REVIEW OF GEOTHERMAL DRILLING OPERATIONS – TOWARD MORE EFFECTIVE OPERATIONS

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INTRODUCTION

Drilling practices and operations for geothermal development have usually been adaptations of oil field or mining experience and equipment. The subsurface conditions, rocks, and environment in geothermal reservoirs are quite different. Mining exploration drilling equipment, primarily diamond core drills, have been a primary method used for geothermal exploration, and this equipment has been used very successfully worldwide. These shallow, small diameter, core hole rigs are optimized for the very hard; abrasive, fractured rocks encountered in geothermal areas. These core holes are intended primarily for thermal gradient determinations and for fluid sampling and monitoring [1,2].

The adaptation of production well drilling from the oil field has been less successful and the resulting high drilling costs remain as one impediment to more rapid geothermal development in the United States and elsewhere in the world. Drilling costs are increased over oil field drilling at comparable depths due to the harder, abrasive rocks and extreme temperature encountered in most geothermal reservoirs. Drilling costs are a significant factor in a geothermal electric power plant development project[3], and range from 40 to 60% of total project costs in the United States; and can be an even larger fraction in other locations in the world. Therefore drilling cost reduction and optimization of production drilling operations can have a significant influence on the rate of geothermal development progress.

There are additional significant differences between oil field and geothermal well drilling strategies and risks. The usual oil field practice concentrates drilling activities early in the field development and the production rate declines over the production history, a condition acceptable to the petroleum market. Initial geothermal field drilling usually includes only enough wells early in the project to supply the first power plant to be constructed[4], and the pressure and enthalpy supply rate must be maintained constant to the plant. A declining production cannot be tolerated, so a few extra wells (usually with about 20%) are drilled initially. Experience indicates that about one new well (or a standby well activated) must be drilled per year per 100 MW(e) of power capacity to sustain production and replace damaged and aging wells.

In the US, most geothermal drilling equipment methods, and operations have been adopted and adapted from the petroleum industry. But, because the average depth of geothermal wells (2.1 km in the US) is twice that of the average oil well, and is drilled in very hard, abrasive, crystalline rocks at high temperatures, geothermal drilling costs are often 2 to 4 times those of comparable oil wells[5]. As a result of these factors; however, many of the problems causing the higher costs have technological solutions[3]. Another major element in high geothermal drilling costs is the large variations in subsurface geology. It has often been observed that geologic changes within the reservoirs on a scale less than the well spacing are common. Reduction of increased costs due to extreme subsurface complexities can be achieved by close on-site support and coordination of the drilling operations by the project geologists, geochemists, and geophysicists. Projection of the subsurface conditions for each new well, detailed well planning and review, and close on-line monitoring of drilling are the essential functions of this team of professionals, if costs are to be reduced.

There are two primary areas of geothermal drilling where appropriate improvements will result in major cost reductions. These are lost circulation control and enhanced drill bit life. The remainder of this paper will focus on these two topics.

LOST CIRCULATION CONTROL

Table 1 and Fig. 1 record the statistical data[6] for US geothermal drilling problem areas given both by relative frequency of the problem and impact (*i.e.*, relative frequency times days required for resolution of the problem). As indicated, the data show that many of the secondary problems are often caused by lost circulation, and frequently production casing cementing problems are due to failure to adequately seal loss zones. Although similar data are not available for geothermal well drilling in Japan, discussions (September 1985 and November 1986) with major operators and drillers in Japan indicated that the lost circulation problem is perhaps more severe than in the US. It has been estimated that improved lost circulation control may reduce geothermal drilling costs on the average to better than half of current levels.

Figure 2 depicts four stages of lost circulation control. Initially (Fig. 2a), following petroleum drilling practices, fine particles of lost circulation materials (LCM) are pumped through the drill bit nozzles[7]. In fractured reservoirs this approach is not effective. Current research attempts to develop high temperature LCM of suitable size and shape to be pumped down an open ended drill pipe. If successful, this approach may increase the probability of sealing off fractures (Fig. 2b). The most commonly used method of lost circulation control is setting of cement plugs (Fig. 2c). However, it is well known that this approach is not very effective, often requiring many plugs, and not reliable. Use of an special setting plug on the end of the drill pipe and measurement or monitoring of liquid (mud) level in the well will improve reliability. However, it may be that the cement-filled fractures are a potential reservoir connected permeability, subsequently attempted clean-out of the cement is usually not successful. Figure 2d shows the use of an air[9] (or inert gas[10]) lightened mud system that can be used to combat lost circulation. If air is used, then the additional problem of enhanced drill pipe corrosion[10] must be addressed. There is a general understanding[11] that the present methods are inadequate for lost circulation control, and that new approaches are desirable. Finally, Fig. 2e illustrates how current R&D is attempting to develop a special down hole, two-chamber, setting tool (Fig. 3), to be used to spot a formed-in-place polyurethane material into the fracture zone[12]. This last method is considered the most reliable and will prove to be most effective in practice. There is a general concensus that the last two methods of lost circulation control are the more reliable and most effective methods. Both of these latter operational approaches require some special equipment, instrumentation, and experience in order to yield consistent cost reductions. There are also many opportunities to develop rig instrumentation and expert systems and models to aid with the detection and rig-site diagnosis and control of lost circulation. Provision for rig floor water depth, mud pressures, and differential flow rates are extremely valuable in detecting and assessing the severity and location of the loss zone, and evaluation of the best methods to be used to combat the lost circulation problem.

