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IMPROVED DRILLING - A PART OF THE ENERGY SOLUTION

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ABSTRACT

Future energy sources include fossil fuel, geothermal, magma, nuclear and solar. All of these sources except solar require large amounts of drilling to explore and produce. The cost of drilling is becoming so expensive, since most of the easy drilling has been done, that the economics involved may limit the amount of energy available for consumption. This increased cost of drilling is both creating pressure for new drilling techniques and making some older novel drilling techniques more attractive.

This paper substantiates the above statements, indicates the areas of needed research, and discusses some possible novel drilling approaches which could reduce the cost of future drilling.

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Need for Drilling

Most of our future energy will result from fossil fuel, geothermal, magma, nuclear and solar sources. All of these except perhaps solar require large amounts of drilling for both exploration and production. For example, the drilling done in the United States by the petroleum industry amounted to approximately 110 million feet in the first three quarters of 1974¹ and approximately 22 million feet² for the uranium industry. To meet future energy demands, significantly increased drilling is required as a correlation exists between new reserves found and footage drilled.

Drilling Capability

Most drilling is done today by the rotary drill method. The rotary cone bit was developed around the turn of the century and has been improved upon since then. It has drilled to 31,440 feet and through hard geological formations.³ One of its limitations is that it can only deliver between 50hp and 100hp to the rock to be drilled. This results in low drilling rates and correspondingly high drilling costs.

Drilling Costs

The cost of drilling goes up almost exponentially with depth. This can be seen in Figure 1 as the average costs of petroleum drilling in the United States is shown for 1972. With the pressure of inflation, and need for the wells to be deeper, today's costs are even higher. A recent well drilled in Alaska to a depth less than 14,000 feet was reported to have cost \$10.4 million.⁴ The deep wells in the Anadarko basin reportedly cost more than \$6 million each and are approximately 30,000 feet deep. Recent information of drilling rig costs in the North Sea indicate that they are as much as \$80 thousand a day. With the average predicted drilling cost of \$24 per foot, the drilling costs in just the United States for 1974 should be slightly greater than \$4 billions. Future drilling is even likely to cost more.

Figure 1

Future Drilling

When drilling is required in harder formations, such as drilling for geothermal or magma energy, the costs will be greater. Figure 2 shows the drilling rate comparison between a sedimentary and some basement type formations. As the drilling rate is reduced, the overall drilling expenses will be increased. In addition, high formation temperatures and high concentration brine solutions are likely to be encountered and these will probably add to the drilling costs. All of this indicates that future drilling costs will be higher and be a larger fraction of the energy costs.

Energy Relationship

Drilling will be a significant portion of future energy costs. These costs must be kept to a minimum so as to produce the marginal type energy resources. For example, an oil well that costs \$10 million to drill cost \$1 million per year interest at a 10% annual rate. If at least a 10% return on the investment is required, that is another \$1 million. At \$10 a barrel for oil, the well must produce 200,000 barrels per year to be a marginal well. This is a large amount of oil, yet this amount of energy may not be available for the consumer in the future if the cost of drilling is not reduced or the price of oil does

not go higher. Reducing the cost of drilling would probably be more popular than increasing the costs of energy.

THE EFFECT OF BIT LOADING ON PENETRATION RATE FOR VARIOUS ROCKS
LABORATORY DATA - ATMOSPHERIC PRESSURE.

Figure 2

Drilling System Approach

A measure of formation drillability is the amount of energy required to remove a given amount of rock. This is usually referred to as the specific energy of rock. When this specific energy is applied to drilling a given size hole at a given rate, the power required for drilling is defined. This relationship is a hyperbola:

$$(\text{DRILLING RATE})(\text{SPECIFIC ENERGY}) = \text{CONSTANT} .$$

This relationship has been graphically illustrated in Figure 3. As much of the present

drilling is done at 1 to 20 ft/hr, the specific energy is high. To improve the drilling rate either the energy must be more efficiently coupled to the rock or more power is required.

