

Casing Drilling Allows for Safer Engineering Design

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Abstract

Casing Drilling is an innovative drilling method wherein the well is drilled and cased simultaneously. Historically, drilling design has been based on conventional drilling geometry; however, in time Casing Drilling will become one of the industry's best practices. With Casing Drilling the limits of well construction can be pushed even further since Casing Drilling introduces new benefits that modify conventional practices and offer a safer engineering design.

The small annulus of Casing Drilling can create a controllable dynamic ECD (Equivalent Circulating Density). Casing Drilling technology permits the same desired ECD to be achieved using a lower, but optimized, mud weight, plastic viscosity, and flow rate.

Casing Drilling eliminates conventional drill-pipe tripping. This allows for a wider operational mud weight window since the swab and surge safety margins do not have to be considered. Moreover, the Plastering Effect of Casing Drilling creates a very less permeable mud cake on the wellbore wall which augments the pressure containment of the borehole. The added pressure gradient might be enough to eliminate a string or enable the casing to be set deeper. This is very important for cases where the mud weight window is narrow such as in deep-water, depleted zone, and with HPHT wells.

Introduction

Years of drilling and exploiting petroleum reservoirs has left the drilling industry with a much more complex environment in which to work. Current drilling applications are frequently located in troublesome zones with depleted reservoirs and wells with severe wellbore instability. For this reason, flawless drilling engineering design is needed to assure success and minimize the risk of unwanted events. The more flexible engineering design of Casing Drilling has been extensively used to successfully drill through troublesome well sections where conventional drilling techniques have failed. Casing Drilling offers unique benefits due to its inherent design differences with conventional drilling. These differences allow for a more efficient use of the available

parametrical resources and, hence, a safer engineering design. This paper compares Casing Drilling with conventional drilling and seeks to quantify the differences between the two and explain how Casing Drilling is not only safer but also more efficient.

No Swab and Surge; Wider Operational Mud Weight Window

Swab and surge during tripping can be very problematic because this can cause the pressure to exceed the fracture gradient or fall below the kick tolerance. Since there is no tripping in Level 2 Casing Drilling (Figure 1), the problem of swab and surge is eradicated. For level 3 Casing Drilling (Figure 2), the BHA is tripped through the drift of the casing and swab/surge is mitigated by large bypass through the BHA as the tools are retrieved (Level 1 Casing Drilling involves reaming the casing to the bottom of a previously drilled well). This eliminates "off-bottom" well control situations and eliminates the possibility of kicks due to the swab pressure while tripping out of the hole. Moreover, the continuous circulation even when tripping prevents surge or swab conditions even when a new BHA is being used.



Fig. 1) Level 2 Casing Drilling



Fig. 2) Level 3 Casing Drilling

The importance of eliminating swab/surge cannot be overstated, as this frees operators from having to consider the trip margin when drawing the operational mud weight window. Trip margin is an overbalance to compensate for the loss of ECD and to overcome the effects of swab pressure during a trip out of the hole (trip margin is usually 0.5 ppg to 1 ppg). Elimination of trip margins from the operational mud weight window can help set the casing deeper or even eliminate a string. Figure 3 illustrates how in one example Casing Drilling has eliminated a string.