DRILL BIT PERFORMANCE

Limited drill bit life is a very significant factor causing higher geothermal drilling costs in comparison to wells drilled for petroleum. In the US, on average, a 30 to 40% active drilling time is recorded for geothermal wells, in contrast to a 60 to 70% of on bottom drilling time noted for petroleum projects. This reduction in bit life is due to the hard, abrasive rocks and harsh, corrosive environment found in most geothermal reservoirs. Solutions for improved life for rock bit[13] and pollycrystalline fixed-cutter bits[14] are in progress. These advances are due to both materials and design improvements. The roller cone, tungsten carbide (TCI) bits, will have a polycrystalline diamond compact (PDC) coating, Fig. 4, and the possibility exists for bearings made of this material[15]. Drag, or fixed-cutter, bit improvements will come about through design changes [14,16] as depicted in Fig. 5. Therefore, use of PDC technology and new bit design concepts can be expected to double geothermal drill bit and bottom hole assembly life.

Rock bit rate of penetration (ROP) usually averages about 4.5 m/h (15 ft/h) in many geothermal projects and for crystalline rock[17] drilling projects. This relatively low value is mainly due to bit load constraints that are limited by hole straightness requirements. Significant advances in ROP will only come about through use of down hole drilling motors. This will require a very reliable, long-life high temperature, turbodrill to accomplish any meaningful cost reductions through ROP enhancement.

SUMMARY AND CONCLUSION

Geothermal drilling projects are plagued by two major problems: (1) lost circulation and (2) limited drill bit performance. New technology and operating approaches are available (lightened drilling fluids) or in progress (down hole plug setting tools and chemicals) to reduce time and costs due to lost circulation. New polycrystalline diamond compact materials and bit designs are currently in development that offer large increases in bit life; perhaps a factor of two or greater. Greater drilling rates must await the practical, reliable, and cost-effective field applications of high-temperature-rated turbodrills. An average penetration rate of 4.5 m/h (15 ft/h) is recorded for geothermal and crystalline rock well drilling; and advances in ROP will only be achieved by application of suitable down hole drilling motors.

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TABLE 1

SUMMARY OF US GEOTHERMAL DRILLING PROBLEM STATISTICS

A. Relative Frequency of Drilling Problems,[a] Ranked.

Problem Area	Relative Frequency, f
Cementing*	0.54
Lost Circulation	0.46
Stuck Pipe*	0.38
Fishing*	0.26
Side Tracking*	0.26
Twist Off*	0.24
Sloughing Hole*	0.16
Casing*	0.10
Rig Repair	0.10
	1.00

* *These problems are often caused by, or related to, lost circulation.*

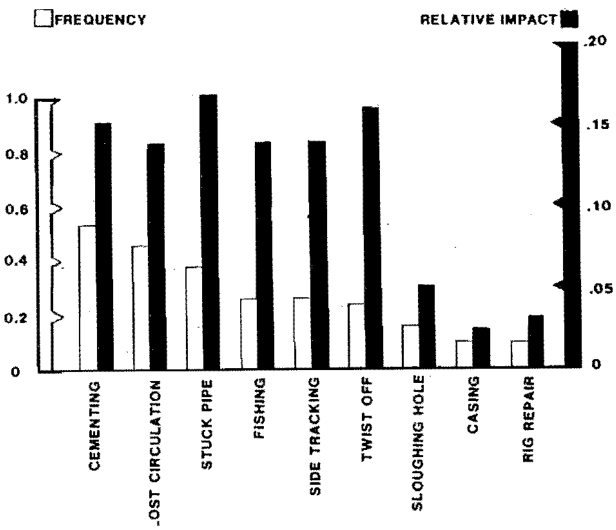
B. Relative Impact[b] of Drilling Problems, Ranked.

