TECHNOLOGY STATUS ASSESSMENT

For Project DE-FC26-NT42951
"Development and Application of Insulated Drill Pipe for High Temperature, High Pressure Drilling"

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Overview

The objective of this document is to provide a summary report describing the state-of-the-art of the proposed technology. When we refer to "the proposed technology" of insulated drill pipe (IDP), however, we should remember that IDP addresses several effects of high-temperature drilling that are usually addressed with different technologies. This assessment, then, will look at several different kinds of HT drilling tools as they relate to the use of IDP.

Among the problems encountered in high-temperature reservoirs are premature failure of both surface equipment and downhole equipment – the more costly of these failures include downhole motors, logging-while-drilling (LWD), measurement-while-drilling (MWD), drill bits, and other tools that incorporate hydraulic seals and electronic components. Drilling fluid properties can also deteriorate at these high temperatures resulting in an inability to carry the cuttings and promoting higher wear rates on drill bits due to the higher temperatures at the bit face. This latter effect is particularly acute with bits having pressure seals. Finally, steel alloys used for drill pipe can lose 8-10% of their yield strength at temperatures above 450^{o}F.

Each of these problems can be addressed by individual technology developments, but this process can be very costly in both time and resources. An alternative approach is simply to control the temperature of the downhole environment so that existing drilling technology can more easily survive in this harsh environment.

Conventional rotary drilling uses steel drill pipe with drilling fluid circulating down the pipe, passing through the bit to clean the hole-bottom, and returning up the annulus between the pipe and borehole. Because the drill pipe is an effective counter-flow heat exchanger, drilling fluid temperatures inside and outside the pipe are very similar to each other at any given depth (see Figure 1 – the left-hand side of each curve is temperature inside the drill pipe and the right-hand side is temperature in the annulus between the drill pipe and wellbore). Fluid temperatures also tend to follow the formation temperature. In a given formation, downhole temperatures are affected by many drilling parameters – fluid flow rate, rate of penetration, fluid properties, bit-jet sizes, and the like – but sensitivity studies have shown that these factors are minor in comparison to the thermal conductivity of the drill pipe. Figure 1 shows the calculated temperature reduction with IDP compared to conventional drill pipe (CDP) in a 15,000 foot gas well, with 4.75" bottom-hole diameter, assuming that the well is drilled with water-based mud over a period of 50 days. Thermal properties for IDP are taken from those of existing 3.5" IDP. Drilling parameters and formation temperatures used in these calculations are based on those in an actual South Texas gas well.

Several important aspects of this scenario are illustrated by the figure.

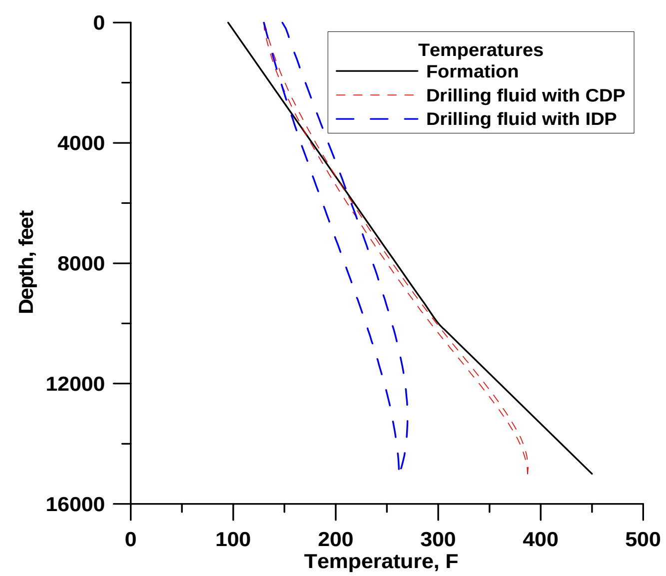

Figure 1 – drilling fluid temperatures with IDP and CDP

- Bottom-hole circulating temperature is reduced from 387^{o}F with CDP to 252^{o}F with IDP. This is the temperature that downhole motors, steering tools, or measurement-while-drilling (MWD) instrumentation must survive. A temperature reduction in this temperature range is especially important because many tools have a performance limit at about 310-325^{o}F.
- Maximum fluid temperatures, which are not at the bottom of the hole, are 388^{o}F for CDP and 270^{o}F for IDP. For drilling fluid additives that degrade at high temperature, this difference can be critical.
- Fluid return temperatures are 130^{o}F for CDP and 148^{o}F for IDP (with inflow temperatures of 130^{o}F.) This can mean that mud coolers are more likely to be needed with IDP than with CDP.

Given this background, the report will describe the relation of IDP to state-of-the-art high-temperature technology in the following functional areas:

- Downhole electronic tools
- Drilling motors
- Drilling fluids

<u>Downhole electronic tools</u>

Downhole electronics are used in virtually every well, for logging, measurement-while-drilling (MWD), or logging-while-drilling (LWD), but conventional electronic components-are temperature sensitive and will normally not function above about 325-350^{o}F. This limitation has been addressed through thermal flasks, HT electronic components, and active cooling, described separately below.