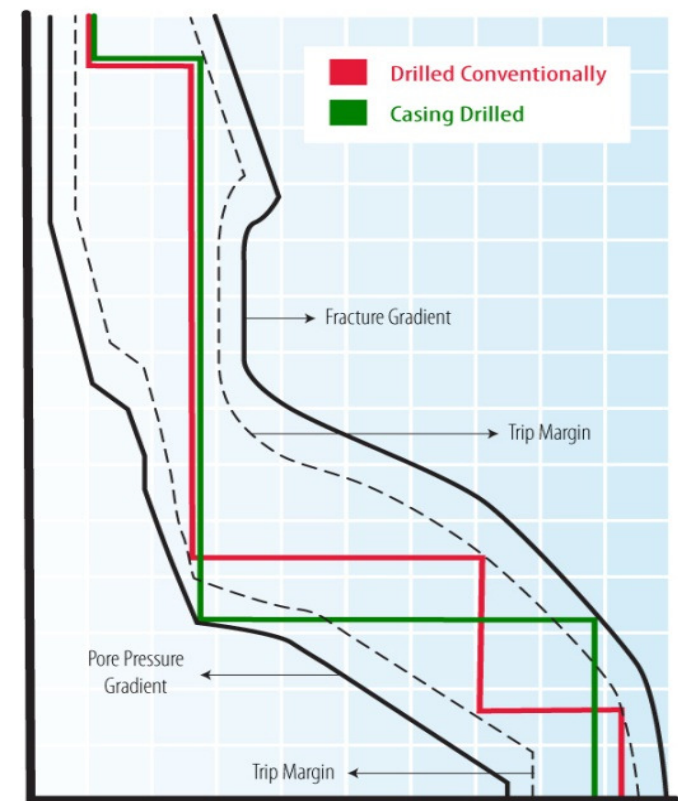


Fig. 3) Elimination of trip margins from the operational mud weight window can help set the casing deeper or even eliminate a string.

ECD Versatility

Casing Drilling geometry provides a better control on the annulus pressure profile. The small annulus brings about higher friction which leads to higher equivalent circulating density (ECD) in comparison to conventional drilling. At this section we provide several examples to show the differences inherent in Casing Drilling compared to conventional drilling. Consider the following scenario in which a same hole section is drilled using conventional drilling and Casing Drilling (Figure 4 and 5).

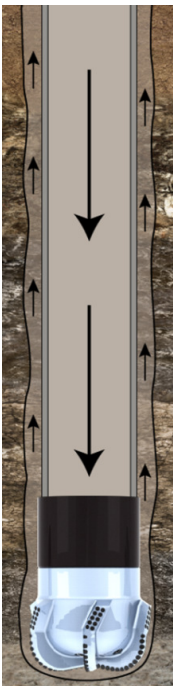


Fig. 4) Casing Drilling

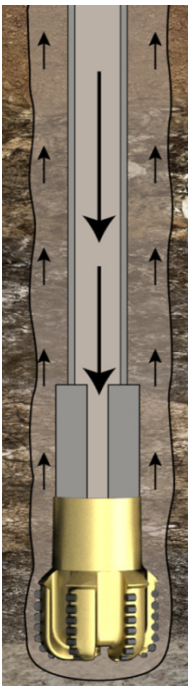


Fig. 5) Conventional Drilling

Table 1 summarizes the parameters used to drill these sections using both methods.

Parameter	Drilling Method	
	Conventional Drilling	Casing Drilling
Hole Size, in	8.75	
Bit Depth, ft	8000	
Previous Casing Depth, ft	500	
Flow Rate, gpm	450	
Mud Weight, ppg	11.8	
Plastic Viscosity, cp	14	
Yield Point, lbf/100ft^2	11	
Casing Size, in	NA	7
Drill Pipe Size, in	4	NA
Drill Collar Size, in	6.25	NA
Casing String Length, ft	NA	8000
Drill Pipe Length, ft	7460	NA
Drill Collar Length, ft	540	NA

With the conditions described in Table 1, the on-bottom ECD for both cases will be as follows:

Parameter	Drilling Method	
	Conventional Drilling	Casing Drilling
ECD at bit depth, ppg	12.1	14.1

The 2 ppg difference demonstrates the bad situation that can result from applying conventional thinking to Casing Drilling. There are certain practices that should be followed

with the more advanced design of the Casing Drilling hydraulic. These practices will be discussed in the following sections.

Smaller Annulus; Lower Pump Rate

The smaller annulus of Casing Drilling allows the use of a fraction of the pump output while still achieving the desired ECD. Table 3 shows that for the previous example the same ECD can be achieved by lowering the flow rate to about two-thirds (2/3) of the conventional drilling value.

Table 3) Effect of lowering the flow rate on Casing Drilling ECD

Parameter	Drilling Method	
	Conventional Drilling	Casing Drilling
Flow Rate, ppg	450	300
ECD at Bit Depth, ppg	12.1	12.9

Smaller Annulus; Possible to Lower the Mud Weight

Another way of redesigning the ECD is to lower the mud weight. Table 4 shows that for the above-mentioned example mud weight can be reduced to about 1 ppg of the original value.

