

Conf-950494--1

SAN095-03310

Advanced Drilling Systems Study

CONTRACT INFORMATION

Contract Number DE-AC04-94AL85000

Contractor Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0419

Other Funding Sources U. S. Department of Energy
Geothermal Division EE-122
Energy Efficiency and Renewable Energy
1000 Independence Ave.
Washington, DC 20585

Contractor Project Manager James C. Dunn

Principal Investigators Kenneth G. Pierce
Billy J. Livesay, Livesay Consultants

METC Project Manager Albert B. Yost II

Period of Performance September 1994 to Spring 1995

INTRODUCTION

This work was initiated as part of the National Advanced Drilling and Excavation Technologies (NADET) Program. It is being performed through joint funding from the Department of Energy Geothermal Division and the Natural Gas Technology Branch, Morgantown Energy Technology Center.

Interest in advanced drilling systems is high. The Geothermal Division of the Department of Energy has initiated a multi-year effort in the development of advanced drilling systems; the National Research Council completed a study of drilling and excavation technologies last year; and the MIT Energy Laboratory recently submitted a proposal for a national initiative in advanced drilling and excavation research. The primary

reasons for this interest are financial. Worldwide expenditures on oil and gas drilling approach \$75 billion per year. Also, drilling and well completion account for 25% to 50% of the cost of producing electricity from geothermal energy. There is incentive to search for methods to reduce the cost of drilling.

Work on ideas to improve or replace rotary drilling technology dates back at least to the 1930's. There was a significant amount of work in this area in the 1960's and 1970's; and there has been some continued effort through the 1980's. Bill Maurer documented much of this effort in two books: *Novel Drilling Techniques*, published in 1968 (ref. 1), and *Advanced Drilling Techniques*, published in 1980 (ref. 2).

MASTER

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Undoubtedly there are concepts for advanced drilling systems that have yet to be studied; however, it is almost certain that new efforts to initiate work on advanced drilling systems will build on an idea or a variation of an idea that has already been investigated. Therefore, a review of previous efforts coupled with a characterization of viable advanced drilling systems and the current state of technology as it applies to those systems provide the basis for the current study of advanced drilling.

A SYSTEMS APPROACH

Nearly all studies of advanced drilling systems concentrate on methods of reducing rock. There is often little or no discussion of how these methods would fit into the full system necessary to drill, maintain, and complete a well. Unless the entire system is considered, much effort and money could be spent improving specific aspects of drilling technology only to discover that other facets of the problem prevent successful deployment of the system. Consequently, this study has not just investigated novel methods for reducing rock, but has examined all aspects of drilling systems necessary to make and complete a well.

Table 1 identifies six basic functions that must be performed by all drilling systems. The last function, preservation of the borehole, includes completion, i.e. casing and cement. This is not a necessary function in the sense that a well could be drilled without completion. However, completion is considered a basic function for two reasons:

1. Completion is necessary for a well to be of any use, and
2. Completion is a significant well cost.

In addition to the functions listed in Table 1, there are a number of constraints imposed on

Table 1. Basic Drilling Functions

- Transmission of energy to the system-rock interface
- Reduction of the rock
- Removal of the rock
- Maintenance of the borehole
- Control of formation fluids
- Preservation of the borehole

all viable drilling systems. For instance, environmental impact must be considered. The system footprint, any emissions to the local environment, and the control of hazardous materials cannot be ignored. Similarly, operational safety must be weighed. Also, all viable systems must be capable of directional control and must have some capability for sensing and communication with the operator. These constraints are summarized in Table 2.

Table 2. Drilling System Constraints

- Environmental impact
- Operational safety
- Directional drilling and control
- Sensing and communication

While we have classified drilling systems according to cutting mechanism in this study, we have analyzed the systems according to how they perform the functions listed in Table 1 under the constraints given in Table 2.

STUDY GOALS

The purposes of this study are to provide information that will help policy makers and project managers make decisions concerning the development of advanced drilling systems, and to update the history and determine the current status of research in advanced drilling. To accomplish these purposes, the objectives listed in Table 3 have been identified.

Table 3. Study Objectives

- Provide system descriptions
- Estimate capital and operating costs
- Assess system performance
- Identify common problems
- Outline possible development programs

In addition to the basic description defined by the drilling functions and constraints, particular capabilities and advantages of various systems have been identified, and technical as well as financial limitations have been studied for each system.

The development of estimates of the capital and operating costs is ongoing. Estimating the cost of equipment that exists in concept only is an uncertain operation at best. However, much of the equipment associated with advanced drilling systems is common to current technology. This commonality will have the effect of reducing the uncertainty in the overall system cost estimates.

