NEW DRILLING SYSTEM CONCEPT COULD REDUCE GEOTHERMAL DRILLING COSTS

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ABSTRACT

The energy price for one kilogram of hot geothermal fluid is far less than for one kilogram of hydrocarbon production. But the costs for drilling average geothermal wells are nearly two to four, or more, times those for oil wells drilled to a comparable depth. Therefore, the incentives for geothermal well drilling cost reductions are far greater because well costs are a significant 40 to 60% of total geothermal electric power projects.

Incremental improvements by use of specific technology have made some cost reductions possible over the past two decades. However, these short-term modifications of presently used oilfield drilling equipment and practices, have not provided the major gains needed. Therefore, an innovative purpose-designed advanced geothermal drilling system has been proposed. It is based upon the development of a new, high-temperature, hydraulic percussion hammer. This hammer is designed for deep drilling in the very hard volcanic, metamorphic, and crystalline rocks of geothermal reservoirs. This percussion hammer, an all-metal downhole drilling motor, will improve the rate of penetration by at least a factor of five increasing from a current low of < 3 m/h to perhaps 15 m/h. A dual-wall corrosion resistant alloy drillstring configuration is proposed. This type of drill string will solve two major problems of geothermal drilling: severe lost circulation to highly fractured rocks, and also control the bottom hole circulating temperature of the boreholes by using reverse circulation. A depth capacity of 4 km, and a temperature rating of 400° C, are targeted. An international team has been conducting a feasibility design study for such a purpose-developed advanced geothermal drilling system. Thus far the results indicate that significant operating cost reductions are possible. The time frame for this development is considered a midterm effort, realizable in 5 to 10 years. Details of the design, components of the system and analytical results thus far are presented, and the present status of the project reviewed. Current activities and future directions are presented.

INTRODUCTION

This is a report of work-in-progress for a project that was initiated in 1993. As advocated by a study and workshop of the Nat'l Academy of Sciences (Nat'l Academy Press, 1994) a systems approach to improve geothermal drilling performance is proposed. Further recommended was a development strategy that provides for: short-term (less than 5 years); a midterm (5 to 10 years); and a long-term (10 years or greater) portfolio of research and development efforts to be conducted.

Because geothermal developments are worldwide, a team of drilling experts was formed to select the system and guide the project. It was decided to focus on a midterm strategy, and to select a drilling system approach that used known and established drilling technologies. These technologies are suited to the subsurface conditions of geothermal reservoirs far better than the current adaptation of the drilling technology used for petroleum drilling. Therefore, the focus of the selection was: (1) Higher penetration rates in hard and abrasive rocks, (2) Long life components in very high-temperature wells, and (3) Provide a solution to severe lost circulation problems within the system configuration.

The magnitude of the improvement goal is illustrated in Fig. 1, where the cost of geothermal well drilling (Kelsey, 1987) is compared to oil and gas drilling in the USA. This is a direct comparison of the use of a drilling technology designed, and extensively developed for over 70 years, which is applied to totally unsuitable subsurface geothermal conditions. Figure 2 illustrates the subsurface temperature conditions encountered in geothermal drilling, and shows the extreme difference from the highest temperatures found in the deepest, hottest petroleum wells that are 175° to 210° C. Table 1 further indicates the nature of the rock types encountered in geothermal drilling and provides a scope for the very low rates of penetration (ROP) usually experienced.

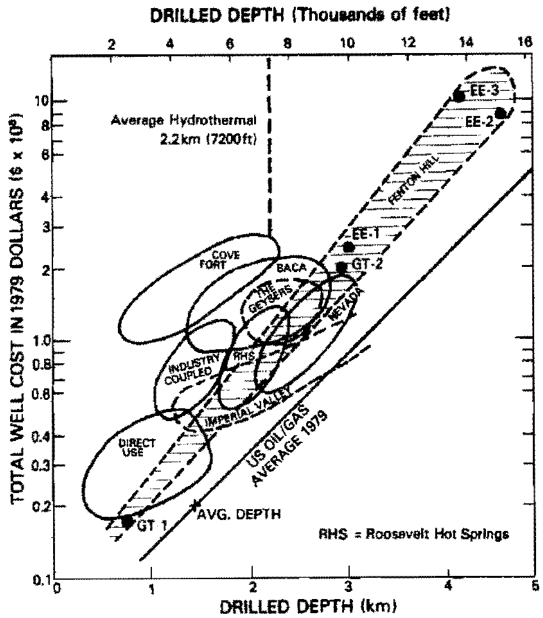

Fig. 1. Comparison of geothermal & oil & gas drilling costs in the USA (Kelsey & Carson, 1987).

