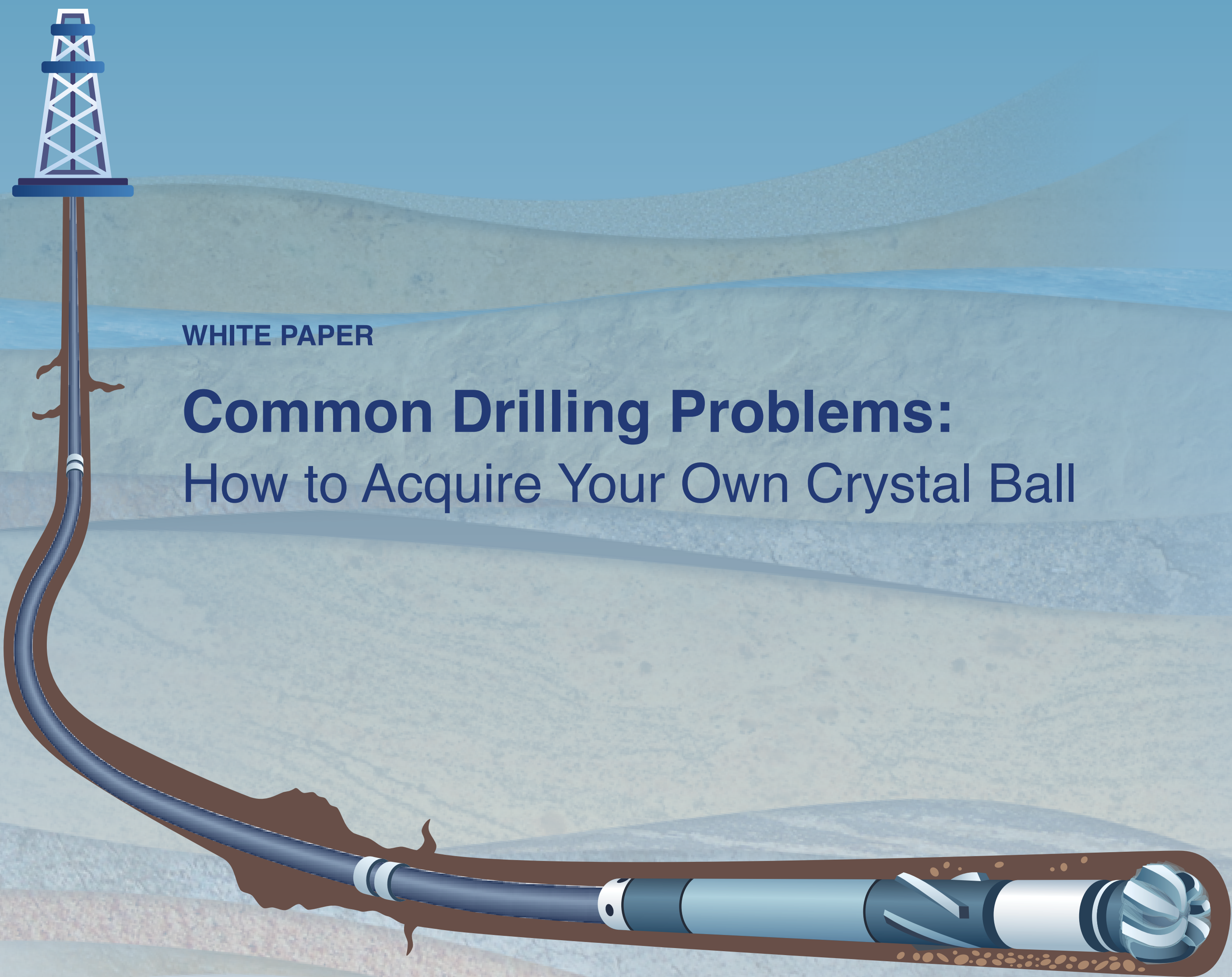
Pegasus Vertex, Inc.