Performance assessment for most systems is difficult. The stage of development varies dramatically from concept to concept. There is little data, other than that collected in laboratory bench tests, associated with many of the concepts that are under consideration. It is neither easy nor accurate to extrapolate expected performance characteristics from such data. For many concepts, the best that can be done is an order-of-magnitude estimate of the expected rate-of-penetration (ROP). Performance assessment for some systems consists of an estimate of the necessary performance in order for the system to compete with current technology.

Because of the systems approach taken in this study, we have identified a number of problems and needs that are common to several advanced drilling systems. These are discussed later in this paper.

The last objective listed in Table 3 is to identify the technical problems and needs of the various concepts and assess the likelihood of successfully solving these problems.

STUDY PROGRESS

In consultation with the sponsors, we have determined the systems and concepts for study and have developed system descriptions. We have defined the equipment and material requirements for each system by function as well as by source (i.e. capital, rental, service, expendable).

We have also conducted a survey of the industry. The discussions in this survey consisted of one or more of the following topics:

1. Study direction and organization,
2. Previous work performed on advanced drilling in general or one of the concepts in particular, and
3. Ongoing efforts in the area of drilling research.

We have collected a significant amount of data concerning the capital and operating costs associated with drilling. The analysis of these data is ongoing.

DRILLING CONCEPTS

Table 4 lists the concepts, sorted by cutting mechanism, that have been studied. This list was developed to cover the range from current technology, through ongoing efforts in drilling research, to highly speculative concepts. Included are cutting mechanisms that induce stress mechanically, hydraulically, and thermally.

The initial analyses of rig capital and operating costs indicate that it is not possible to build a new rig and operate at a profit given current rates. Rig rates today are artificially low

**Table 4. Systems and Concepts:
Sorted by Cutting Mechanism**

- Baseline technology
- Emerging technology
- Rotary-assisted drilling
 - jet-assist
 - projectile-assist
 - spark-assist
 - thermal-assist (microwave)
- Mud hammer
- Thermal spallation jet
- High-pressure jet
 - abrasive jet
- Spark
- Explosive
- Pulsed-laser water-jet
- Plasma arc
- E-beam
- Laser thermal
- Subterrene (rock melting)

due to excess equipment and low demand. Thus, it is necessary to estimate the true costs of current and emerging technology, and the resultant day rates, as a basis for equitable comparisons to the expected day rates of other systems.

Most, if not all, of the concepts listed in Table 4 will be familiar to anyone who has followed the efforts in the development of novel drilling systems. The only concept less than twenty years old is the pulsed-laser water-jet that is being developed by Powerpulse Systems of Lakewood, CO (ref. 3). An unusual aspect of this system is the use of the laser. We generally think of lasers as thermal sources. However, with this system, the laser is being used to impart a mechanical impulse to the rock.

Many of the concepts listed in Table 4 are currently being studied or developed. At least three companies; FlowDril in Kent, WA (refs. 4 through 9), Maurer Engineering in Houston, TX, and Drilling Technology in Plano, TX (refs. 10

and 11); are actively pursuing jet-assisted drilling. Tround International of Washington, DC, has an operational projectile-assisted drilling system (refs. 12 and 13). Both Tetra Corporation (ref. 14) in Albuquerque, NM, and the Twin Cities Research Center of the U.S. Bureau of Mines in Minneapolis, MN, are studying the use of spark discharge for reducing rock. The Twin Cities Research Center also has recently been active in the following areas:

1. The use of lasers for cutting kerfs,
2. The use of microwave energy to alter properties and aid the mechanical destruction of rock (ref. 15), and
3. The use of chemicals for modification of rock properties.

Novatek in Provo, UT, has an operational mud hammer (ref. 16). In conjunction with MIT, Los Alamos National Laboratory in Los Alamos, NM, has been studying thermal spallation under a full column of liquid (ref. 17). Los Alamos National Laboratory also has a program studying the use of a rock melting system for environmental drilling (ref. 18).

In addition to systems built around the rock-cutting mechanisms listed in Table 4, we have also looked at the capability of other approaches to reduce drilling costs. Included are underbalanced drilling, coiled tubing, reduced casing sizes, and chemical modification of rock properties.

COMMON PROBLEMS

This study has taken a systems approach to avoid overlooking some facet of the problem that would prevent successful deployment of the system. However, there has been another consequence of the systems approach: we have identified a number of common problems that run

across multiple systems. Table 5 lists some of these common problems and needs in two groups.