Table 4) Effect of lowering the mud weight on Casing Drilling ECD

Parameter	Drilling Method	
	Conventional Drilling	Casing Drilling
Mud Weight, ppg	11.8	10.7
ECD at Bit Depth, ppg	12.1	12.9

Higher Annular Velocity; Possible to Lower the Plastic Viscosity

The Casing Drilling annulus generally provides a more restricted flow path so higher pressure losses are encountered. While the flow path is more restricted, it is also more uniform so the annular velocities are nearly constant from the casing shoe to the surface. (In conventional drilling, the annular velocity is different around the pipe and drill collar). Casing Drilling makes it possible to clean the hole with relatively low flow rates, but the drilling fluid properties must be properly considered and adequate hydraulic energy must be provided to clean the bit - and under-reamer, if level 3. Table 5 shows the annular velocities for the mentioned example.

Table 5) Casing Drilling wellbore cleaning vs. conventional drilling

Parameter	Drilling Method		
	Conventional Drilling	Casing Drilling	Casing Drilling with cuttings 30% smaller
Annular Velocity, ft/min	242.7 pipe	533.3	533.3
	392.0 collar		
Cutting Slip Velocity, ft/min	60.54 pipe	76.14	50.76
	69.91 collar		
Net Cutting Rise Velocity, ft/min	182.2 pipe	457.2	482.6
	322.1 collar		

It has also been observed that Casing Drilling generates smaller cuttings (due to grinding effect of the casing), and as the smaller cuttings are easier to transport, the Net Cutting Rise Velocity has improved for Casing Drilling (Table 5) as compared to conventional drilling where the cuttings transported to the surface are the same size as they are when generated (no grinding).

Cutting Carrying Index

CCI is calculated by an empirical relationship. If CCI is equal to 1 or higher, hole cleaning is more effective. If CCI is 0.5 or less, hole cleaning is relatively poor. Table 6 shows the improvement in CCI caused by the small annulus of the Casing Drilling. This becomes very important for wellbores with 35-65 degree inclinations where cutting transport becomes very problematic.

CCI is calculated using the following formula, where A_v is annular velocity in ft/min, M_w is mud weight in ppg, and K is the Power Law Constant:

$$CCI = \frac{K A_v M_w}{400,000}$$

Table 6) Cutting Carrying Index, Casing Drilling vs. conventional drilling

Parameter	Drilling Method	
	Conventional Drilling	Casing Drilling
Cutting Carrying Index	1.67 pipe	3.67
	2.69 collar	

It is believed that the small annulus of the Casing Drilling generates a mechanical agitation effect of the casing that helps prevent formation of cutting beds and facilitates cutting transfer. Moreover, due to the elimination of tripping, the well is being circulated most of the time. This eliminates the opportunity for cuttings to settle at the bottom of the wellbore as much as they do with conventional drilling. The higher annular velocity, the casing's mechanical agitation, and consistent circulation could be the reason why much less barite sag problems are present in Casing Drilling.

So far the lower flow rate and mud weight have been discussed as two ways to manage the ECD. The other possibility is to modify the plastic viscosity. Table 7 demonstrates how cutting the plastic viscosity to 50% of the original value affects the Casing Drilling ECD.

Table 7) Effect of plastic viscosity on Casing Drilling ECD

Parameter	Drilling Method	
	Conventional Drilling	Casing Drilling
Plastic Viscosity, cp	14	7
ECD at Bit Depth, ppg	12.1	13.7

Lowering the plastic viscosity could not have been possible if it was not for the higher annular velocity of Casing

Drilling (as there is less dependence on viscosity to transport the cuttings).

While different parameters can be modified to achieve the desired ECD, changing only one of them (flow rate, mud weight, or plastic viscosity) might create other problems. To prevent these extreme situations, the combination of these parameters must be carefully optimized. Table 8 shows a desirable situation in which all the parameters are modified and yet the same ECD is achieved.