Drilling Software | Sophisticated Yet Simple

WHITE PAPER

Common Drilling Problems:

How to Acquire Your Own Crystal Ball



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I. Abstract

Common Drilling Problems Intro

When the author of this paper first entered the industry, he heard the challenges of reaching and operating in the downhole environment likened to that of reaching and operating in space. Certainly, at thousands of pounds per square inch, it is not for the faint of heart, with extremely high temperature and dynamic downhole conditions that are difficult to measure they are often only guessed drilling and completing wells to access hydrocarbon resources. In this white paper, we will examine common challenges in drilling, their causes and potential solutions. With a little know how and a little help, you can acquire your own personal crystal ball.

Drilling Problems

There are many common problems encountered during drilling and many ways to group and reflect on how to address these challenges. Some of those challenges include hole deviation, pipe failure, borehole instability, formation damage, lost circulation, pipe sticking, mud contamination, and poor hole cleaning. We will group those problems into categories related to mechanical, wellbore, and mud.

- **Mechanical Problems:** Hole Deviation; Pipe Failure
- **Wellbore Problems:** Borehole Instability; Formation Damage; Lost Circulation; Pipe Sticking
- **Mud Problems:** Mud Contamination; Poor Hole Cleaning

II. Mechanical Problems

Hole Deviation

Those outside of the oil and gas industry may be surprised to find drilling through rock isn't done in a straight line and gradual curves. Like grains in wood, rock is not homogeneous in texture. As the earth moves and tectonic plates shift, dip angles form. Even while drilling vertical wells during the industry's infancy, drillers quickly recognized that the bit would not drill straight down, but rather 'walk.'

Figure 1: Hole Deviation

In response to this tendency of the bit to deviate from the center, heavy weight was stacked on top of the bit in an effort to rely on gravity to bring the bit pointed back in a downward direction each time it walked away from vertical. The solution was the development of the first bottom hole assemblies, or BHAs, which were made primarily of thick, heavy components known as drill collars.

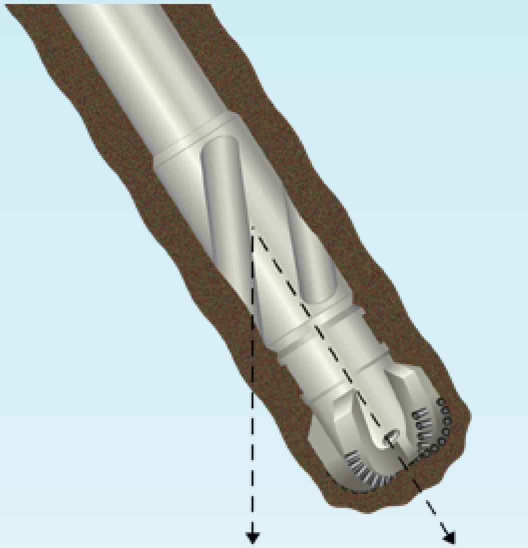


Figure 2: BHA and Gravity's Pull

Other methods of maintaining a less tortuous and more straight direction while drilling includes the use of stabilizers, bit type selection, operational parameters, and even evaluating the geology to choose the most likely locations to drill through to the hydrocarbon reservoir. Placing a stabilizer near the bit and potentially others in the BHA will help the string stay centered, and the bit pointed in the correct direction. When deviated wells require a smooth wellpath, rotary steerable systems (RSS), can be selected in preference of the more commonly used mud motors.

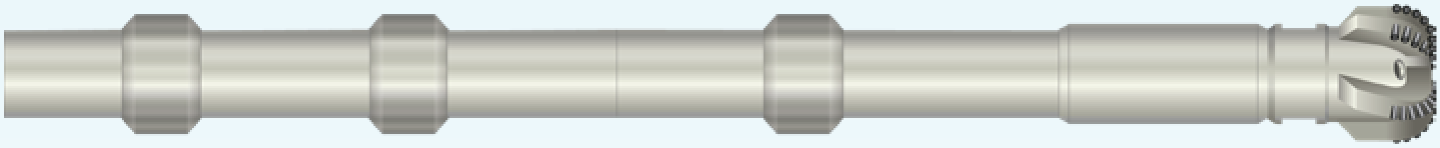


Figure 3: BHA with Components

Operational parameters include the strings speed of rotation, or rpm, and the weight that the rig loads onto the bit, called weight on bit or WOB. When the drilling operation is optimized to achieve the highest rate of penetration (ROP), the wellbore trajectory can become less smooth.

