sacrificial in this case, requiring periodic replacement. The electrical power required to achieve the desired effect for a 4-1/2 inch drill bit is determined to be on the order of one milliwatt. Additionally, up to 250 feet of 4 inch drill pipe could be protected from corrosion with power levels on the order of 150 milliwatts. These relatively low power levels suggest that dry cell batteries could alternatively be employed as the power source; however, the temperature limitations of commercially available batteries would have to be overcome for geothermal applications.

OPTIMIZATION OF BIT HYDRAULIC CONFIGURATIONS, David A. Glowka, Sandia National Laboratories, Soc. Petrol. Engr. Journal, February 1983, p. 21.

Measurements of flow field characteristics across the face of a study-mounted PDC bit have been obtained in a new test facility which simulates downhole flow fields. This facility and the measurement techniques employed to obtain the data are described. Flow tracer tracking and cutter heat transfer coefficient measurements are shown to be valuable in determining flow field characteristics, whereas the utility of the dye injection system tested is low. Three hydraulic configurations for the bit have been tested to determine the effects of nozzle location on bottomhole crossflow velocities and cutter cooling rates. The configuration that provides higher velocities and cooling rates is determined to be the one that employs smaller nozzles located near the center of the bit.

DIFFUSION BONDING OF STRATAPAX FOR DRILL BITS, SAND 82-2309, John N. Middleton and John T. Finger, Sandia National Laboratories.

A process has been developed for the diffusion bonding of General Electric's Stratapax (Registered trademark of General Electric) drill blanks to support studs for cutter assemblies in drill bits. This report describes the diffusion bonding process and provides bond strength test data for a variety of materials. The extensive process details, provided in the Appendices, should be sufficient to enable others to successfully build diffusion-bonded drill bit cutter assemblies.

IMPLEMENTATION OF TWO GEOLOGIC CONSTITUTIVE MODELS IN THE HONDO
FINITE ELEMENT CODE, SAND 83-0238, Daniel V. Swenson, Sandia
National Laboratories.

Two constitutive models for use with geologic materials have been incorporated into the HONDO finite-element program. Both models have the same behavior in tension, using a stress criterion to form cracks normal to the maximum principal stress. In compression, the two models give upper and lower bound solutions to the unconfined post-failure strength. The first model uses a Coulomb criterion to form explicit shear cracks, while the second model uses an elastic-plastic formulation developed by Krieg. Two sample applications, an indenter test and fracture of a borehole, are presented.

RESEARCH AND DEVELOPMENT OF IMPROVED CAVITATING JETS FOR
DEEP-HOLE DRILLING, V. L. Johnson, Hydronautics, Inc., under
contract to Sandia National Laboratories, SAND 83-7461

Improved cavitating nozzles have been developed as part of an ongoing program to increase the rate of penetration of deep-hole drill bits. Based on the four criteria of: incipient cavitation number, amplitude of pressure fluctuation (and hence enhanced structuring of the jet flow), rock cutting, and cleaning chips from the hole bottom -- these new, "STRATOJET" (STRuctured Acoustically Tuned Oscillating JET) cavitating nozzle systems have out-performed both conventional drill bit nozzles and the basic CAVIJET^(R) cavitating jets. Although nozzle designs which provide large amplitude pressure modulations are now available for the operation in water, additional research is needed to optimize self-resonating jets for use: (a) in mud, (b) in specific drill bit designs, and (c) at higher system pressures than now currently used for deep-hole drilling.

B. Fluid Technology

EVALUATION OF AQUEOUS FOAM SURFACTANTS FOR GEOTHERMAL DRILLING FLUIDS, SAND83-0584, P. B. Rand, O. J. Montoya, Sandia National Laboratories.

Aqueous foams are potentially useful drilling and cleanout fluids for geothermal applications. Successful use of foams requires surfactants (foaming agents) that can survive in the high temperature geothermal environment. In this study, solutions of aqueous foam forming surfactants have been exposed to 260°C (500°F) and 310°C (590°F) in various chemical environments to determine if they can survive and make foams after exposure. Comparison of foams before and after exposure and the change in solution pH were used to evaluate their performance. Controlled liquid volume fraction foams, made in a packed bed foam generator, were used for all tests. These tests have shown that many commercially available surfactants can survive short high-temperature cycles in mild acids, mild bases and salt solutions as evidenced by their ability to make foams after exposure to high temperatures.

A QUASI-STEADY MODEL FOR PREDICTING TEMPERATURE OF AQUEOUS FOAMS CIRCULATING IN GEOTHERMAL WELLBORES, SAND 82-0899, Bennie F. Blackwell and Alfonso Ortega, Sandia National Laboratories.

