Casing Protection for Geothermal Wells

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ABSTRACT

Drilling and completing geothermal wells in the Salton Sea Geothermal Area represents a unique challenge. Acidic, corrosive produced fluids, combined with high temperatures and the requirement for a long service life often necessitate high cost, corrosion resistant casing materials. Unfortunately, these materials can be susceptible to wear. Therefore, casing protection becomes vital in providing a long service life. Wear must be minimized, because the resulting damage can be impossible to repair. Rotating drill pipe protectors have been run to protect casing for years, but with shallow casing set points and long bit runs, maintaining protection of the casing results in these protectors being run into open hole. This often causes damage to the protectors, resulting in debris in the hole and subsequent loss of casing protection. On one well in the Salton Sea area, an operator had experienced difficulties in running rotating protectors in open hole. The large volume of debris from damaged rotating protectors caused a well sidetrack. Non-Rotating Protectors (NRPs) were investigated as an option. As a result, a high-temperature, high-strength version of a Non-Rotating Protector (NRP) that is commonly used in oil and gas cased hole applications, was developed and tested. These tests were run alongside other casing protection methods to evaluate both their durability and their suitability for protecting casing in geothermal wells. In a 2,314 m vertical geothermal well with 1,372 m of 2507 super-duplex stainless steel casing, non-rotating protectors were run immediately above the BHA to evaluate suitability in open hole conditions. They were run 549 m into open hole for more than 130 rotating hours at temperatures ranging from 120°C to 190°C. The protectors showed minimal wear and no signs of significant damage. As a result, a program was developed to provide effective casing protection while maintaining an optimized drilling program. The program included the use of computer simulations that predict contact forces and casing wear.

Introduction

Casing protection is important in all drilling, but it is vital in the geothermal drilling and completion at the Salton Sea, due to the specialized casing materials required by the high temperature and highly corrosive produced fluids. These specialized casing materials are very costly and highly susceptible to wear. If there is casing wear from the drilling process, it will severely limit the service life of these wells. A solution for reducing casing wear is needed, which has usually been filled by conventional rotating drill pipe protectors. However, the shallow casing depths result in running the rotating protectors into open hole where they can be damaged, fail to perform, or totally fail and pile up as debris in the wellbore. A more robust non-rotating protector (NRP), which is often used in oil and gas wells, was investigated and tried as a possible improvement to better protect casing and withstand the open hole drilling conditions.

For one operator, the current method of casing protection is conventional rotating protectors (RP). The RP's are installed near the tool joint on the drill pipe and create standoff by having an outer diameter which is larger than the adjacent tool joint. These RP's are usually installed by the rig personnel, having no estimate of the side force that the RP's might experience downhole. Further, these protectors are not typically intended for use in open-hole. However, the detrimental effects of casing wear are severe enough to warrant taking the risk of running protectors into open-hole.

The elevated temperature, use in open-hole, and minimal onsite monitoring can lead to failure of the rotating protectors. This failure can result in rubber and steel debris in the wellbore to the extent that a well must be sidetracked. One such sidetrack prompted an operator to find an improved solution to the problem of casing wear.

Evaluation of Current Drilling Methods

Evaluation of an improved casing wear solution requires conducting a study of the current drilling methodology and wellbore conditions. In the Salton Sea in California, bottom-hole static temperatures can reach 260°C. The use of directional drilling tools allows for precise targets, but requires downhole tools that are temperature-sensitive. To combat this problem, mud coolers are used to reduce the mud temperature and frequent stops are made to circulate and cool the well while tripping in. As an ancillary benefit, conventional directional drilling using a motor also helps reduce drill string rotation and thus casing wear. The amount of expensive casing is limited as much as possible to keep costs down. This results in shallow casing and long hole sections to drill below the casing, As a result, the protectors must spend much of their time in open hole.

As in conventional torque and drag analysis, the projected wellpath, actual surveys, drill string, wellbore fluids, and drilling parameters were used to calculate the side forces and drilling torque. The test case indicated side forces on the order of 1,000lbs per 31ft (4,448N per 9.5m). This level of side force would be considered of mild concern using conventional steel casing, but can be produce severe wear in exotic geothermal well casing materials.