Pipe Failure

When the mechanical limitations of the pipe body, welded areas, or threads are exceeded, pipe failure can occur. These mechanical constraints are broadly related to tensile capacity, torsional yield, burst/collapse resistance, and fatigue stress endurance. While entire textbooks could be written about these limitations for mechanical engineering classes, we will discuss some of the most common pipe failures, their causes, and potential remedies in broad strokes.

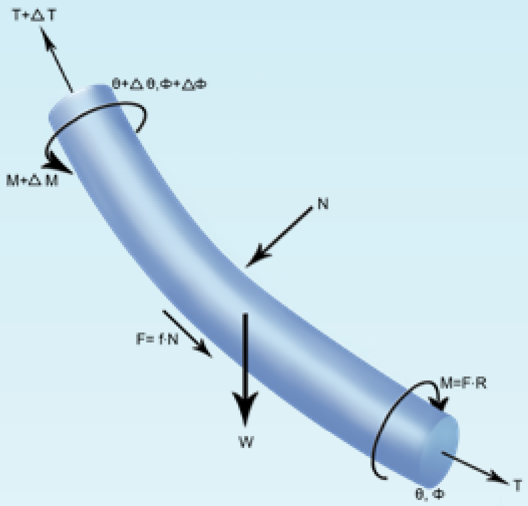


Figure 4: Torque and Drag String Segment

Drill pipe has a tension limitation that is calculated directly from the pipe body's cross sectional area and yield strength in psi, with a safety factor usually applied. The torsional limitation of the pipe is calculated in a similar manner. If the string becomes stuck and the rig does not respond quickly enough, it is possible to build up a significant amount of tension while pick up or torque while rotating that the pipe body's limits are exceeded. Fatigue happens due to repeated movement under stress that slowly weakens the pipe over time, in much of the same way that bending a metal coat hanger back-and-forth repeatedly will allow a child to break it for roasting s'mores over a campfire.

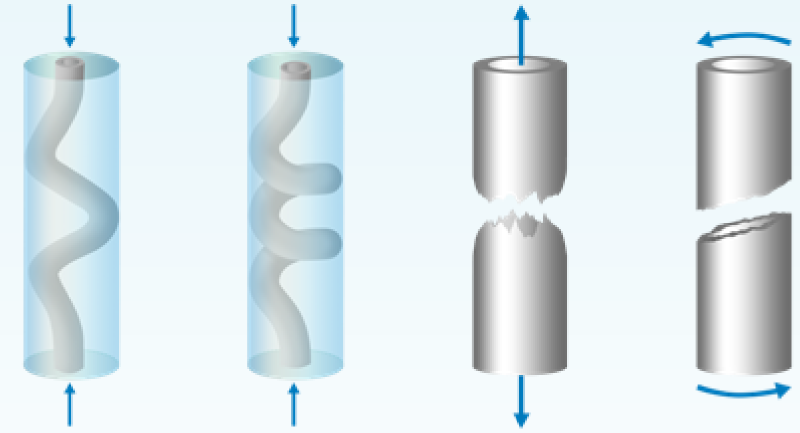


Figure 5: Torque and Drag Common Failure Modes

There are many potential downhole events and characteristics that can cause mechanical pipe failure. Significant doglegs, a high friction factor as a result of a tortuous wellpath or a poorly cleaned hole, and other issues such as using too heavy a string, encountering an obstacle, or the need to transfer weight or torque to a downhole tool. Though drilling a straight and clean hole may be earnestly attempted, no wellbore is perfectly smooth or squeaky clean.

Regular, thorough inspections of the drill string are recommended to ensure that it has not weakened due to reduced wall thickness, cumulative fatigue, or a chemical process such as rust or sour gas corrosion. Modeling the expected forces in a torque and drag (T&D) program and establishing a risk profile using a friction factor sensitivity can be crucial to successfully operate within the pipe's limits.

