

TURBODRILLING IN THE GEOTHERMAL ENVIRONMENT

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ABSTRACT

Geothermal drilling, historically, has presented what seemed to be insurmountable barriers to the efficient and extended use of downhole drilling motors, especially those containing elastomeric bearing or motor components. In addition to being damaging to rubber, the typical temperatures of 177° to 371°C (350° to 700°F) create other operating problems as well. Recent innovations, specifically in turbodrill design, have opened heretofore unrealized potentials and allowed, for the first time, extended downhole drilling of geothermal wells.

A considerable amount of experience has been obtained both in The Geysers and Imperial County areas of California primarily in directional drilling applications using insert, diamond, and polycrystalline diamond compact bits. Other hot-hole applications are currently being drilled successfully or planned in other states, both on- and off-shore.

The turbodrill is devoid of any elastomers or other temperature-sensitive materials, hence, its capabilities are closely matched to the requirements of the industry. The bearing assembly can withstand the rigors found in the drilling of typical geothermal formations and provide the performance necessary to stay in the hole, thus providing increased penetration rates and, hence, more economical drilling.

This paper will present case histories of recent turbodrill performances in all areas where used. Furthermore, data will be presented showing the performance of insert, diamond, and polycrystalline diamond bits as they relate to the turbodrill, together with forecasts as to the potential that turbodrills have to offer in accelerating and controlling the drilling of geothermal wells.

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INTRODUCTION

Typical geothermal wells drilled in the United States present formidable, but not insurmountable, technical difficulties in the effective use of such standard tools as downhole motors and bits that are used every day in the oil industry. The foremost obstacle to the continued operation of these tools is elevated temperature environments. Research is being done to alleviate these difficulties on a continuing basis.

The positive displacement motors and turbodrills presently used contain elastomeric components which cannot survive in the temperature ranges encountered. This fact provided the impetus for the development of turbodrills capable of performing in these conditions. Turbodrills have been developed which can withstand the high operating temperatures while providing the power necessary to drill the most commonly encountered formations, i.e. graywacke, granite, siltstone/claystone which, by their lithology, present very tough drilling conditions.

It should be emphasized that these drilling conditions have demanded the development of the motors. Standard rotary assemblies used for drilling these wells do not realize the same life as their counterpart in the oil industry. This is true for two reasons: (1) Doglegs or sharp bends in the hole accelerate wear on the rotating assembly due to the wall friction with these hard formations, and (2) the higher stresses, both bending and thermal, reduce the fatigue life of the material. In view of these conditions, directional drilling most assuredly must be done with downhole motors if economies are to be realized.

The performance of turbodrills varies only slightly with mud weights and plastic viscosity. There is no direct limitation on these that can be handled by the tools; their limited nature applies to the overall surface pump pressure capabilities.

Turbodrills of this design are completely applicable for oil industry use where very hot hole conditions are commonly encountered, and all other uses where downhole motors would present an advantage.

DESIGN FEATURES

A turbodrill consists of a multistage motor, each stage being comprised of a rotor and stator. The stator is the stationary part of the motor, rigidly attached to the housing. The rotor is rigidly attached to the main shaft and makes up the rotating assembly. The turbine develops power by directing the hydraulic flow of drilling fluid passing through the stator to the rotor blades, causing rotation. The blades can be designed with entrance and exit angles configured to develop any required power output. The turbine motor section is attached to the bearing assembly, which can be of any proprietary design capable of

withstanding (1) thrust loads of the turbine motor, caused by pressure forces acting on the rotor blades and (2) drilling loads imposed by the formations encountered.

These thrust loads are of a bidirectional nature in that the rotor section of the motor creates a large down-thrust and the formation, with the application of bit weight, creates a large up-thrust. For optimum bearing life, the two forces can be balanced and provide, theoretically, a zero bearing load. This ideal can be approached, yet in actual practice it has been shown that there exists either an excess off bottom or on bottom thrust load; therefore, in the overall bearing design, careful consideration must be given to the type of drilling to be done. Very high radial loads are quite common and constitute a critical factor in design considerations. In addition to what we might call static loads, the use of conventional three-cone bits can introduce loads with frequencies on the order of three times the rotative speed and amplitudes approaching two to three times the weight on bit. In view of all these factors, it is necessary to design a bearing system capable of withstanding these loads while operating in a mud environment with high temperatures.

To cover all bit combinations, the flow restricting capabilities of the bearing assembly must fall in the 150-1000 psi range, yet not adversely affect tool performance or life. This restricting capacity can come from seals or proprietary orifice designs found in mud lubricated systems. The knowledge gained from second generation positive displacement motor tools, used for long interval drilling, has provided a mud lubricated bearing assembly design which meets or exceeds all the requirements mentioned previously. The use of seals in the bearing assembly must be designed to meet the same qualifications. To date, no seal has been developed which will guarantee consistent performance and reliability on the order that is necessary for high speed mud driven motors to compete economically with rotary geothermal drilling.