Table 8) Modification of parameters to optimize the Casing Drilling ECD

Parameter	Drilling Method	
	Conventional Drilling	Casing Drilling
Mud Weight, ppg	11.8	11
Flow Rate, gpm	450	300
Plastic Viscosity, cp	14	10
ECD at Bit Depth, ppg	12.1	12

Operators should be fully aware of these inherent differences and take advantage of them to better design the Casing Drilling operations. Table 9 and 10 show how one operator has used best practices for their Casing Drilling operations

Table 9) Typical conventional drilling hydraulic parameters used by an operator (Reference: WOCWD-0431-04)

Hole Size, in	Drill Pipe Size, in	Interval Depth, ft	Flow Rate, gpm	Standpipe Pressure, psi	Annular Velocity, ft/sec	Surface Density, ppg	Annular Friction Loss, ppg	Total ECD, ppg
12 1/4	4	550	660	1400	122	8.8	0.1	8.9
8 7/8	4	8,000	500	2,000	203	11.0	0.3	11.3
6 1/4	4	11,500	225	3,000	241	15.0	1.2	16.2

Table 10) Typical modified hydraulic parameters for Casing Drilling used by an operator (Reference: WOCWD-0431-04)

Hole Size, in	Casing Size, in	Interval Depth, ft	Flow Rate, gpm	Standpipe Pressure, psi	Annular Velocity, ft/sec	Surface Density, ppg	Annular Friction Loss, ppg	Total ECD, ppg
12 1/4	9 5/8	550	550	750	257	8.8	0.7	9.5
8 7/8	7	8,000	300	1,300	253	10.5	1.0	11.5
6 1/4	4 1/2	11,500	225	1,800	295	14.5	2.0	16.5

Stiffer Pipe, Better Verticality

Level 2 Casing Drilling is often used in applications where the objective is to set casing across unstable formations and put them behind cement in as little time as possible. The key to drilling these sections successfully is confidence that the well path will be maintained when drilling with casing in either a vertical or in a tangent direction.

Non-retrievable BHA's are designed using the same philosophy that has been used to design conventional packed-hole, build and pendulum assemblies used to drill wells for

more than 30 years. In smaller casing sizes (5 1/2" and smaller) very little is different in Casing Drilling when compared to conventional BHA design; however, as casing OD increases, the stiffness of the assembly increases dramatically.

$$\text{Relative Stiffness Coefficient} = E \times I$$

Where E = Young's Modulus

I = Moment of Inertia

$$\text{And } I = \pi (OD^4 - ID^4) / 64$$

Therefore, 9 5/8" casing is 2.5 times stiffer than 7" casing, and 13 3/8 casing is nearly 5 times stiffer than 7" casing. The stiffer the casing, the less effect stabilization/centralization will have on the directional performance of the casing drilling assembly. When drilling with casing larger than 7" OD, fulcrum or pendulum assemblies become largely unrealistic, as creating the requisite bit tilt requires increasingly large WOB.

Counter to this trend, larger OD assemblies make for increasingly effective packed or holding BHA's. The portion of the BHA that significantly impacts directional control is the first hundred feet behind the bit. After this distance is exceeded, centralization has little effect on bit side cutting. By adding near gauge stabilization at 10', 20', 40' and 80' behind the drillable casing bit, an effective packed hole BHA can be constructed. The stabilizer gauge should be sized to within 1/4" of the well bore for maximum performance. Figure 6 below shows a series of wells drilled with 4 1/2" casing. The first three wells were drilled without any stabilization of the casing, whereas wells 4-7 used a stabilized BHA.