DRILLING RATE FOR 8-INCH-DIAMETER HOLE
VERSUS ROCK TOUGHNESS

Figure 3

Another way of looking at the drilling rate is the average drilling rate which includes life of bit, time to replace a worn bit, and the time to continue drilling while the bit is on bottom. This can be written as:

$$\text{Average Drill Rate} = \frac{\text{Distance Drilled Per Bit}}{(\text{Trip Time}) + (\text{Distance Drilled}) / (\text{Instantaneous Drill Rate}) + \text{Hookup Time}}$$

Using some established rules of thumb, numbers such as: 0.8 hr/1000 ft of depth for trip time, 1%/1000 ft of depth for instantaneous drilling rate reduction, and 0.2 hr/30 ft as the drill stem hookup time, the results shown in Figure 4 can be obtained. The two values shown were arbitrarily chosen, but do show that a high instantaneous drill system is desired over long bit life until the hole depth is greater than 16,000 feet.

DRILLING RATE VERSUS DEPTH

Figure 4

A more general expression can be developed to illustrate the drilling economics involved as a function of drill rate.⁵ Thus, by defining the parameters as:

T = trip time

C = rig cost/unit time

B = bit cost

L = bit life (time)

R = instantaneous drilling rate (distance/unit time)

$\bar{c}$ = rotating cost/unit length

Then $\bar{c} = \frac{(T + L) C + B}{RL} = \frac{C}{R} \left(1 + \frac{1}{K} \right)$ where K is $\frac{L}{T + B/C}$ (non-dimensional bit life).

Assuming that the bit life is an unspecified function of R and that T , B , and C are essentially independent of R , then:

$$\frac{R}{\bar{c}} \frac{d\bar{c}}{dR} = - \left\{ 1 + \frac{R}{K(K+1)} \frac{dK}{dR} \right\}.$$

The cost breakeven point is when $d\bar{c}/dR = 0$ and rearranging one has

$$-\frac{dR}{R} = \frac{dK}{K(K+1)}$$

Integrating this from initial rate (R_0) to the final rate (R) and from initial bit life (K_0) to final bit life (K):

$$-\int_{R_0}^R \frac{dR}{R} = \int_{K_0}^K \frac{dK}{K(K+1)}$$

yields

$$R/R_0 = (1 + 1/K)/(1 + 1/K_0)$$

Therefore, with a known value of K_0 , a cost breakeven curve (R/R_0 vs K/K_0) can be generated, Figure 5. For a given K_0 , any point above the appropriate curve represents a drilling cost improvement, while below the curve represents more expensive drilling. To illustrate the use of curves, suppose a drilling system has the following characteristics:

$L = 25 \text{ hrs}$	$T = 4 \text{ hrs}$	$R_0 = 25 \text{ ft/hr}$
$C = \$1000/\text{hr}$	$B = \$1000/\text{bit}$	

Then $K_0 = 5$ and $\bar{c} = \$48/\text{ft}$ for the rotating cost. Suppose a modification would allow a factor of two increase in drilling rate ($R/R_0 = 2$), what could be the sacrifice in bit life to be of equal economic value? Using the curve for $K_0 = 5$, a factor of 7 ($K/K_0 = 0.143$) reduction in bit life is allowed (see example 1, Figure 5). Any bit life that is better than $1/7 K_0$ will save money. Similarly, if a modification is made which will yield a factor of two increase in bit life ($K/K_0 = 2$), the drilling rate must be kept within 90% ($R/R_0 = .9$) to be economically equal (see example 2, Figure 5). The importance of higher drilling rates can be seen.

Higher instantaneous drilling rates are also desired from a total drilling system approach. With the need for more footage to be drilled per year, and with all available rigs now working (approximately 1700), it means that more rigs and crews are necessary if the drilling rate is not improved.⁶ This is not an easily achieved solution, even if economically feasible, because of the long delays in equipment orders and training of crews.