Only major design considerations are presented here, for the scope of this paper is to show, by run data, that many of the design criteria have been met and quite successfully so. The successful application of turbodrills requires the ability to control rotational speed. To control this speed it is first necessary to determine its magnitude on the surface and thereby optimize penetration and bit performance. Tachometers of various designs have been put forth and tested in field applications. It would not be appropriate to comment on the advantages or disadvantages of one design over another, but only to mention that their use in turbodrilling is of utmost importance. Succinct and easily managed surface readout equipment for the tachometer is of equal importance and assures a high degree of control over the turbodrill.

TURBODRILL USE

Turbodrills have been developed and made available both for directional and for long interval applications. The run data presented in this paper are from directional wells where the use of the tool was planned and from others where it was used as a last resort when trouble was encountered. Depending on the need, turbodrills can be run with all drilling tools associated with directional drilling and positive displacement motors (such as bent subs, steering tools, etc.). In fact, because of the normally light bit weights associated with controlled directional drilling, the need for drill collars is lessened. (This fact is especially true when using Stratapax* bits.)

Turbodrills are designed for optimal use with diamond or Stratapax bits, since the higher rotational speeds associated with turbodrilling are highly detrimental to standard rock bits. As with all bits and drilling systems, these statements require qualification. Not all performances can be generalized with regards to turbodrill/bit combinations, and much more information, experience, and tool development must be realized to establish consistent performances in the geothermal area.

In the North Sea, substantial progress has been made in petroleum drilling with Stratapax/turbodrill systems, especially in Cretaceous/Jurassic type formations using oil-based muds. In these sections high penetration rates have been achieved with very light drilling weights. Geothermal formations are typically much more difficult to penetrate and oil-based muds are not used. On the contrary, the typical system used for these formations is water or light muds combined with heavy bit weights. These weights, however, are usually lessened during periods of directional drilling.

APPLICATIONS - DIRECTIONAL

The turbodrills used in all the following applications were 7-inch O.D. with 100 stages. The bearing assembly is a mud lubricated ball bearing type, with a 1000 psi (bit pressure drop) flow restriction capability.

- I. Location: Geysers geothermal field, Northern California
- Hole Size: 12 1/4 inch
- Formation: Graywacke, greenstone
- Mud Weight: 9.0 lbs./gal.
- Hole Temp.: 380° F
- Depth: 2800 ft.
- Bent Sub: 1 1/2°

* Trademark of General Electric, Co., U.S.A.

Rotary penetration had been 6-6 1/2 ft./hr., prior to running the turbodrill in the hole, using three-cone rock bits. The turbodrill increased penetration to an average of 22 ft./hr. Typical bit weights were on the order of 10,000 - 12,000 lbs., with a maximum of 17,000 lbs. The directional job was completed in 131 ft. with the only limitation on staying in the hole being the rapid wear of the rock bits, which were averaging 4 to 5 hours.

II. Location: Geysers

Hole Size: 12 1/4 inch

Formation: Graywacke, greenstone

Mud Weight: 9.0 lbs./gal.

Hole Temp.: 380° F

Depth: 2300 ft.

Bent Sub: 1 1/2°

This run was quite similar to the previous one. As a matter of fact, the same tool used on the previous report was used without any shop maintenance. Penetration was increased to 20 ft./hr. from 5 to 6 ft./hr. on rotary.

III. Location: E. Brawley, Imperial County

Hole Size: 8 1/2 inch

Formation: Sandy siltstone

Mud Weight: 9.2 lbs./gal., "Mill Temp.", cooled

Hole Temp.: 520-575° F

Depth: 9,000 ft.

Bent Sub: 2°

This hole presented a real challenge to the turbodrill, bits and directional driller. Rotary drilling had deviated the hole very close to the property line 2,000 ft. from the target depth of 11,000 ft. The hole temperature was 520° F at 9,000 ft. and 575° F at 10,200 ft. The formation was medium hard siltstone. Because of severe doglegs and other factors, the drillstring was stuck quite often. This happened twice with the turbodrill in the hole, with the result that 200,000 - 300,000 lb. jarring forces were sustained by the tool 12 times. The turbodrill was chewing up rock bits at an incredible rate, and due to the continual loss of gage, it was necessary to ream to bottom on each subsequent run. This was normally done at light bit weights and full hydraulics which placed the turbodrills in an unbalanced hydraulic thrust condition for extended periods. As a matter of fact, we were unable to apply enough weight in most cases to balance the bearings. Because of the severe directional requirement, these bit weights were on the order of 4,000 to 6,000 lbs. on the rock bits, 10,000 to 15,000 lbs. on diamond bits, and

14,000 to 16,000 lbs. on the Stratapax run.