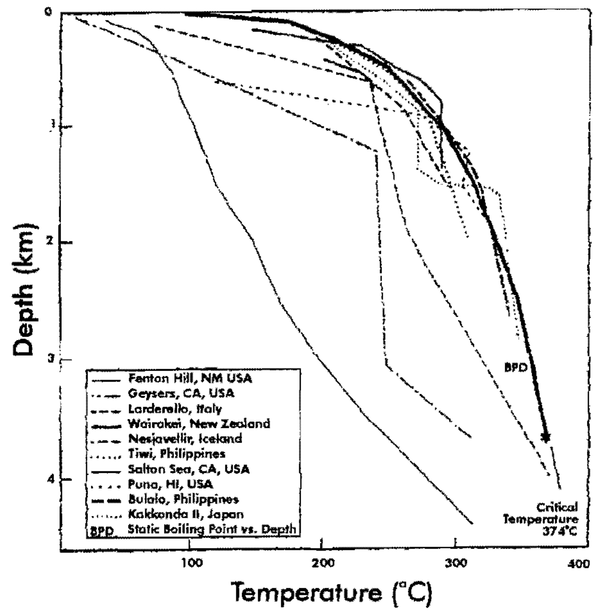

Fig. 2. Selected subsurface temperature profiles (Modified from Otte, et al., 1990).

Table 1. Selected drilling data & rock types for geothermal reservoirs worldwide (Modified from Otte, et al., 1990).

Geothermal Field Name	Country	Geologic Age[1]	Reservoir Rock Type	Average Well Depth (m)	Reservoir Zone: Average Penetration Rate (m/hr)	Reservoir Zone: Bit Size (cm)
Salton Sea	USA	Q-T	Sandstone/shale	1500	18.5	31.1
Cerro Prieto	Mexico	Q-T	Sandstone/shale	1900	2.0	27.0
The Geysers	USA	K-T	Greywacke	2500	8.0	27.0
		Q	Microgranite			
Larderello	Italy	χ	Carbonate/elastic	1000	2.4	31.1
		pε−χ	Phyllite/quartzite	1500	1.7	21.6
Monte Amiata	Italy	T	Anhydrite/dolomite	800		31.1
		pε−χ	Phyllite/quartzite	3500		21.6
Mori	Japan	Q	Tuff breccia	2400		21.9
		pre-T	Limestone/slate/chert			
Onikobe	Japan	Tp	Dacite tuff/tuff/breccia	750		27.0
		Tm	Green tuff			
Broadlands	New Zealand	Q-Tp	Tuff breccia/dacite flow	1300		25.0
			Ignimbrite			
Wairakei	New Zealand	Q-Tp	Rhyolite pumice breccia	800	12.2	19.4
Hatchobaru	Japan	Q	Andesite	1150		27.0
		Tm	Tuff breccia			
Kakkonda	Japan	T	Andesite	1200		21.9
		Tm	Dacitic ignimbrite			
Kakkonda II	Japan	T	Rhyolitic tuff	2500	3.5	21.6
		Tm	Slate sandtone/andacitic tuff		2.5	21.6
Bulalo	Philippines	Q-T	Andesite tuff and lava	1600	8.5	21.9
Tiwi	Philippines	Q-T	Andesite	1800	8.8	21.9
Salak	Indonesia	Q	Andesite	2000	9.1	31.8
Krafla	Iceland	Q	Basaltic lavas and intrusives	2000	7.5	21.9
Coso	USA	K	Granite	1500	3.0	22.2
Fenton Hill	USA	pε	Granite/gneiss	4000	3.5	22.2

[1] Q=Quaternary; Tp=Pliocene; Tm= Miocene; T=Tertiary; K=Cretaceous; χ=Triassic; pε=Precambrian.

OUTLINE OF SYSTEM SELECTION

It is well known that there are solutions to the problems associated with the inappropriate use of oil and gas drilling methods for geothermal drilling. Based on these solutions an advanced geothermal drilling system (AGDS) concept is set forth. Therefore, the following system goals were established: (1) Reduce costs to equal or less than petroleum drilling, (2) Select a rock penetration method that provides an ROP greater by a factor of five than possible with rotary, roller-cone bits, (3) Design the downhole hardware to have a life of > 200 hours, and (4) Select drillstring configurations that already have been developed to combat lost circulation.

The system selected is shown in Fig. 3. It was selected as containing the basic elements needed to solve the major geothermal drilling problems, and to achieve the goals set forth. It consists of: (1) A percussion, downhole hammer ("motor"), that has been long established as a method to achieve high ROP in hard rocks, and (2) a dual-wall, or concentric pipe, reverse circulation drillstring that is well known to be an effective method of controlling lost circulation to highly fractured formations.