III. Wellbore Problems

Boreholle Instability

A general rule is the deeper that a rig drills, the higher the pressure. Rocks have mechanical properties, bear the weight of all the rock above, and can be fractured under stress. Within the rock formation, there is also interconnected pore space that contains fluid under pressure. To make matters even more complicated, the typical highly treated mud additives can chemically interact with the various formation types that are drilled through to reach the hydrocarbon reservoir.

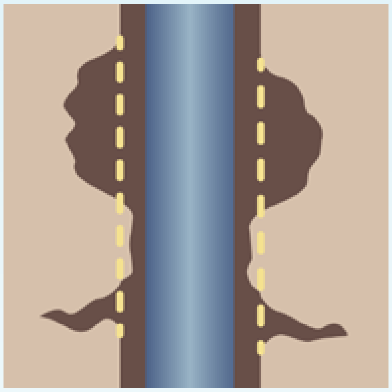
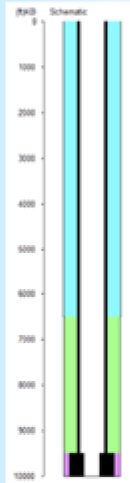


Figure 6: Borehole Instability

Drilling into the formation exposes the previously isolated rock and pore fluid to the wellbore. Interaction between the drilling mud can result in a rock fracture if the fluid circulating pressure in the wellbore is too high, or formation fluid influx into the wellbore if the fluid circulating pressure is too low. The hole might also slough in restricting the hole ID, or wash out enlarging the hole ID.



$$p_p = \Delta p_s + \Delta p_{dp} + \Delta p_{dc} + \Delta p_b + \Delta p_{dca} + \Delta p_{dpa} + \Delta p_h$$

p_p	pump pressure
Δp_s	pressure loss in the surface equipment,
Δp_{dp}	pressure loss inside drill pipe
Δp_{dc}	pressure loss inside drill collar
Δp_b	pressure drop at bit
Δp_{dca}	pressure loss in the drill collar annulus
Δp_{dpa}	pressure loss in the drill pipe annulus
Δp_h	Hydrostatic pressure difference (annulus – pipe)

Figure 7: Pump Pressure

Mud engineers will treat the mud to maintain a density above the pore pressure when static, yet also a density and rheology that allow for an equivalent circulating density (ECD) lower than the frac pressure. Using hydraulics software models, engineers will select the appropriate drill string components that create an annular geometry, allowing for a tolerable amount of pressure loss while pumping, which adds to the ECD. Drillers will attempt to control the downhole circulating pressure by monitoring the pump pressure.

Formation Damage

As the hole is drilled, the formation that meets the bit and the drilling fluid is altered from its isolated virgin state. The mechanical process of drilling a new hole will crush, shear, and otherwise damage the formation. Solids from both the drilling mud and potentially small drilled cuttings can plug the pore spaces. Other factors can occur such as, clays containing hydrocarbons that might swell when exposed to water based mud. Since these alterations result in a reduction in both the near-to-the-wellbore permeability and ability to for formation fluids to flow into the wellbore, they are collectively referred to as formation damage.

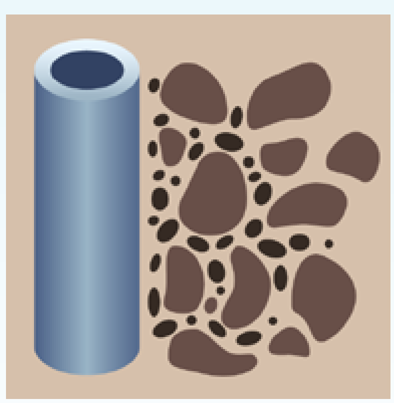


Figure 8: Formation Damage

Underbalanced drilling and/or the use of specific drill-in fluids can affect the impact drilling has on the hydrocarbon formation. Most commonly, completion/workover fluids and operations are used to treat, condition, or access the hydrocarbon bearing formation. Often times the design of the fluid treatments requires the prediction of the flow regime and annular contact time for specific spacers and washers, or mechanical operations such as drilling out frac plugs in long horizontals require thorough torque and drag modeling and analysis.