NRP Improvements and Development

Once the current method of drilling a geothermal well in the Salton Sea area was understood, a plan was made to develop a high-temperature drill pipe protector for use in open-hole. Using an existing high-temperature model of non-rotating drill pipe protector (NRP), shown in Figure 1, as a base for design, several improvements were made and prototypes were produced for a test. This base model has a side force design limit of 8,800 N (2,000lbs) per assembly for continuous use in cased-hole. Depending on side force and wellbore fluids, each NRP sleeve can be reused on several wells. However, this model NRP was not designed for use in open-hole. The improvements include a change in the rubber material of the sleeve, and improved grip from the stop collars.

Figure 1. The existing design of a high-temperature non-rotating drill pipe protector for cased-hole. Each assembly consists of one rubber sleeve and two aluminum stop collars. The sleeve is "free floating" on the pipe between the two stop collars.

Modification to the filler in hydrogenated-nitrile-butadiene-rubber (HNBR) sleeve material produced a 10% improvement in tensile strength over the standard HNBR in identical lab tests. Further, gas intrusion into the modified HNBR material was reduced. The stop collars were redesigned with a shallow straight taper, an additional bolt, and higher-strength bolts with a higher installation torque for an improved gripping strength of approximately 89 kN (25 klbs) before slipping. It was felt that the straight taper would allow the stop collar to move through the casing shoe more easily than the original cove-shaped taper. The open-hole stop collar is shown here in Figure 2.

Figure 2. The open-hole stop collar design with a shallow, straight taper and improved grip strength.

Field Trial #1

Once the open-hole prototypes were manufactured, a well was available nearly immediately for field testing. In February of 2011, information was provided for a torque and drag analysis on a well near the Salton Sea. This vertical injection well had a total depth of 2,314m with 1,372m of super duplex stainless steel. This analysis indicated side force of 1,000lbs per joint of pipe. A recommendation was made to run three NRP's in open hole for endurance testing. The NRP's were run near the bottom of the drill string during four bit runs up to 549 m into open hole. In addition, a collar set, shown in Figure 3, containing a maximum-registering thermometer was run near the bottom-most NRP assembly.

Figure 3. Maximum-registering thermometer shown with one half of the encapsulating collar assembly.

The thermometer records the measurement of the maximum temperature that the assembly experiences. Figure 4 below shows the NRP assembly and a thermometer collar installed on a stand adjacent to a conventional RP. In total, the NRP's experienced more than 130 rotating hours at up to 162°C bottom hole circulating temperature. Table 1 below displays the details of each bit run.

Table 1. Field trial #1 bit run summary.

Bit Run #	Drilling Depth (m)	Bottom-Most NRP (m)	Max. temp. at NRP (°C)
1	1341-1353	1152	162
2	1353-1662	1461	126
3	1662-2080	1327	115
4	2080-2251	1518	-

Note that circulation while drilling tended to cool the well as drilling progressed. Also, circulating every 5 to 10 stands when tripping into the hole helped keep the well temperature down. This practice is critical to safely using NRP's.

Figure 4. A conventional rotating protector installed on nearby stands of drill pipe an NRP assembly and a thermometer collar.

The NRP's were inspected after every bit run. Frequent inspection by trained personnel has proven to be just as important as a quality product. It is not uncommon to replace or turn over a few protectors for additional wear life on the opposing end (typically only one side of the NRP sleeve wears). This test case was closely observed to estimate the usability and wear life of a high-temperature sleeve in open-hole. Figure 5 shows a NRP sleeve after over 130 rotating hours, most of which was in open-hole.

After inspection of the NRP assemblies, the product was deemed fit to perform the task of casing wear and withstand the open-hole wellbore conditions.

Figure 5. NRP sleeve after the initial field test, which included drilling 910 m in 130 rotating hours. Although scratched by the formation abrasion, there was no significant wear or damage to the sleeve.

In addition to trying NRP's as a casing wear solution that can run into open-hole, an in situ bonded material was tried. This material was bonded on the box end of a few tool joints and run in hole just below the NRP's into open hole. Figure 6 below shows this material on a racked joint of pipe.

After encountering difficulty in handling this bonded material in the pipe elevators and iron roughneck, further use this material was discontinued on this well.