Problem Area	Relative Impact (f×days,** normalized)	Average Time (days**)
Stuck Pipe	0.175	2.00
Twist Off	0.161	2.25
Cementing	0.153	3.25
Lost Circulation	0.146	3.00
Side Tracking	0.146	4.00
Fishing	0.111	4.75
Sloughing Hole	0.051	2.25
Rig Repair	0.032	1.75
Casing	0.025	2.25
	1.000	

** *Average number of days required to solve problem area.*

[a] Relative number of US geothermal well records with problem indicated.

[b] Relative average values of days required to solve drilling problems multiplied by frequency of problem. This quantity might be considered a severity index for the problem area.



b Glossary of terms: Cementing = intermediate or production casing cementing; Lost Circulation = those events where drilling fluid and cuttings do not return to the surface, and fluid level in the well becomes sub-hydrostatic; Stuck Pipe = situation when drill string cannot be rotated or removed from the well with normal methods; Fishing = remedial operations needed to attempt to remove drilling tools and hardware left or dropped in well, usually due to a twist off; Side Tracking = drilling operations necessary to drill around a fish in the well, usually as a result of unsuccessful fishing operations; Twist Off = failure or breaking of drill string, or bottom hole assembly, downhole; Sloughing Hole = unstable borehole wall with break-out or crumbling of rocks and partial or complete bridging of well bore, often associated with fault or breccia zones and sub-hydrostatic fluid conditions caused by lost circulation and release of fluid-pressure support for weak or unstable portiouns of the well bore; Casing = difficulties encountered during running of casing, often caused by poor conditions due to hole sloughing, deviated hole, and lost circulation; and Rig Repair = mechanical repair of rig equipment, both due to normal usage and heavy loads imposed during fishing operations.

Fig. 1. Graph of Statistical Data for US Geothermal Well Drilling Problems. (See Reference [6] and Table 1 for descriptions of various drilling problems).

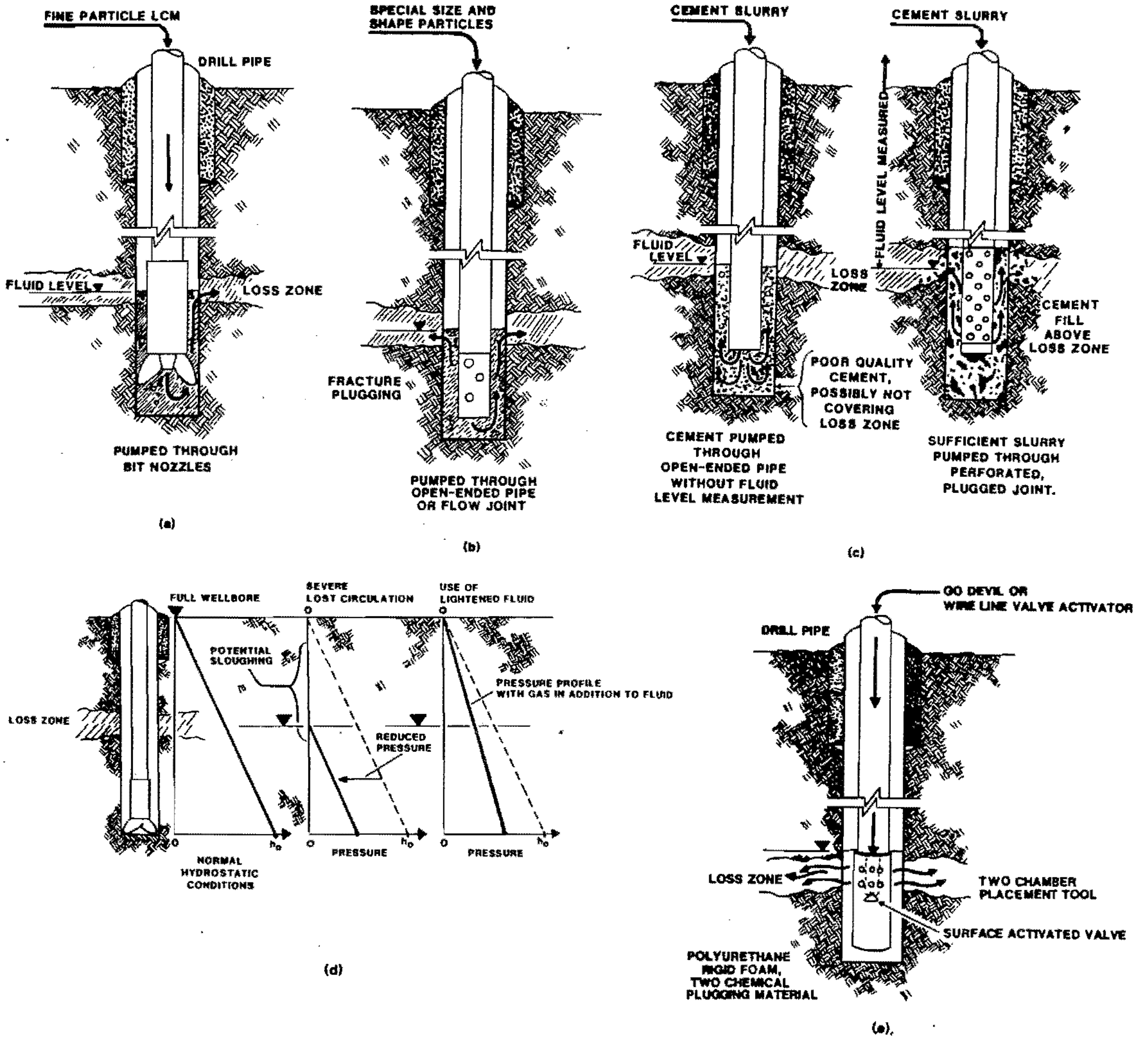
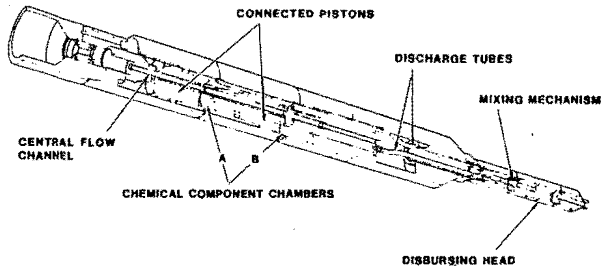
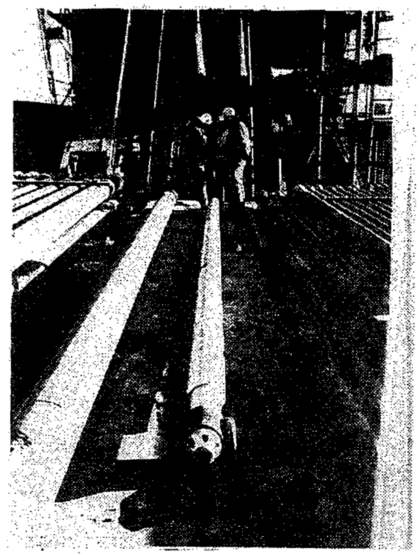