DRILLING COST BREAKEVEN

Figure 5

Desired Future Drilling Characteristics

One or more of the following characteristics would be desirable of a future drill bit: longer life, higher energy coupling efficiency or capability of transmitting more power, and one which would utilize the existing drill rigs. It is doubtful that the standard rotary rock bit will be significantly improved in the near future. This assumption is based upon the past long period of rotary bit development. Future bits can be much more expensive than the present bits if their performance is sufficiently improved.

This does not mean that the rotary bit has a limited future. However, a combination of drilling methods which incorporate the rotary bit appear promising. Two such systems are in development. One system adds a percussion type system to the rotary rock bit.⁷ Another utilizes high velocity mud jets in conjunction with a standard rotary bit.⁸ Both of these approaches make it possible to apply more power to the rock to be drilled. It is not known if the rock specific energy is decreased, but improved drilling rates have been experienced.

Studies of Novel Drilling Techniques

Improved drilling has been desired for many years. In response, many different novel drilling techniques have been proposed. Most of these techniques have been adequately described by Maurer.⁹ The urgency of desired drilling improvements, improvements in materials, and technology gains have caused a renewed interest in these techniques. Some of the techniques attracting attention are:

Fusion Drilling - The Los Alamos Scientific Laboratories have been studying the techniques of drilling with electric heater drills.¹⁰ The LASL drills are called subterrene devices and drill by melting the rock at the bit surface by electrical energy supplied from above ground. The melt can form a glass lining for the hole and can be chilled to form particles which then can be readily removed from the hole. Several drilling experiments have been conducted with the subterrene drill in tuff, granite, alluvium, and simulated permafrost.

The subterrene drill offers a real potential for geothermal and magma drilling. Due to the high formation temperatures involved, which may hinder or stop other drilling techniques, the subterrene offers a capability for continued drilling. Therefore, it could fill a very necessary function for future drilling.

Spark Drilling - When an electrical spark is generated in a fluid as a result of a rapid electrical discharge, a high stress shock wave is generated. This compressive shock wave can be of sufficient magnitude to fracture rock, or may fracture rock by the subsequent rock stress relief or the action of cavitation. The Russians reportedly looked at this method of drilling approximately 20 years ago. Initial success was reported, but due to a required down-hole spark generator, development work was terminated. Figure 6 illustrates the concept.

Spark Drilling Concept

Figure 6

Sandia Laboratories is presently studying this drilling technique.¹¹ Initial efforts are directed at understanding the physics involved and determining the drilling feasibility of such a system. If the initial efforts indicate the desired drilling system characteristics, then system hardware studies will be conducted. Laboratory drilling experiments have been conducted and the results have compared favorably with the Russian results.

Terra Drill - Sandia Laboratories has added terradynamics, the science of earth penetration by projectiles, to the rotary rock bit.¹² The concept is to fire projectiles between the roller cones into the rock to be drilled, thereby prefracturing the rock. The prefractured rock can then be drilled faster than the virgin formation. Figure 7 illustrates the concept.

Preliminary results from drilling Madera limestone showed an increase in drilling rate of approximately two over the rock bit alone. Development work is continuing on this drilling concept.

Renewable Bit Cutting Surface - From the equation developed for drilling rate, it can be seen that if the trip time can be deleted, the average drilling rate can be increased. This can be done by developing a system which can renew the cutting surfaces without tripping the drill stem. Sandia Laboratories is also working on this concept in cooperation with the former Division of Applied Technology, USAEC.

Conclusion

A large amount of drilling is being done to obtain new energy resources. Even more and tougher drilling is needed in the future. The expense of drilling is so large that even a 10% improvement would have resulted in \$400 millions being saved in 1974. This expense may start affecting the amount of our usable energy reserves.

Some approaches future drilling research should take have been presented. To obtain maximum return for the amount invested in future research a coordinated effort should be mounted. Since the results will benefit all and since no one company should be expected to absorb the loss accrued by a single high risk drilling research program, the Federal Government is considered the logical program sponsor. The program would have the potential for increasing our usable reserves and maintaining our drilling technology advantage.

Terra Drill Concept

Figure 7

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