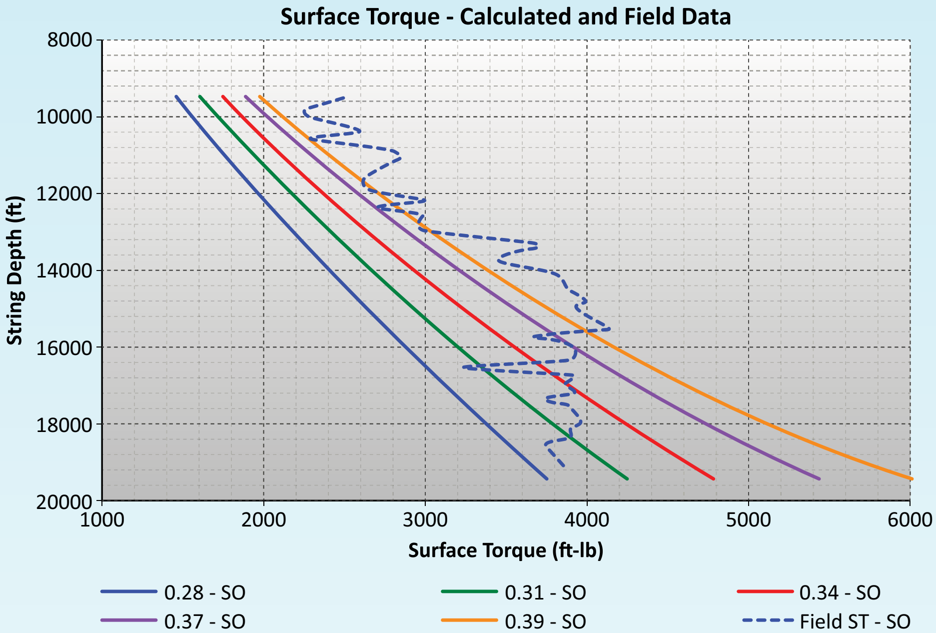


Figure 9: SPE 204410 Torque FF Matching Graph

Lost Circulation

Lost circulation is experienced when the uncontrolled flow of the drilling mud into the formation occurs. This flow is either called a partial or total loss, depending on how much of the drilling mud is lost as it is circulated past the lost circulation zone. As mentioned in the borehole instability section above, when the downhole pressure of the fluid during pumping (or ECD) is too high, the formation might fracture. Highly permeable and low pressure formations are also susceptible.

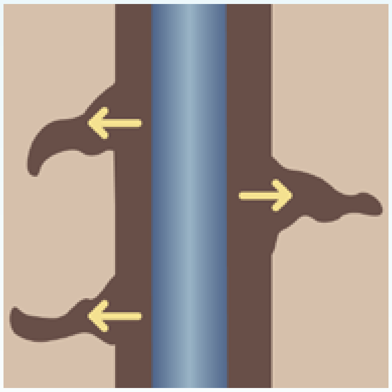


Figure 10: Lost Circulation

Maintaining proper downhole pressure to prevent losses occurring in the first place is desired. “An ounce of prevention is worth a pound of cure,” as the saying goes. Drilling engineers will also evaluate known formation pressures and depths of the well that they will drill to establish casing depths, and leak of tests (LOTs) and formation integrity tests (FITs) are performed once the casing is cemented to ensure zonal isolation.