Thermal flasks: The temperature-sensitive components of logging tools, for example, can be enclosed in a thermal flask, or Dewar, that functions as a thermos bottle. These are very effective for a limited time, and allow conventional electronic components to be used in the tool design. These are generally unsuitable for drilling because, like a thermos bottle, they will eventually (usually < 12 hours) equilibrate with the outside temperature, losing their insulating effect and requiring a trip to change tools. The flasks themselves impose design restrictions on the size of the tool and are expensive, as well as relatively delicate.

High-temperature electronics: Several companies and laboratories (Halliburton, Schlumberger, Honeywell, Sandia) are developing tools and HT electronic components that can operate without thermal protection at temperatures above 390^{o}F. This will eventually be the optimum solution for downhole electronics, but several factors mean that it is not an immediate panacea. First, the HT components are much more (~100X) expensive than conventional components, so the cost of the electronics will rise from trivial to a significant fraction of the total cost of the tool. Second, the HT components are not simple plug-in replacements for the conventional equivalent, but will require completely new tool designs (which will be considerably larger than their low-temperature versions.) Finally, availability of the HT components will be driven by the market size, and drilling industry requirements may not be enough to support high production rates, thus limiting dissemination of this technology.

Active cooling: APS Technologies has a prototype thermo-electric (TE) cooling device that can be inserted into a downhole tool. Although not a production item, it could be designed to protect a small number of specific components, preferably inside a Dewar. The TE device, however, draws substantial electrical power – more than could be supplied by batteries – so it would require a downhole power supply, limiting many applications.

Drilling motors

Most downhole motors used for directional drilling are the positive-displacement type in which a metal rotor turns inside an elastomer stator. The stators are vulnerable to high temperature because they swell, which means that the motor can lock up and/or chunks of the stator can rip off and plug the bit. Either of these will lead to a trip without circulation, and this lack of circulation is also highly detrimental to the electronics that are virtually always associated with the motors. Even if the bottom hole assembly makes it back to the surface without further damage, there is a high repair bill for the motor. Conventional practice with PDMs is to use a rotor-stator set with high clearances to allow for the swelling, but this gives low efficiency at lower temperatures and is not fool-proof for avoiding the problems.

Downhole turbines with higher temperature resistance are sometimes used in hot holes, but generally they operate at higher rotary speeds and lower torque than optimum drilling would suggest. A number of attempts have been made to build gear reducers that will alleviate this problem, although they have had limited success so far.

Drilling fluids

Almost all HTHP wells are drilled with oil-based mud (OBM), primarily because it maintains its properties at elevated temperature better than water-based muds (WBM). Even so, the rheological properties of OBM deteriorate as temperature increases – “However, most commercial oil base drilling fluid systems have limitations such as reduced rheology and filtration control if the fluid is exposed to temperatures higher than 300°F (149°C) for prolonged periods of time”[1]. Reducing the maximum and average temperatures seen by the drilling fluid will improve its performance, particularly since the reaction rate for any contaminants in the fluid will increase exponentially with temperature.

It is also possible in some cases that reducing drilling fluid temperature could allow the use of WBM instead of OBM. Many wells, especially offshore, are in environmentally sensitive areas where OBM is rigorously controlled because of its potential ecological impact. Case histories[2] have shown that custom-designed WBM could replace a conventional oil-based mud that was essentially unusable because of environmental restrictions -- this does not relate to temperature *per se*, but simply shows the problems that OBM can present. Finally, OBM are typically much more expensive than WBM, so this potential replacement would be an up-front cost savings in consumable material

Summary

Compared with other high-temperature drilling technologies, some of which can and will be used in conjunction with IDP, insulated pipe has the following limitations relative to conventional pipe.

- Weight: Nominal 3.5" diameter IDP weighs approximately 25% more than conventional pipe. With smaller pipe sizes typical of deep gas, this will not be an issue of rig capacity, but very deep wells might require a tapered string to support tensile load. Tensile tests during Phase 1 should clarify this limitation.
- Hydraulics: Because of the smaller inside diameter created by the insulation and liner tube, there will be a greater pressure drop than with conventional pipe of the same nominal size with the same flow rate. A 1999 field test with a full string of 5" IDP showed that the additional pressure drop in IDP was smaller than might have been expected from only considering the inside diameters.
- Returns temperature: Drilling fluid returns will be hotter with IDP than with CDP, but if this is an issue for surface equipment, it can be controlled with mud coolers (a mature technology.)
- Market acceptance: There is always some resistance within industry to unproven technology, but we intend this project to have a major impact on that attitude.

All other high-temperature drilling technologies, however, are attempts to withstand the high-temperature environment – only IDP gives a method to control that environment. It has these specific strengths.

- Ease of use: IDP is handled exactly as conventional pipe, with no learning curve for the rig crew.
- Ruggedness: The IDP design is straightforward, and prototype joints have already withstood significant exposure in actual drilling conditions. This project will extend, and document, that capability.
- Flexibility: Figure 1 showed the difference in drilling fluid temperature profiles with IDP and CDP, but if a profile between those two is required, it can be tailored by combining the two kinds of pipe in the drill string.

References

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Much more detail on previous IDP work is given in these documents.

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