Field Trial #2

With the positive results of running the NRP's in the first field trial, another opportunity arose for further evaluation in April 2011. The well was 2101 m total depth with a 13 3/8 inch liner to 1156 m. In this trial, cement operations and a wellbore cleanout run inside of an Inconel liner were planned. Although very little drill pipe rotation was planned, wear to the Inconel casing could not be tolerated at this final stage. Well information was provided and a torque and drag analysis was conducted. This well indicated side forces up to 1744 daN (3,963 lbs) per joint of drill pipe, which are significant, from a casing wear stand point. Figure 7 below indicates an area of concern from 700 m to 900 m.

Figure 6. Bonded material shown on the box ends of two joints of drill pipe.

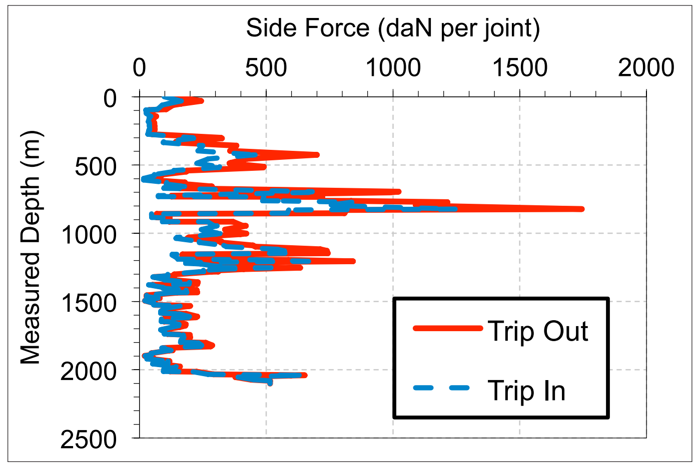

Figure 7. The side forces calculated from the well information provided in the second field trial.

Using the results of the torque and drag analysis, a placement of NRPs was provided to the operator. Once agreed upon, 93 NRP's were installed on the drill string for cementing operations. Again, a thermometer collar was run to measure the maximum temperature experienced at the NRP assemblies. The cement and liner float equipment were drilled and the NRP's were inspected to be in excellent condition. The thermometer collar indicated a maximum of 68°C near the liner shoe at 1171 m.

After drilling out the cement and liner shoe, the NRP's were reconfigured for a clean out run to the bottom of the well, 2101 m. Additional NRP assemblies were placed deeper in the well to provide coverage throughout more of the run and to test the temperature endurance of the sleeves. For the cleanout run a total of 117 NRP assemblies installed with 17 run into open-hole. Of the 17 NRP's in open hole, 12 were run to approximately 1700 m or 615 m below the liner shoe. Upon removal, the NRP's were inspected and in excellent condition and could be

Figure 8. NRP assembly and sleeve run 615 m into open-hole during the cleanout run.

used in another well. The thermometer collar near the bottom NRP indicated a maximum temperature of 204°C with a return flowline temperature of only 73°C. Figure 8 below shows one of the bottommost NRPs assemblies both prior to removal and after cleaning.

Additional Field Trials

In May and June 2011, an additional 85 NRP's were run in open hole to drill 1200m in 14 days. The NRP sleeves and collars properly withstood the open-hole conditions and temperature. Further use of this same equipment is planned in July 2011.

Conclusion

The first field trial tested the capacity of the NRP in open-hole under mild side force, and the second field trial tested the temperature endurance of the NRP in high side force and high-temperature conditions. These two trials represent two significant challenges for elastomers in the drilling industry: abrasion and temperature. The results of the trials indicate that prior engineering-based analysis and planning, combined with robust design and attentive onsite monitoring can provide an improvement in mitigating casing wear in geothermal drilling. The reduction in casing wear can allow the sensitive casing materials used in geothermal wells reach their maximum service life. The benefits are numerous and the implementation of NRP's as common practice is possible due to these careful trials.

Through these trials the NRP's have been shown to:

- Withstand open-hole abrasion and drilling conditions in vertical wells.
- Maintain material integrity at a continuous bottom hole temperature of 148°C and intermittent temperatures up to 204°C.
- Provide adequate pipe gripping force for exiting and reentering the casing shoe safely.
- Perform successfully as casing wear reduction tools in conjunction with onsite wear and temperature monitoring.
- Perform adequately according to the estimated side loads indicated by the WWT torque and drag analysis and placement recommendation.