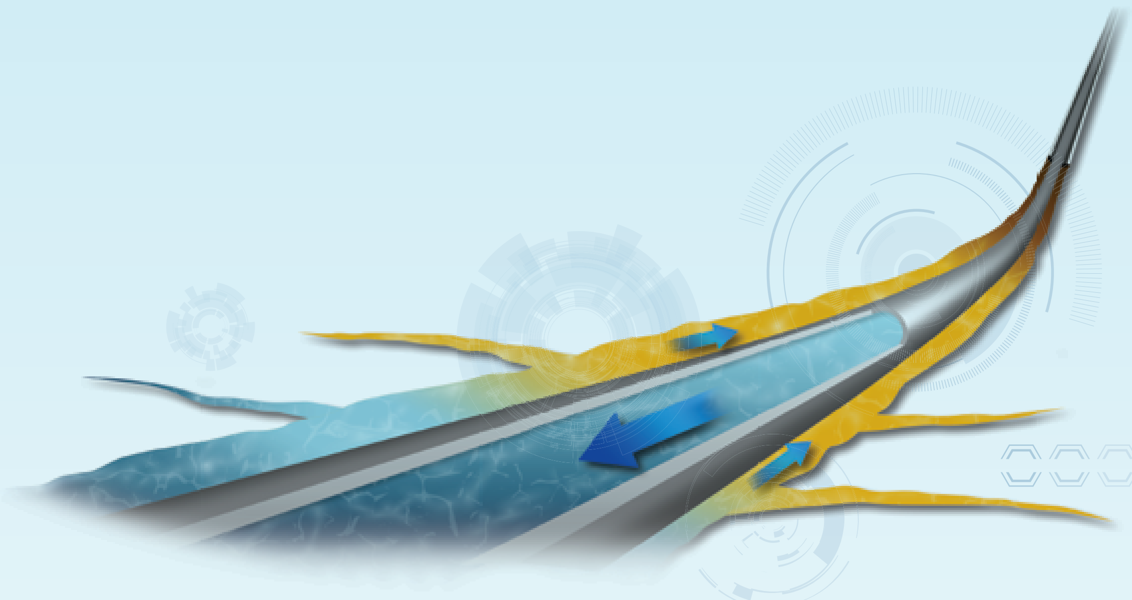


Figure 11: Lost Circulation Illustration

Bridging agents can be selected using engineering analysis based on pore and permeability values, as well as particle blend sizes, to form a filter cake while drilling that helps prevent formation/wellbore fluid communication. Lost circulation materials (LCM) can also be prepared to plug fractures and loss zones. Though LCM can be synthetic, natural materials like walnut shells are also used.

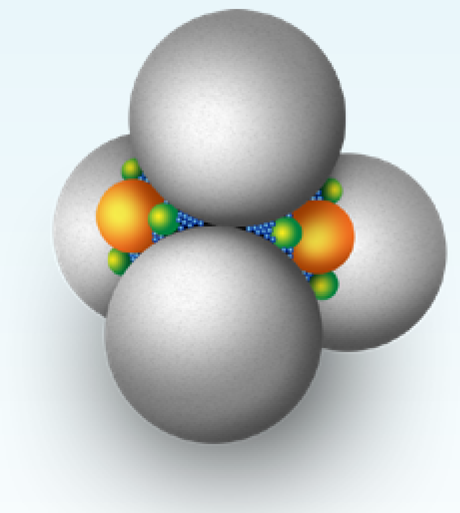


Figure 12: Bridging Agents

Pipe Sticking

The weight of the work string, drag in the wellbore, and long deviated or horizontal wellbores are mechanical aspects that make it difficult to move pipe in and out of the well. Excessive cuttings loading in the drilling fluid or lost circulation can also cause the same hydraulic challenge. When the annular pressure on the pipe is greater than the pressure in the formation, a suction on the work string can cause differential sticking.

Figure 13: Pipe Sticking

The drilling fluid properties can be managed to help prevent differential sticking, and lubricious additives or a slick mud system like oil based mud can be used to reduce drag. Filter cake maintenance via properly selected bridging agents in the drilling mud also helps, as this protects the string from the lower formation pressures seen while drilling overbalanced. Proper selection of pipe for adequate tensile capacity can help free differentially stuck pipe by allowing the rig to pull it free, and a broomstick plot evaluating a range of friction factors can assist with identifying the needed capacity.

