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Topical Report

Preliminary Design of Insulated Drill Pipe for High Temperature, High Pressure Drilling

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Abstract: This report contains a summary of the design and construction of a preliminary version of Insulated Drill Pipe. We list the design principles, component materials, and assembly methods used in IDP construction. Critical issues to be addressed during the project are also identified.

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Executive Summary

Insulated Drill Pipe is a technology that allows management of downhole drilling fluid temperatures. This is valuable for protection of expensive electronics, drilling motors, and other vulnerable components in the bottom-hole assembly (BHA). This report summarizes a preliminary design for IDP that would be suitable for HTHP deep gas wells. The underlying principles that led to this design, the materials used in construction, the assembly method, and the critical issues to be addressed during this project are described. Certain details of the insulation material and the assembly method are proprietary to Drill Cool Systems, but these details have been provided to DOE in a separate document.

1.0 Design Principles

In considering the general concept of insulated drill pipe, many design decisions are necessary: what kind of insulation should be used, how should it be applied/attached to the drill pipe, how much protection does it need, and what should be the overall configuration of the assembled pipe? Many of these decisions, however, are greatly simplified by the fundamental principle that a relatively small amount of insulation has a major impact on drilling temperatures. With that in mind, we can examine several design features in more detail.

Insulation quality: The general concept of IDP is shown in Figure 1.

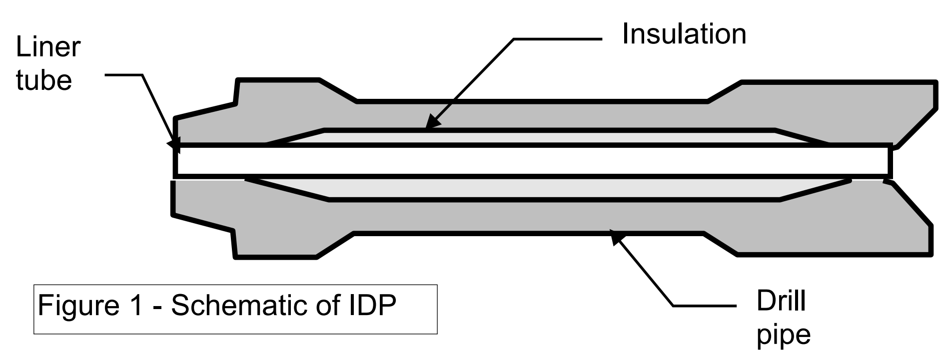

Figure 1 - Schematic of IDP

In the equation for heat transfer through a unit length of the insulated portion of the pipe, five quantities make up the thermal resistance through the pipe wall: convective heat transfer coefficients at the outside and inside surfaces, and conductivities of the drill pipe, the liner tube, and the insulation. For conditions typical of drilling, four of the five quantities are numerically of similar magnitude. Only the quantity that represents the low-conductivity insulation is much larger than the others. For conventional steel pipe (CDP), then, the convective and conductive terms are relatively equal in importance, while the insulation dominates the total heat transfer for insulated pipe. This means that even a small amount of insulation has a significant effect on heat transfer; in other words, the insulation doesn't have to be extremely efficient.

Another limit on minimum heat transfer is set by the uninsulated tool joints at each end of each piece of pipe (Figure 1), which would conduct heat even if insulation in the pipe body were perfect. In considering possible insulation materials, there are many kinds of plastic, glass, or rock that have conductivity, or *k*, values from 0.1 to 0.5 B/hr-ft-F, compared to steel at 26 or good insulators such as cork at 0.025 or glass wool at 0.022 B/hr-ft-F, so a key question is to determine what range of *k* value is necessary. In evaluating insulation requirements, however, calculated drilling fluid temperatures (including the effect of the tool joints) show that there is little difference in performance among IDP designs with an insulating layer having conductivity values of 0.05, 0.3, and 1.0 B/hr-ft-F (see Table 1 for calculations in a 10,000 ft. geothermal well).

Insulation conductivity, B/hr-ft-F	Bottom-hole circulating temperature, ^{o}F
None (conventional drill pipe)	400
0.05	165
0.3	172
1.0	192

Table 1—Effect of insulation value

<u>Tool joints</u>: Using the same rationale as above, there is little advantage to insulating the tool joint area, since this only represents about 10% of the total length of the drill string (and the tool joints' wall thicknesses are already much greater than the pipe body, which reduces heat transfer through them.) Insulating the tool joints is also a difficult technical challenge, which would adversely affect cost, complexity, and reliability.