A quasi-steady model has been developed for predicting the temperature profiles of aqueous foams circulating in geothermal wellbores. The model assumes steady one-dimensional incompressible flow in the wellbore; heat transfer by conduction from the geologic formation to the foam is one-dimensional radially and time-dependent. The vertical temperature distribution in the undisturbed geologic formation is assumed to be composed of two linear segments. For constant values of the convective heat-transfer coefficient, a closed-form analytical solution is obtained. It is demonstrated that the Prandtl number of aqueous foams is large (1000 to 5000); hence, a fully developed temperature profile may not exist for representative drilling applications. Existing convective heat-transfer coefficient solutions are adapted to aqueous foams. The simplified quasi-steady model is successfully compared with a more sophisticated finite-difference computer code. Sample temperature profile calculations are presented for representative values of the primary parameters. For a 5000 ft. wellbore with a bottom hole temperature of 375°F, the maximum foam temperature can be as high as 300°F.

C. Borehole Mechanics

LOST CIRCULATION IN GEOTHERMAL WELLS: RESEARCH AND DEVELOPMENT STATUS, SAND83-1312C, B. C. Caskey and G.E. Loeppke, Sandia National Laboratories, Geothermal Resources Council 1983 Annual Meeting, Portland, Oregon, October 24-27, 1983.

Three of the most common severe problems encountered in drilling and completing geothermal wells are lost circulation, stuck pipe, and inadequate cementing. Since lost circulation may cause or aggravate the other problems, it is considered the single most serious well development problem. Sandia National Laboratories has initiated a multi-faceted program directed at understanding and helping to solve this problem. The program involves characterizing loss zones, developing an analytic fluid dynamics model of zone plugging, screening lost circulation materials in the laboratory and testing some solutions in a large scale test facility. The status and plans for this program are presented.

A FULL-SCALE FACILITY FOR EVALUATING LOST CIRCULATION MATERIALS AND TECHNIQUES, SAND 83-1311C, G. E. Loeppke and B. C. Caskey, Sandia National Laboratories, Proceedings, Geothermal Resources Council 1983 Annual Meeting, Portland, Oregon, October 24-27, 1983.

Lost circulation is often a problem during well drilling and completion, and can be especially severe in naturally fractured geothermal formations. Sandia National Laboratories has designed and built a full-scale facility for the evaluation of lost circulation materials and techniques under simulated down-hole geothermal wellbore conditions. System capabilities include a maximum temperature of 400°F, maximum allowed working pressure of 1150 psi, and a variable pumping rate up to 280 gpm at 1000 psi. The system will be utilized to evaluate candidate lost circulation materials and techniques that may be useful to solving geothermal well drilling lost circulation problems.

D. Diagnostic Technology

A WELLBORE INERTIAL NAVIGATION SYSTEM, SAND82-1711C, James R. Kelsey, Sandia National Laboratories, Proceedings, IADC/SPE 11359, 1983 Drilling Conference, Society of Petroleum Engineers and International Association of Drilling Contractors, February 20-23, 1983, New Orleans, Louisiana.

This paper describes a prototype wireline tool which includes a downhole inertial platform and a surface computer to spatially map a well. The hardware is basically a single-gimbaled inertial platform with accelerometers and gyros to obtain three-axis motion information. The gyroscope and accelerometer output are transmitted to a computer at the surface which calculates probe attitude relative to north, east, and vertical. Double integration of the accelerometer data provides the position information. A conventional seven-conductor wireline is used for the system data transmission.

System accuracy is enhanced by advances made in the computer software which processes the data received from the tool. The software uses statistical sampling techniques to obtain optimal estimates of the system errors. These errors are periodically "subtracted" from the data. This procedure, known as Kalman filtering, results in increased accuracy of the data.

This new wellbore survey system promises to increase mapping accuracy by at least a factor of ten. Present mapping systems have an X-Y-Z location accuracy of ± 100 to ± 200 feet for a typical well depth of 10,000 feet. Our test results show that the new system is accurate to about ± 1 foot per 1000 feet of well depth.

Unlike conventional systems, the inertial navigator does not require any sort of projection of the cable length (which may not be accurately known). Also this system provides continuous data throughout the wellbore and logging speeds on the order of 10 ft/sec appear possible.

This paper will describe the hardware and software associated with this mapping system and will report the recent field test results. These field tests in a 7000 foot well in Nevada verified laboratory estimates of increased accuracy.

DEVELOPMENT OF A GEOTHERMAL ACOUSTIC BOREHOLE TELEVIEWER, SAND83-0681, F. E. Heard and T. J. Bauman, Sandia National Laboratories.

Most geothermal wells are drilled in hard rock formations where fluid flow is through systems of open fractures. Productivity of these wells is usually determined by the extent of intersec-

tion of the wellbore with the fracture systems. A need exists for fracture mapping methods and tools which can operate in a geothermal environment. In less hostile environments, the acoustic borehole televiewer has been shown to be a useful tool for determining location, orientation, and characterization of fractures as they intersect the borehole and for general wellbore and casing inspection. This report describes the development conducted at Sandia National Laboratories to adapt an acoustic borehole televiewer for operation in a geothermal environment. The modified instrument has been successfully tested at temperatures as high as 280°C and pressures up to 5000 psi, and used successfully to map fractures and casing damage in geothermal wells.