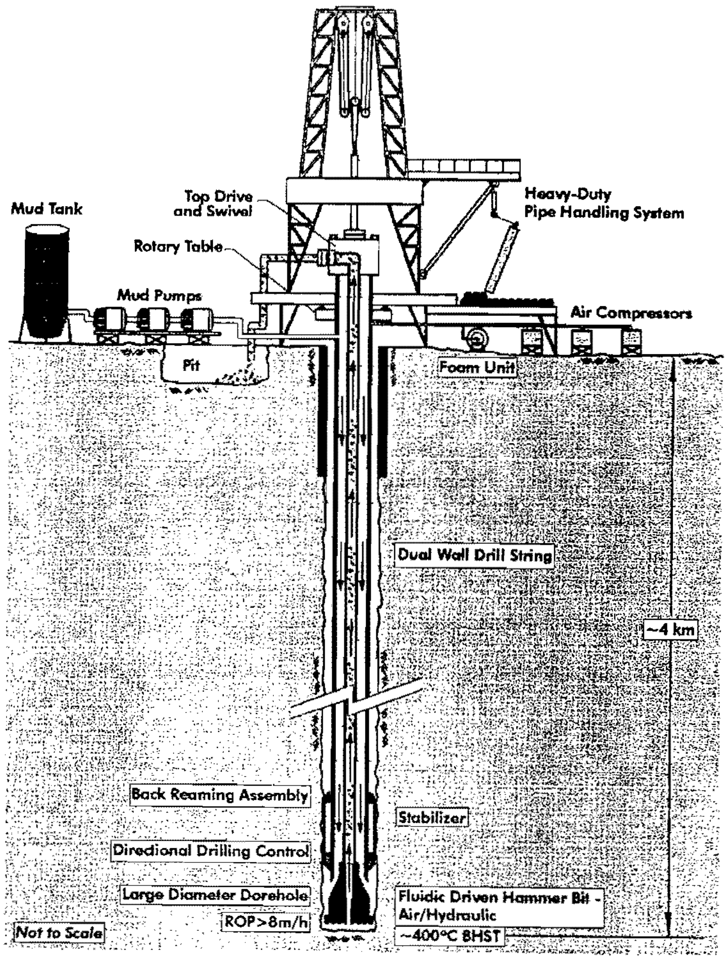

Fig. 3. Proposed advanced geothermal drilling system.

CURRENT PROJECT STATUS

Several technical publications are available that attest to the correctness of the AGDS selections (Rowley, et al., 1993; Rowley, et al., 1994; Rowley, et al., 1995a, Rowley, et al., 1995b; Rowley, et al., 1996). The initial emphasis of the project activities was to research the current status and use of hydraulic percussion hammers for deep drilling (Liu, 1994; Deutsch et al., 1996; Knott, 1996; Pet. Engrg. Int'l. 1996; Jour. Pet Tech, 1995; and Malamed, et al., 1997). We learned that there is a growing interest in the petroleum industry in percussion drilling tools for deeper, harder rocks of reservoirs now being exploited. Therefore, the period from 1994 to 1995 was spent in motivating the commercial development in the USA of a percussion hammer dedicated to geothermal drilling. This development was accomplished (Pixton & Hall, 1995). It is important in the development of any AGDS that the determination of the penetration method (hole-making technique) must be established first. Any advanced drilling project must be developed "from the bottom up." A schematic sketch of the percussion hammer as proposed by the Novatek Co. (Provo, UT, USA) is shown in Fig. 4. A sketch of the proposed bottom hole drilling assembly (BHA) is shown in Fig. 5.

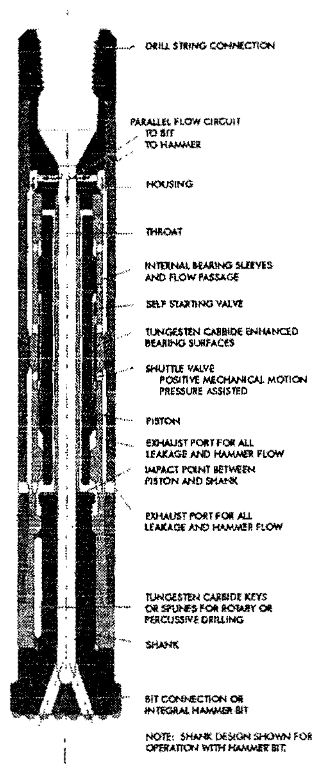

Fig. 4. Hydraulic percussion hammer for geothermal applications (Pixton & Hall, 1995).