Table 5. Common Problems and Needs

- Multi-channel conduit (gas/liquid/electrical)
 - Electric conduit downhole
 - Maintenance of the borehole gage
 - Controllable thruster/retractor/director for the drilling head
-
- Reduced rate-of-penetration with depth
 - Well control and wellbore stability in the absence of liquids
 - Methods to reduce the size of the surface system

The first group might be considered engineering problems; since, in many cases, technical solutions have been found, but these solutions have proven impractical. The second group is more fundamental in nature.

ENGINEERING PROBLEMS

A number of the systems under consideration require multiple conduits for the transmission of different fluids and/or electrical energy. Multi-conduit pipe can be manufactured. However, when compared to standard drill pipe, it is both heavy and expensive.

Problems with transmission of electrical energy downhole was one reason Sandia Laboratories quit working on spark drills twenty years ago. A number of systems would benefit from cheap and reliable methods to transmit electricity to the drill head. This is especially true of the high-energy systems listed in Table 4. Even rotary technology would benefit from such a development. A power cable would allow the use of electric motors as well as other tools that need electric power. A major impediment to the expansion of measurement-while-drilling systems is data transmission rate. The development of

fast, reliable telemetry would allow not only the use of current downhole sensors such as pressure, temperature, and formation evaluation tools; but also the development and use of systems to evaluate the condition of the bit, to detect kicks almost instantaneously, and to provide data for real-time analyses of downhole conditions. An electric cable would provide the necessary transmission capability for diagnostic, look-ahead, and other smart sensors.

While no practical method has been developed to make electrical connections at each joint when using drill pipe, electric cables can be run in coiled tubing. Coiled tubing sizes to 3.5-inch OD are currently available with 4.5-inch to 5-inch tubing expected in the near future. However, because of fatigue strength limitations, coiled tubing for drill pipe is currently restricted to about 2.375-inch OD. This size limits fluid flow and, hence, maximum hole size. The use of coiled tubing also requires the use of a mud motor which significantly increases the cost of operations. The inability to turn from the surface results in other disadvantages for coiled tubing.

Maintenance of borehole gage is a concern for nearly all of the system concepts that are not rotary hybrids. For a given set of conditions, the diameter of the hole created with high-pressure jets and thermal systems will depend largely on the advance rate of the drilling head. There is a minimum hole diameter needed for running casing. Above this minimum, though, excessive variation will cause problems when cementing the casing.

A number of systems require some type of downhole mount for the drilling head. This mount needs to be capable of controlling both rate and direction of advance of the drilling head. As with other problems listed in Table 5, the development of such a device would not only solve problems for novel rock reduction mechanisms, but would also be beneficial to rotary cutting technology.

FUNDAMENTAL PROBLEMS

While studying past efforts to develop novel drilling concepts, we have discovered instances where engineers claim that programs were terminated at least partially because of reduced cutting effectiveness at depth. These instances include the efforts with spark drills at Sandia Laboratories, the efforts with mud hammers at Amoco, and the efforts with high-pressure jets at Exxon. This suggests that there is still a need for better understanding of the effects of depth and fluid pressure on rock properties as they apply to drilling. But more importantly, it is clear that a first step in the development of any new drilling system should be to test the performance of the concept at depth. There are facilities capable of independently simulating pore pressure, rock stress, and borehole fluid pressure at depth. Unconventional rock-cutting concepts should be tested at one of these facilities prior to the expenditure of significant resources on system development.

A number of the concepts listed in Table 4 are unable to operate under a full column of liquid. While cuttings can be removed with air, the absence of drilling mud greatly inhibits the ability to control formation fluids and maintain borehole stability. Thus the applicability of any system that cannot operate in the presence of drilling mud is greatly diminished. The development of concepts such as temporary borehole lining, casing-while-drilling, or other methods to control formation fluids and maintain borehole stability in the absence of drilling mud would increase the viability of many concepts.

The last item in Table 5, methods to reduce the size of the surface system, is rather deceptively worded. For a land-based rig, the capital investment in the surface system is on the order of ten-million dollars. Investigation of the surface system reveals that little of it is dependent on the way rock is cut.

The sizes and specifications for the mast, substructure, and drawworks are determined by the need to handle casing, not by how the rock is cut. The requirements of the mud pumps, pits, and mud-cleaning equipment are determined by the need to remove the cuttings, not by how the cuttings are produced. Eliminating rotary drilling could reduce the load on the diesel-electric generators. However, energy must be supplied in some form for any rock-cutting system.

About the only equipment that depends on how we cut rock is the bottom hole assembly. It is doubtful that any novel rock cutting mechanism will cost less than drill collars, stabilizers, and bits. Overall, it is unlikely that significant savings in materials and equipment can be achieved by simply changing the way we cut the rock.

Similar conclusions are reached when daily operational costs are considered. The numbers and skills of the crew are determined by the surface equipment. Rig insurance is determined by capital investment; liability insurance and workman's compensation costs are dependent on payroll. Fuel charges vary with energy consumption.