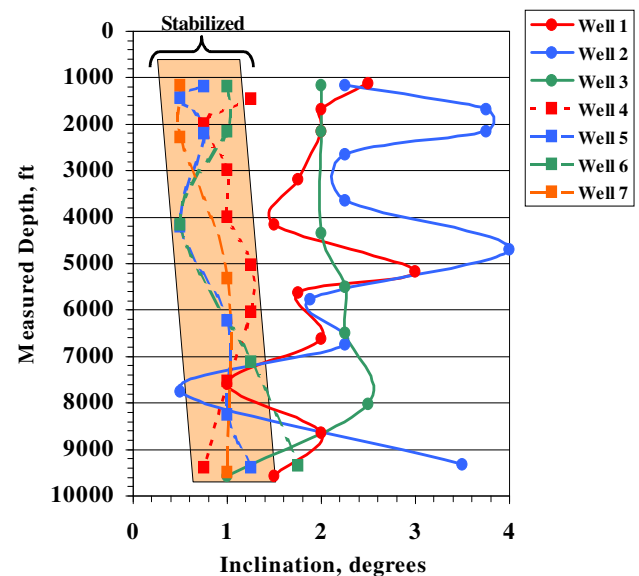


Fig. 6) Effect of stabilization on Casing Drilling directional performance

It is observable that the variation in inclination is dramatically reduced when the casing is centralized and stabilized. Lower torque at TD was also recorded for intervals 4-7 due to the resulting decreased well tortuosity. With properly designed centralization, Casing Drilling BHAs can be reliably used to drill vertical wells without the need for directional tools. The larger the casing OD, the stiffer the assembly and the less likely the assembly will deviate from vertical. In tangent sections, large OD casing can be used to drill for extended sections without gravity or formation tendency having significant effects on direction. Figure 7 shows the stabilization plan used for wells 4-7 in the previous example (Figure 6).

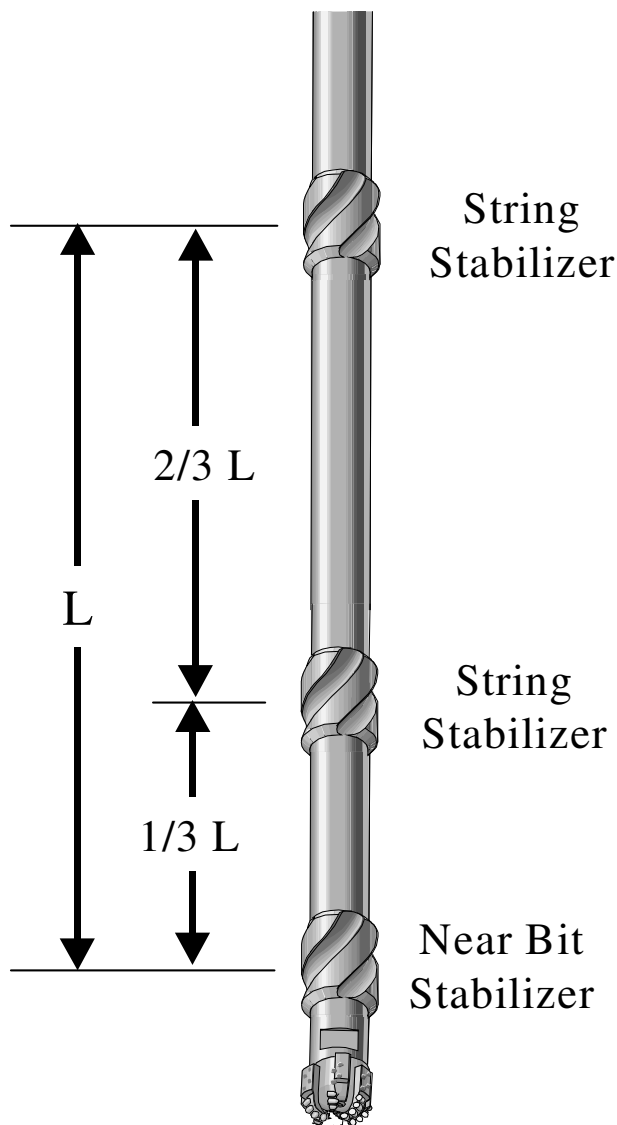


Fig. 7) Stabilized drill-string used for wells 4-7.