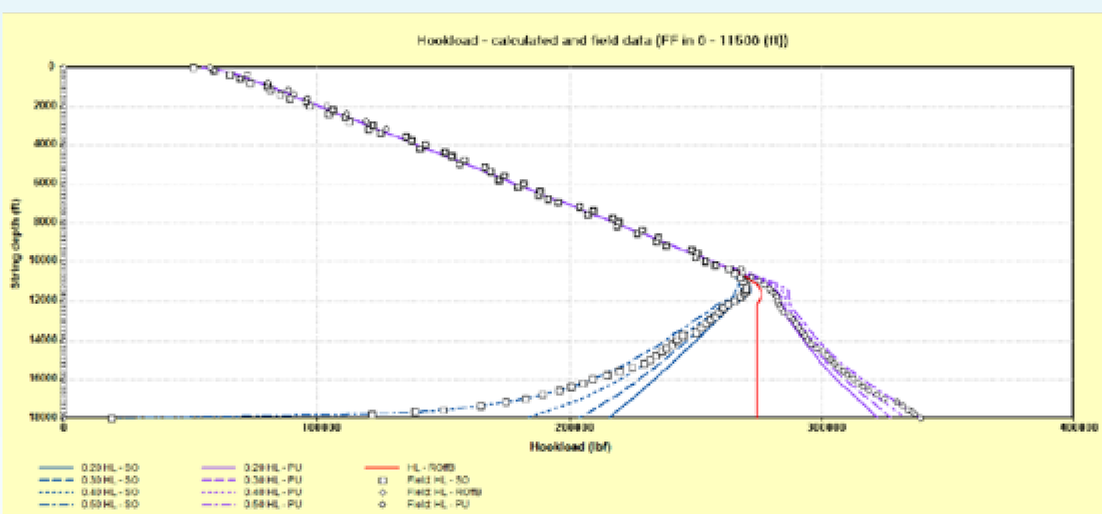


Figure 14: Hookload FF Sensitivity for Pickup Line; SPE 156945

IV. Mud Problems

Mud Contamination

Many aspects of how the drilling system interacts with the downhole environment are intricately linked to mud properties. Maintaining the rheology of the drilling mud in the desired window is a large part of why full time, back-to-back mud engineers are present on drilling rigs across the globe. Constant monitoring allows the mud engineer to add base fluid if the additive concentrations rise too high, drilled materials accumulate in the mud system, or a variety of other changes, such as evaporation or environmental losses, occur. One of the telltale signs of mud contamination is an increase in the rheological properties. If the mud is measured on a regular basis, the mud engineer will notice that the fluid is thickening and becoming more viscous. If testing the mud does not catch the contamination, an undesired slowing of the rate of penetration (ROP) may occur. The ROP is a key indicator of drilling performance, measuring how fast the rig is able to drill additional holes.

Figure 15: Drilling Fluids

One of the main methods for recording, tracking, and communicating the ever-changing conditions of the mud, additives used, and losses/additions to the volume of the mud system is the daily mud report (DMR). Depending on the mud company at the rig site, this could potentially be done by hand and paper, using a home-crafted spreadsheet, or a sophisticated software program. The DMRs are often viewed on a daily basis by the operator, multiple service companies, in addition to the rig staff.