<u>Insulation protection</u>: Given that the insulating layer is contained between inner and outer metal tubes, there is a question as to how much protection it needs. Early in the IDP evolution, the inner tube was designed to be strong enough to withstand internal pressure on its own, but with the use of an insulating material having enough compressive strength to support the liner tube against internal pressure in the pipe, the liner tube can be of much less robust construction.

<u>Pipe strength</u>: Because of the design approach discussed above, strength of the IDP is taken to be the strength of the parent drill pipe. This pipe is first modified by attaching the liner tube and by drilling a hole in the flank of the tool joint to fill the annular cavity with the insulation material. The liner tube and the insulating material are thus assumed to neither detract from nor add to the strength of the original pipe insofar as pressure capability is concerned. Because the IDP is somewhat heavier than equivalent CDP (16.4 lb/ft versus 14.2 lb/ft for the preliminary 3.5" design) there may be an issue with tensile strength for very long drill strings.

2.0 Design Drawings

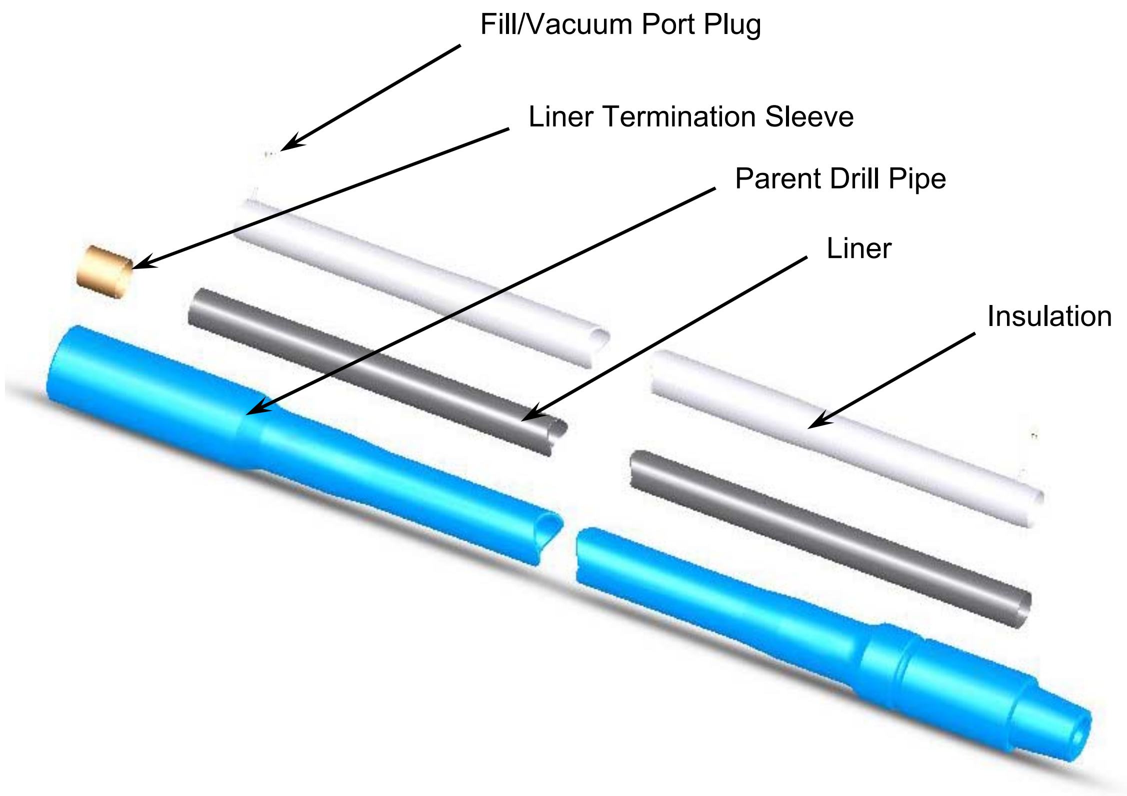

Figure 2: IDP Components

Conventional Drill Pipe Description	3-1/2"	13.3#	NC38
Conventional Drill Pipe Tool Joint ID (in)		**2.125**	
Conventional Drill Pipe Nominal ID (in)		**2.764**	
Insulation Thickness (in)		0.195	
Liner ID - IDP Adjusted ID (in)		**2.245**	
IDP Adjusted Weight per Foot (lbs/ft)		16.426	

Table 2: IDP dimensions

The parent drill pipe is conventional drill pipe, but its tool joints are modified for its conversion to Insulated Drill Pipe (IDP). These modifications can take place before or after the tool joints are welded onto the pipe and do not affect the mechanical (strength) performance of the parent drill pipe.