Lower Energy Consumption

Quantitative Analysis of Excess MSE & Correlative Analysis of Misused MSE

This section describes some of the parameters that characterize energy consumption while drilling, as well as the reciprocal relationship between energy misuse and performance limiters. Within the context of this writing, energy sources fall into two categories – Mechanical and Hydraulic. The former is exemplified herein, with specific focus on Teal's Mechanical Specific Energy (MSE) as a relative measure of drilling efficiency and as a criterion to find the founder point of the current system. During recent operations, quantitative analysis of MSE has been used to confirm or extend the design limitations of the current setup. Similarly, correlative analysis of wasted or misused MSE has been used to identify not only the root causes of various performance limiters but also the corrective actions that are suitable to maintain satisfactory levels of performance.

MSE has been used, as an operating tool, to characterize the manner in which bits drill and the factors that may affect their performance. Dupriest et al. (2005) evaluated efficiency with respect to the comparison between the theoretical energy that is required to destroy a given volume of rock versus the amount of energy that is actually used by the bit. The authors, furthermore, state that bits tend to transfer only between 30% and 40% of their input energy into the process of destroying rock. Increasing the WOB, to improve Depth of Cut (DOC), translates into proportionate gains in Rate of Penetration (ROP). Efficiency, on the other hand, remains unchanged due to the greater amount of energy that is being applied.

MSE can also be used to evaluate the efficiency of Casing Drilling. Sanchez et al. (2010), for example, depicted the observed energy requirements of Casing Drilling in Northern Oman through the UeR, FIQA Shargi, and Natih formations – also stating that historically high Rates of Penetration were reached for top-hole sections. Time-based MSE analysis, which they also described, revealed lower energy consumption for Casing Drilling in comparison to conventional drilling practices which, in some cases, have incurred considerable NPT or failed to reach TD. Figures 8a, 8b and 9a, 9b demonstrate example conventional drilling parameters in comparison to Casing Drilling. Figure 10a and 10b show how Casing Drilling parameters can be used to identify performance limiters.