A HIGH-TEMPERATURE PROTOTYPE INSTRUMENT FOR DOWNHOLE ACOUSTIC SENSING, SAND82-2952C, Hsi-Tien Chang, Sandia National Laboratories, 1983 International Geoscience and Remote Sensing Symposium, San Francisco, CA, August 31-September 2, 1983.

This paper presents the design for an acoustic instrument which can operate at frequencies of 10-40 KHz and temperatures up to 250°C. It first introduces a high-temperature circuit using Sandia's Sprytron switching tube and Krytron over-voltage gap. Next, the high-temperature performance of a 2 V Permendur magnetostrictive transducer (for the transmitter), and a piezoelectric material (for the receiver) is described. The problems encountered and the corresponding solutions are revealed. The design of an acoustic isolator and the mechanical housing of this instrument are presented. Finally, applications for such an instrument are addressed.

FIELD PATTERNS FOR ANTENNAS SITUATED IN A SIMULATED BOREHOLE, SAND 83-2673, Larry D. Scott, Mission Research Corporation, and Hsi-Tien Chang, Sandia National Laboratories.

The need for improved detection range and directional resolution for pulsed electromagnetic radar type downhole probes, can be satisfied by the construction of simple antennas optimized to produce the narrowest beam widths and the lowest side lobes while being designed to physically fit within the confines dictated by the borehole diameter. Until now, no measurements have been reported of the field patterns for the eccentrically located dipole or monopole within a high dielectric constant media. However, Lytle and Laine have made theoretical predictions.

The reasons for selecting a high dielectric constant media within the confines of the borehole are twofold. First, the borehole is likely to be filled, at depths of primary interest, with water (high relative dielectric constant, 80), hence to minimize the number of discontinuities traversed by the radar pulse the antenna should be immersed in a similar dielectric constant media. Secondly, a directional antenna design is enhanced by the electrical length shortening factor afforded by the antenna immersed in the media. To effectively control an antenna array pattern, separation distances on the order of element lengths are needed. The presence of water then, as the dielectric in which the array elements are immersed, permits a relatively higher gain (improved directional) antenna to be designed within the confines of a water or brine filled borehole with minimal electrical discontinuities to scatter the radar energy.

E. Systems Analysis/Program Summaries

GEOHERMAL DRILLING -- PROBLEMS AND SOLUTIONS, SAND83-1219C, J. R. Kelsey, Sandia National Laboratories, 1983 Winter Meeting of ANS, San Francisco, CA, October 30- November 4, 1983.

Geothermal wells represent approximately 50% of the cost of generating electricity from geothermal resources; typical wells cost \$2 M to \$3 M. This paper describes some of the problems which lead to these high costs and outlines some of the solutions which are being studied by the geothermal industry and the national laboratory research programs. Specific discussions of drilling fluids, advanced drilling methods, and down-hole diagnostic hardware are presented in the paper.

GEOHERMAL WELLS - THE COST BENEFIT OF FRACTURE STIMULATION ESTIMATED BY THE GEOCOM CODE, SAND83-7440, G. L. Brown, the BDM Corp., and C. C. Carson, Sandia National Laboratories.

In the development of many geothermal reservoirs it has been common to encounter production wells in which either there is insufficient flow of geothermal fluids or flow cannot be started at all, even though the wellbore itself is free of problems that would impede flow. Attempts to increase flow from such wells are categorized as "well stimulation techniques" and commonly include:

1. Redrilling the well (e.g., to deepen or underream it, or to drill a new leg).
2. Pumping the well.
3. Treating the producing formation with chemicals (e.g., acid washing).
4. Fracturing the producing formation.

A sometimes viable alternative is to abandon the existing well (perhaps converting it to an injector) and to drill a new production well. In determining which technique to use, it is important to estimate both the cost and the effectiveness of each option. This report examines the costs and effectiveness of fracture stimulation.

THE COST EFFECTIVENESS OF FRACTURE STIMULATION IN INCREASING THE FLOW FROM GEOTHERMAL WELLS, SAND 83-7439A, Gerald Brown, The BDM Corporation. Proceedings, 9th Annual Workshop on Geothermal, Palo Alto, California, December 13-15, 1984.

GEOCOM, a computer code for analyzing the impact of completion activities on the life-cycle costs of geothermal wells, was used to study fracture stimulation at the Geysers, the Imperial Valley, and other geothermal resource areas in the United States. Technologies for fracturing the reservoir near the wellbore involve the creation of a pressure pulse in the wellbore by means of either hydraulic or explosive force. The cost of a single fracture stimulation job can vary from \$50,000 to over \$500,000, with typical cost by around \$300,000. The code shows that additional flow achieved by fracture stimulation must exceed five tons per hour for each \$100,000 invested in stimulation in order for a fracture treatment to be cost effective. In some reservoirs, the additional flow must exceed fifteen tons per hour. The cost effectiveness of fracturing has not yet been demonstrated in the field. The Geothermal Well Stimulation Program achieved an overall average of about four tons per hour for each \$100,00 invested.

II. AUTHOR LISTING

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