The Box tool joint is bored through to provide full clearance for the Liner and also has a radial hole for insulation fill.

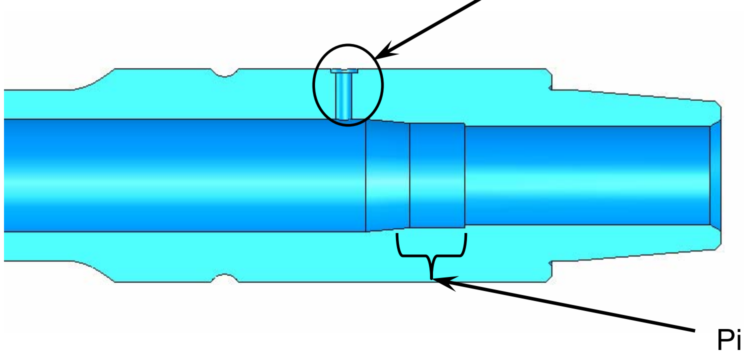

Figure 3: Pin Tool Joint Modifications

The Pin Liner Register provides a clearance fit to the liner as it is inserted into the parent drill pipe through the box tool joint, and serves as a “stop” to position one end of the liner. The two ports placed in the tool joints provide a point to inject the, then liquid, insulating component into the annular cavity created between the internal upset of the drill pipe and the outside diameter of the liner.

Liner:

The liner has two functions: it combines with the internal upset of the parent drill pipe to create an annular cavity into which the insulation is injected, and it protects the insulation from damage during drilling processes such as logging runs. It is important to note that the liner does not provide any mechanical strength to the drill pipe, but transmits all loading to the parent drill pipe.

Material selection for the liner still provides a number of opportunities for improvement. Due to the prototype nature of this design, thin wall tubing in 1020 carbon steel was selected due to its economic benefits and availability.

Liner Termination Sleeve:

The Liner Termination Sleeve positions the Liner in the box tool joint. Sleeve material is currently type 360 Brass.

Insulation:

The Insulation is the most critical component of the IDP design. The insulation is comprised of a high temperature elastomer composite good for over 500ºF and 18,000 psi.

Assembly:

Liner Placement:

The Liner is inserted into the box end of the Parent Drill Pipe, then measured and cut to length.

Liner Termination Sleeve Placement:

With the Liner in place, the Liner Termination Sleeve is inserted into the box tool joint and verified for correct placement. It is then mechanically fixed in place to secure the Liner.

Injection of Insulation:

With the insulation components mixed and properly de-aerated, it is ready for injection into the annular cavity between the internal upset of the drill pipe and the outside diameter of the Liner.

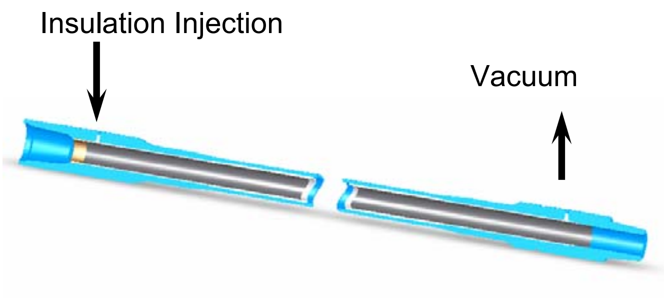

Figure 4: Injection of Insulation

Insulation Production Cure & Installation of Port Plugs:

With the insulation in place, it is allowed to complete its an-aerobic cure process. After curing, the fill equipment is removed and Port Plugs are installed. Bakerloc™ locking/sealing compound is applied to the exposed plug to provide a finished surface.

3.0 Materials

There are only four major components of the IDP: drill pipe, insulation, liner termination sleeve, and liner tube, with the minor addition of the fill plug for the insulation cavity. Materials for these are listed below.

SPECIAL NOTE: Specifications for the insulation material and details of the liner installation process are PROPRIETARY to Drill Cool Systems

Drill pipe: 3.5” S-135 internally upset (IU) drill pipe with a NC38 connection

Insulation: High Temperature Elastomer Composite

Liner termination sleeve: type 360 Brass

Liner tube: 1020 carbon steel thin-wall tubing

Fill plug: ⅛” NPT Hex Socket Plug, yellow brass.