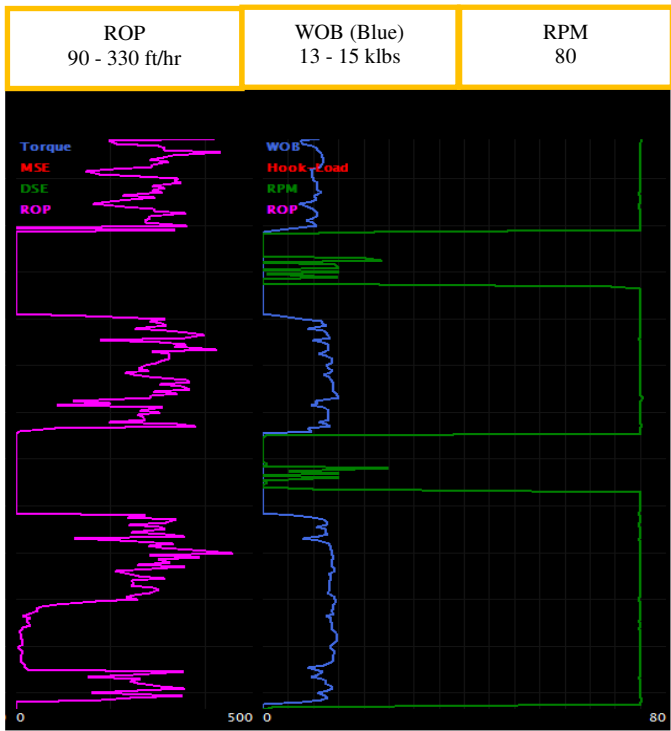


Fig. 8 a) Drilling parameters used in conventional drilling operation

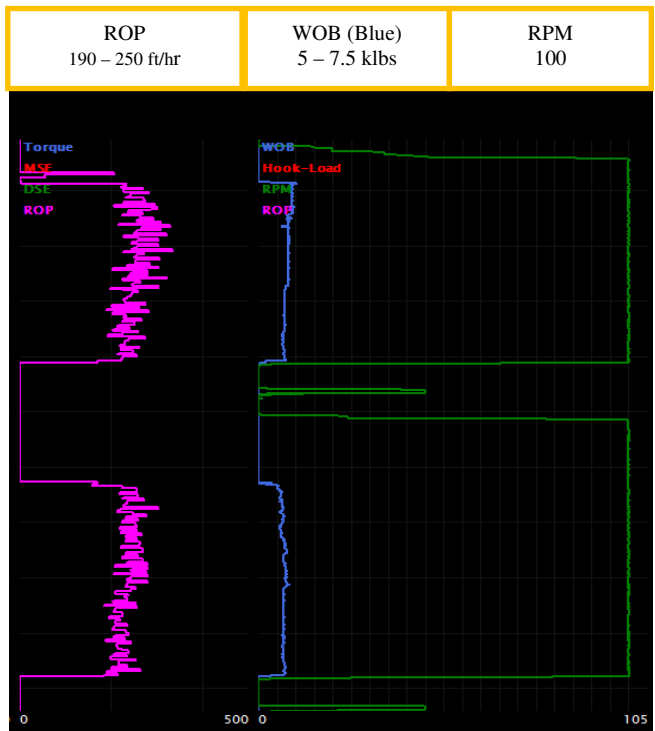


Fig.9 a) Drilling parameters used in Casing Drilling operation

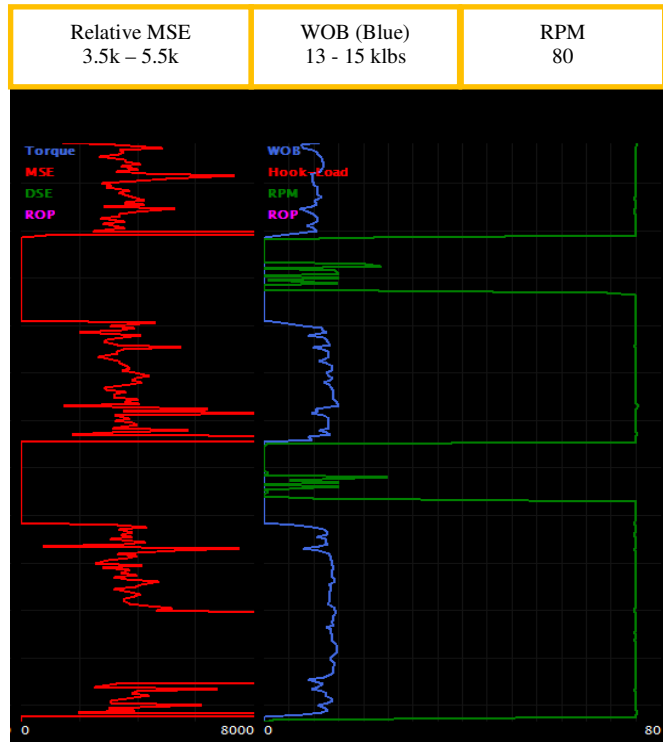


Fig. 8 b) Drilling parameters used in conventional drilling operation

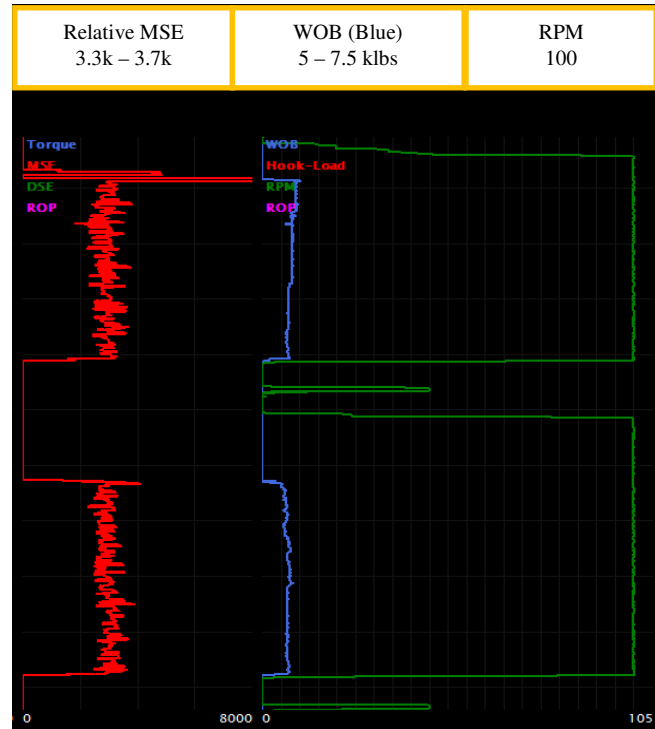


Fig.9 b) Drilling parameters used in Casing Drilling operation

MSE increase (in red) denotes the development of conditions in which the transfer of energy from the bit to the rock is constrained.