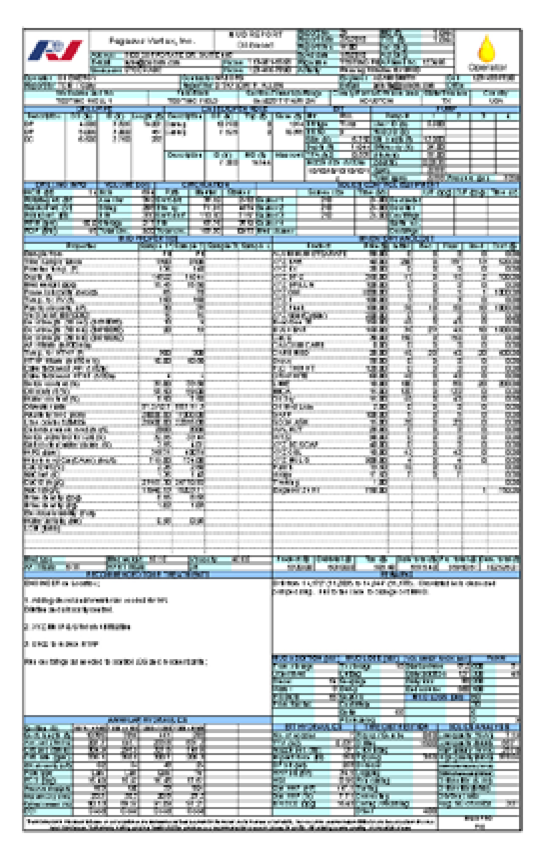

Pegasus Vertex, Inc.
MUD REPORT
Operator

Figure 16: Daily Mud Report

Poor Hole Cleaning

Though there are numerous potential causes for problematic occurrences such as excessive torque and drag, premature bit or downhole tool wear, and reduced ROP, poor hole cleaning is a common cause of all three of these downhole challenges. As the bit drills up the rock to make new hole, the circulating mud will carry these cuttings up and out of the hole. When the volume of cuttings generated while drilling exceeds the volume of cuttings transferred out of the hole, a buildup of cuttings known as cuttings bed occurs.

Figure 17: Poor Hole Cleaning

The dynamics of cuttings transport of a fluid are less favorable in a highly deviated or horizontal wellbore than for a slightly deviated or vertical one. As highly deviated wells became commonplace, so did the presence of cuttings beds. Mud properties are also important as low viscosity, or thin, fluids have a lower carrying capacity than thicker, more viscous mud systems. It is also not uncommon for the mechanical aspects of drilling to outperform the hydraulic capabilities of the mud system. The hole is simply being drilled too quickly in this case.

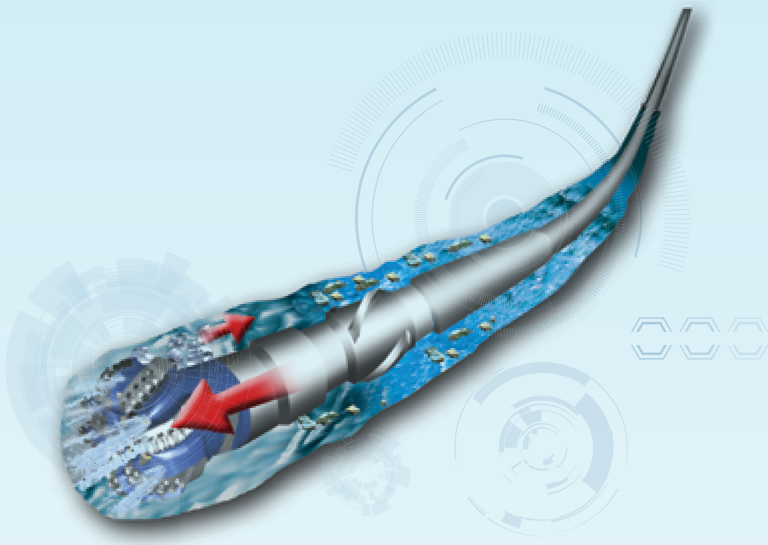


Figure 18: Drilling Hydraulics Illustration

Cuttings removal and transport is assisted at higher annular fluid velocities, so the pumping rate plays an important role. Rotation speeds of the pipe also affect hole cleaning, especially in highly deviated wells. The fluid properties are critical to cleaning the wellbore. Evaluating all of these aspects in concert prior to and during drilling requires a robust hydraulics hole cleaning model, which can often be provided by the mud company.

IV. Conclusion

The downhole environment is quite challenging, and this white paper has only addressed in a very general way some of the common problems associated with drilling wells to reach oil and gas deposits. Education, experience, and proper engineering analysis are all critical to successful drilling operations. As evidenced by their widespread use in the oil and gas industry, software is a needed tool to properly predict, analyze, and solve various challenges that arise while drilling.

When looking towards an upcoming well, using the experiences from prior similar wells will assist the drilling engineer in predicting potential challenges. These wells, which may be similar in geometry, depth, and location, are known as offset wells. Even with prior experience and data from offset wells, no engineer's crystal ball is... well, crystal clear. Every hole is unique, and any changes to the drilling system will have an impact on many aspects of that highly complex and interconnected system.

Figure 19: Some of the Popular PVI Drilling Software

To learn more about drilling software in general, or a specific type of program, please visit the Pegasus Vertex, Inc. (PVI) website at www.pvisoftware.com. Links to numerous technical papers, videos, and other resources are available on the site. Inquiries can also be sent to info@pvisoftware.com.

Thank you for taking the time to read through this white paper, and best of luck with your continued learning and development!

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