SPECIAL NOTE: Specifications for the insulation material and details of the liner installation process are PROPRIETARY to Drill Cool Systems

4.0 Anticipated Environments

Insulated pipe can be used in any HTHP environment serviced by conventional drill pipe. None of IDP's components are susceptible to high temperature and its performance does not change with temperature. The parent drill pipe can be any grade, in case there is a need for corrosion resistance or other unique properties.

Figure 5 shows the calculated effect of IDP on drilling fluid temperature in a 15,000 ft gas well modeled using drilling parameters from an actual well. Impact on fluid temperatures will be affected much more by drilling parameters than by properties of the pipe itself. Drilling fluid type, fluid flow rate, formation lithology, and other variables will all have an effect on the drilling fluid temperature, but the most important variable is likely to be the initial formation temperature profile.

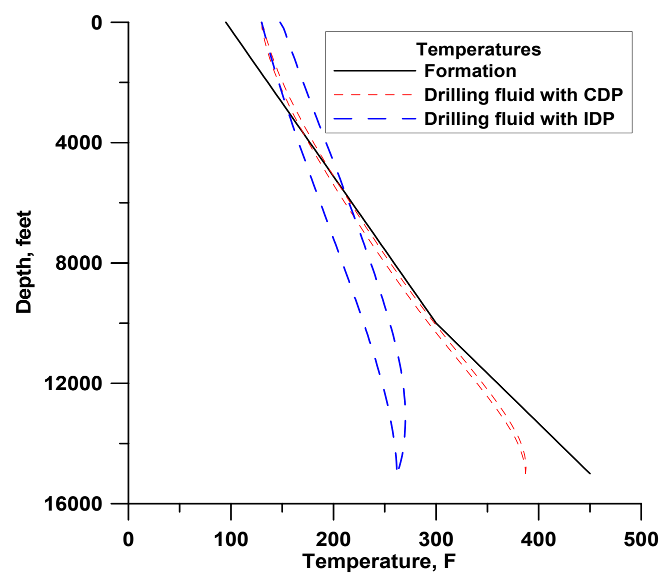

Figure 5 – Drilling fluid temperatures with IDP and CDP

Because of these variations, it is impossible to guarantee that IDP will change fluid temperatures by a given amount in an arbitrary well, but we believe that the case modeled here, as well as numerous others examined in the past, are typical enough to assure effective temperature management in a large share of HTHP wells.

A possible limitation on IDP use is its inside diameter, which is smaller than equivalent conventional pipe because of the liner tube. This means that, for a given flow rate, there will be greater pressure drop through a string of IDP than through an equivalent string of conventional pipe. A key feature of our industry interviews will be development of a consensus on what pressure drops are acceptable – this answer may drive the final choice of size for the prototype IDP.

5.0 Critical Design Features

Based on previous industry comments and experience with earlier versions of IDP, there are several design features that will receive special attention during development of the mechanical testing and inspection plans. These are listed below, although they are not in any priority rank.

- Hydraulics – as discussed above, there is some industry concern over potentially high pressure drop in long IDP strings. We expect to resolve this issue during industry interviews and develop final design criteria for the prototype pipe that will be acceptable to a majority of users.

- Inspection – insertion of the liner tube will prevent direct optical inspection of the drill pipe ID. We will develop an inspection plan to evaluate appropriate inspection methods for detecting flaws on the drill pipe's inner surface.

- Fill plug – there has been some concern that the fill plug could come loose, which would almost certainly lead to a washout. Both the inspection plan and the mechanical testing plan will address this concern, and we will modify the fill plug final design if necessary.

- Liner attachment – if the liner tube attachment fails, it is possible that the tube could deform, or even detach completely, blocking flow through the pipe and possibly damaging downhole equipment. Both the inspection and mechanical testing plans (including fatigue testing) will address this issue.

- Internal pressure – during mechanical testing, we will verify the compressive strength of the insulating material and, if necessary, establish pressure limits for IDP application.

6.0 Acronyms and Abbreviations

IDP -------- Insulated Drill Pipe
CDP ------- Conventional Drill Pipe
BHA ------- Bottom Hole Assembly
HTHP ----- High Temperature, High Pressure
B ----------- British Thermal Unit
k ----------- Thermal conductivity
EW -------- Electric Welded
DOM ------ Drawn over Mandrel
ID ---------- Inside Diameter