Reduction of drilling costs can occur only by changing the nature of the surface system or increasing the rate of penetration. Neither capital investment nor daily operational costs are significantly affected by the way we cut rock. Any increase in capital or operating costs must be offset by a commensurate increase in penetration rate. Unconventional rock-cutting mechanisms can reduce costs only if they can increase the rate of penetration.

CONCLUSIONS

This study of advanced drilling systems is ongoing. The discussion in this paper summarizes the efforts to date. We have investigated a number of drilling concepts from a systems

perspective. We have achieved some preliminary insights particularly concerning common problems and requirements.

Preliminary analyses indicate that little of the cost of drilling is due to the way we cut rock. A large part of the capital and operating costs associated with drilling are determined by the nature and size of the surface system. Changes to the surface system to reduce these costs will not only help novel cutting mechanisms, but will also reduce the cost of drilling with current cutting technology. In addition to reductions in surface system, increasing rate of penetration can also reduce overall well costs. Novel cutting mechanisms that dramatically increase the rate-of-penetration may be beneficial, especially in hard-rock drilling.

It is emphasized that the results and discussions presented here are preliminary. A final report will be issued after completion of the cost and performance analyses.

Note: Work performed at Sandia National Laboratories is supported by the U.S. Department of Energy under contract DE-AC04-94AL8500

REFERENCES

1. William C. Maurer, *Novel Drilling Techniques*, Pergamon Press, Library of Congress No. 68-17738, 1968
2. William C. Maurer, *Advanced Drilling Techniques*, Petroleum Publishing Company, Tulsa, OK, ISBN 0-87814-117-0, 1980
3. John G. Sellar, *Rock Excavation Using a Pulsing Laser-Water Jet*, report prepared for the EPRI Center for Materials Production, Pittsburgh, PA, CMP report number 93-7, November 1993
4. Jeff Littleton, editor, *Jet Drilling Technology Advances*, Drilling, November/December 1987
5. Rich McNally, associate editor, *Increasing Penetration Rates with High-Pressure Mud*, Petroleum Engineer International, December 1987
6. Mike Killalea, editor, *High Pressure Drilling System Triples ROPS, Stymies Bit Wear*, Drilling, March/April, 1989
7. T. Butler, P. Fontana, and R. Otta, FlowDril Corp., *A Method for Combined Jet and Mechanical Drilling*, SPE paper 20460, September 1990
8. Mike Cure, Grace Drilling Co., and Pete Fontana, FlowDril Corp., *Jet-Assisted Drilling Nears Commercial Use*, Oil & Gas Journal, March 11, 1991
9. J. J. Kolle, QUEST Integrated Inc., and R. Otta and D. L. Stang, FlowDril Corp., *Laboratory and Field Testing of an Ultra-High-Pressure, Jet-Assisted Drilling System*, SPE paper 22000, March 1991
10. Frank J. Schuh, *MultiCon™ Drilling System Potential*, Drilling Technology, Inc., Plano, TX, February 1994
11. Frank J. Schuh, *MultiCon™ Drilling System Economics*, Drilling Technology, Inc., Plano, TX, January 1995
12. Robert J. Regan, *Mining Cannon is a Real Rockbuster*, Iron Age, June 24, 1983
13. Allen Howland, *Machine Gun Bit Speeds Air Drilling*, Drilling Technology, August 1984

REFERENCES (cont)

14. William M. Moeny and James G. Small, *Focused Shock Spark Discharge Using Multiple Electrodes*, U.S. Patent #4,741,405, May 1988
15. D. P. Lindroth, W. R. Berglund, R. J. Morrell, and J. R. Blair, U. S. Bureau of Mines, Minneapolis, MN, *Microwave-Assisted Drilling in Hard Rock*, SME nonmeeting paper 91-224, Mining Engineering, September 1992
16. David S. Pixton, Yu Xiangguang, Vance I. Fryer, Steven J. Payne, David R. Hall, *A New Generation Mud Driven Rotary Percussion Tool: Summary of Current Research and Development Efforts*, Second Ed., Novatek, Provo, UT, February 1990
17. Worldrill Corporation, *Improvements in or Relating to Drilling with Centrifuge/Vortex Combustion Jet Spallation*, British and Foreign Patent Application, continuation of patent application PCT/GB94/00515
18. Sue J. Goff, Gilles Y. Bussod, Kenneth Wohletz, Aaron Dick, and John C. Rowley, *Rock Melting: A Specialty Drilling System for Improved Hole Stability in Geothermal Wells*, Los Alamos National Laboratory, Los Alamos, NM

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