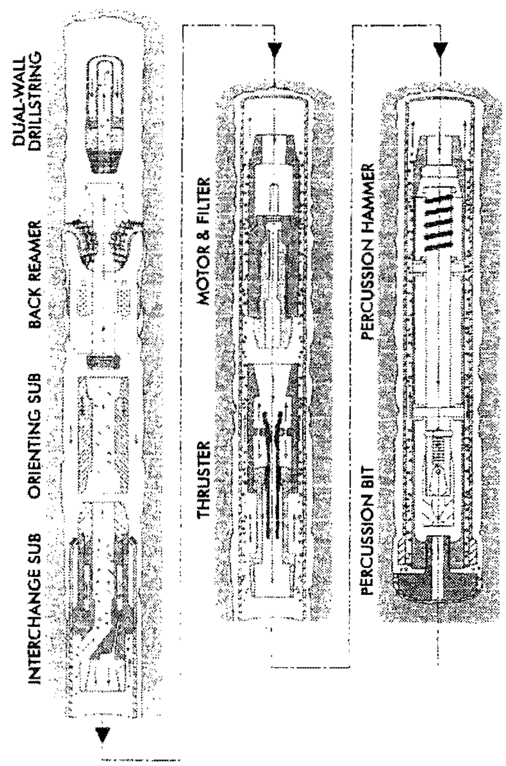

Fig. 5. Sketch of bottom hole drilling tool assembly components (Rowley, et al., 1995).

It should be pointed out that a downhole motor, for example, an all metal turbine, and a PDC drill bit developed for harder rocks, is another good choice for an AGDS. Such a project is under way in Japan (Karasawa, et al., 1996).

Once the BHA preliminary design was established, the AGDS project has turned attention to the drillstring designs. Two configurations were selected for initial study; these are shown in fig. 6. The one is a rather conventional dual-wall string. The second is a new, innovative string, termed a MultiCon design. Both feature the use of the annulus between concentric pipes to provide the downward flow of drilling fluids, and the central pipe for return flow. This is the so-called reverse circulation method. This drillstring selection, basically, leaves the annulus between the outer pipes and the borehole free of any function except to be used to control lost circulation. Such drillstring are ideally suited for use with a variety of fluids: 1) the unusual muds, (2) nitrogen, to avoid the corrosion problems with air, and (3) mist or foams. The high-temperature and corrosive fluids often encountered in geothermal wells downhole will dictate that corrosion resistant alloys are selected for these types of drillstrings. Preliminary analyses of fluid, thermal, and structural designs of these drillstrings are underway.

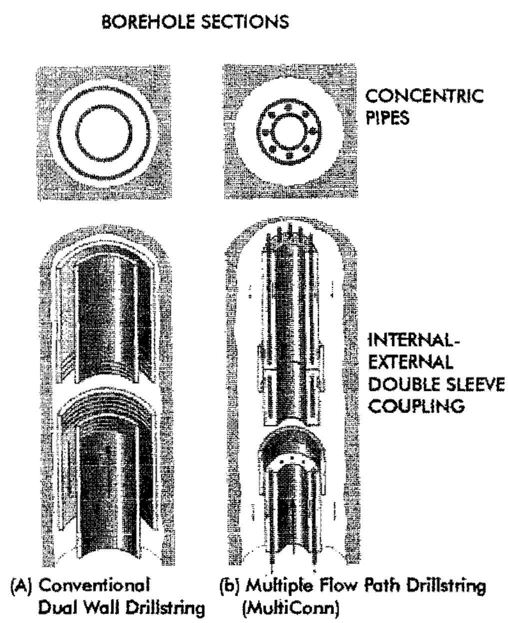

Fig. 6. Two options for multi-flow path, reverse circulation, drillstrings (Rowley, et al., 1996).

DISCUSSION AND CONCLUSIONS

While this AGDS project has yet no formal sponsor, it does have a rather dedicated design team. The concepts have been heavily reviewed through the submission and publication of technical papers. It remains to now find a sponsor, and to provide a focus of technical effort. Thus far the proposed AGDS concept has received good inputs from many experienced drilling and design engineers. The proposed AGDS will continue to be presented by publications and reviews for technical critiques and inputs.

It seems that perhaps the petroleum drilling industry is currently undergoing rapid changes, and is focusing on advancements (Oosterling and Faure, 1996 and Leisner et al., 1996). From the current trends, for long-term research and development, it can be projected that advanced drilling systems will be based on a reeled system of deployment of the drillstring. Therefore, eliminations of the present coupled joints of 10 meter lengths of pipe and the ability to both run the tubing or pipe very rapidly are possible. Also, the potential exists for reeled strings that are concentric tubes with space for utilities, two-way communication or telemetry systems, and instrumentation cables. This could lead to truly automatic drilling systems. An advanced geothermal drilling system, that further exploit percussion hammer methods, is possible because percussion drilling is a leading candidate for use with these new reeled tubing strings.

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