We were running a 2° bent sub above the tool which created a tight fit for a 7" O.D. turbodrill in 8 1/2" hole. As a result, very high side loads were placed on the radial bearings which the tool handled with no problems. Penetration rates with the rock bits were 8 to 14 ft./hr. (running light weights). The rate of change taking place in turning the hole was not adequate, so a Stratapax bit was to be run. This run was preceded by that of a rock bit which, when pulled, showed a loss of 1 1/4 inch off the gage, leaving the balls and roller bearings in the hole. After recovering most, but not all, of the junk in the hole, the Stratapax was run in with the turbodrill. This combination was very aggressive and succeeded in turning the hole in 37 ft. At this point, the penetration ceased and later inspection showed the bit to be completely worn. After the Stratapax bit was pulled, the follow-through drilling with a turbodrill/diamond sidetrack bit combination showed significant hole direction change. (I might note that while going in the hole with the sidetrack bit, it became stuck on a gap in the casing. The Stratapax is believed to have hit this abutment which could have knocked off a stud or two. This fact, coupled with that of remaining roller and ball bearing junk in the hole, may account for the bit's early demise.) The hole was turbodrilled for 262 ft. at 12 ft./hr. at which point they switched back to conventional drilling. After drilling conventional for 407 ft., the hole went off course and two more turbodrill runs were necessary. The turbodrills were used to within 800 ft. of the target depth on course, and the hole was completed conventionally.

IV. Location: Los Alamos - Fenton Hill

Hole Size: 12 1/4 inch

Formation: Granite

Mud Weight: 8.34 lbs./gal. (water)

Hole Temp.: 280-300 $^{\circ}$ F

Depth: 7,845 ft.

Bent Sub: 1 1/2 $^{\circ}$

Conventional drilling had deviated the well off course, and our objective was to directionally drill back to plan using the turbodrill. The hole at that point was 7,845 ft. deep. Carbide insert rock bits were being used and would be run with the turbodrill.

The severity of doglegs in this hole rendered effective bit weight control difficult at best; the hole was 1/32 inch under gage and the bit was 1/32 inch over gage. So it took quite some doing to condition the hole adequately to finally seat the bit. With 10,000 lbs. weight on bit, the tool ultimately achieved a penetration rate of 12 ft./hr., but due to the severity of the

deviation and a number of steering tool and wireline problems, we only drilled 10 to 12 ft.

The problems, particularly with the steering tool, resulted from hot hole conditions and prevented effective monitoring and use of the turbodrill. Consequently, the drilling personnel decided to call out another wireline company, pull the turbodrill and utilize a positive displacement motor. We were asked to return for another attempt using a turbodrill/tachometer combination as soon as one could be made available. This will be pursued sometime in December or January.

V. Location: Niland, California (Imperial County)

Hole Size: 12 1/4 inch

Formation: Sandstone, Siltstone, Claystone

Mud Weight: 9.9 lbs./gal.

Hole Temp.: 400-520° F

Depth: 5,965 ft.

Bent Sub: 2°

Once again, conventional drilling had deviated the well off course. The depth-in was 5,965 ft. The turbodrill was run with mill tooth rock bits and drilled extremely well. We were holding back on the bit weight to control deviation and still drilling 25 ft./hr. continuously. The directional driller was having problems orienting, which necessitated long soak times for survey and circulation (a steering tool was not used at the start of this job.) The turbodrill was used for 468 ft. with an average penetration rate of 12 ft./hr. This tool, since it had not been used to any extent, had been sent directly from Los Alamos without being serviced.

VI. Location: Brazos Area, Bek #A69, Offshore Texas

Hole Size: 8 1/2 inch

Formation: Sand Shale (medium hard)

Mud Weight: 18.1 lbs./gal. 9 Black Magic (oil based)

Hole Temp.: 350° F

Depth: 13,600 ft.

Bent Sub: 2°

While this is not a geothermal location, it serves to point up the usefulness of the turbodrill in hot oil field applications. The objective of this job was to kick-off a cement plug with 90 to 120 ft. of hole. The turbodrill was run with a diamond sidetracking bit. The kick-off required extended drilling with zero bit weight and full hydraulics. The maximum weight used after the direction change was 15,000 lbs. Average penetration rate

was 8 ft./hr. for the kickoff with a drilling rate of 30 ft./hr.; 106 ft. was drilled to the customer's extreme satisfaction.

To round out our current data, we have run another test using a straight hole turbodrill/tachometer combination at the Los Alamos, Fenton Hill project. Due to unforeseen hole problems, no actual drilling took place, but the operation of the tachometer was demonstrated and validated.

REMARKS

As seen in some of the previously mentioned wells, they required the use of the turbodrill after troubles were encountered, rather than being a planned part of the project. Part of this is due to the lack of knowledge of the fact that these high temperature tools exist. Turbodrills are normally designed to be used with diamond bits which can withstand the higher rotational speeds. Rock bits do not survive on these tools. The most predominant failure is loss of gage which makes subsequent drilling very tedious and demanding. Diamond bits, typically, do not provide the aggressiveness of rock bits, and this is precisely the quality that will make the teaming of Stratapax and turbodrills capable of revolutionizing both geothermal drilling and oil drilling. There are numerous obstacles, and much more information must be gathered, but the potential for cost-effective operation in these hostile environments demands the effort.

We have not exhaustively tested our turbodrills and we have a long way to go. We have tools at Fenton Hill right now which will be utilized very soon. These will be run with a tachometer, allowing the tool operation to be governed quite closely.

REFERENCES

¹Sii Dyna-Drill pamphlets, literature and internal documents.