Fig. 2. Methods and Operations for Lost Circulation Control. (a) Fine Particle Lost Circulation Material (LCM) Pumped Through Bit. (b) Special LCM Pumped Through Open-ended Drill Pipe. (c) Cement Plugs. (d) Drilling Fluid Lightened by Gas. (e) Rigid Polyurethane, Foamed-in-Place, Plugging Tool.



(a)



(b)

Fig. 3. (a) Sketch of Polyurethane Foam Production, Two-Chamber, Placement Tool. (b) Photo of Placement Tool (Courtesy NL Baroid).

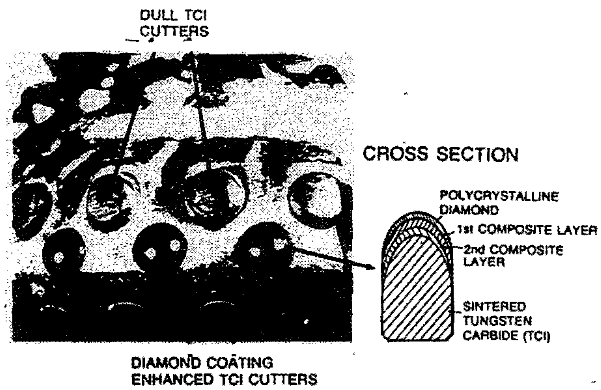
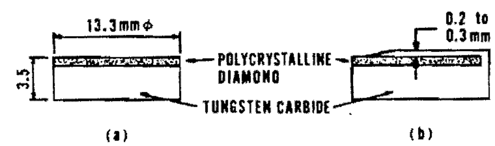
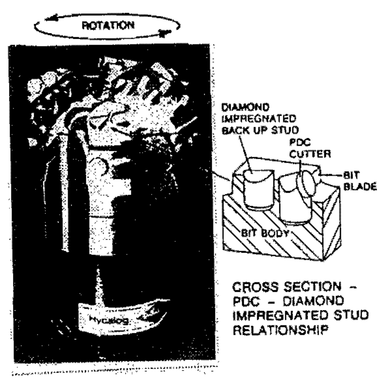


Fig. 4. Rock Bit with TCI Buttons with Polycrystalline Diamond Compacts (PDC) Coatings.



(a)



(b)

Fig. 5. Polycrystalline Diamond Compact (PDC) Fixed Cutter Bit Design Improvements. (a) TCI Coating on Cutter Surface. (b) Diamond Impregnated Stud Protection Design.