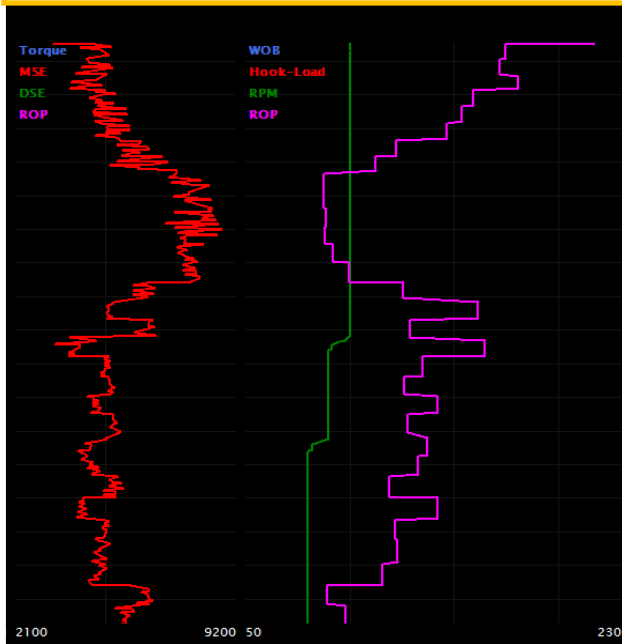


Fig.10 a) Real-Time MSE analysis, during Casing Drilling operation, for identifying performance limiters

Torque trend (blue) reveals occurrence of Stick/Slip. RPM (green) were decreased to mitigate performance limiter and increase ROP (purple).

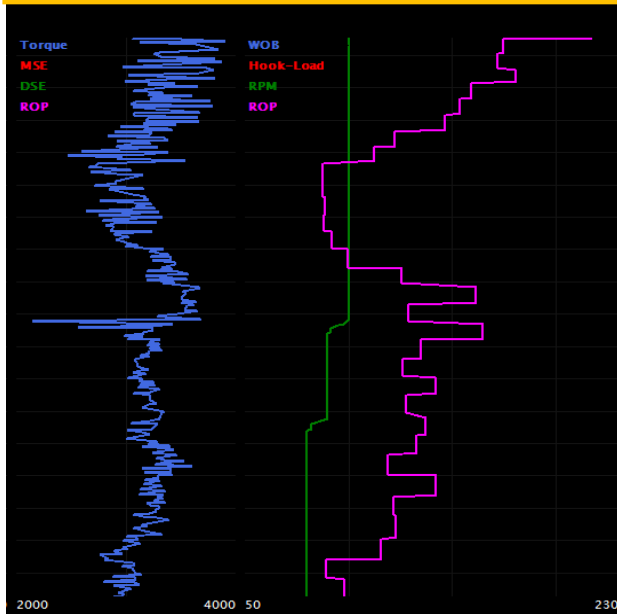


Fig.10 b) Real-Time MSE Analysis, during Casing Drilling operations, for identifying performance limiters

Dupriest et al. (2005) also stated that Hydraulics do not eliminate bit balling but, rather, extend the founder point such that this phenomenon occurs at higher WOB and higher ROP. To the contrary, recent findings suggest that Improved Hydraulics and Lower Energy Requirements enable Casing Drilling to transfer a greater amount of energy from the bit to the rock when drilling formations in which the accumulation of cuttings within the cutting structures is imminent.

MSE trend (in red) depicts the inefficiency associated with added WOB during bit balling. Reducing the WOB yielded higher rates of penetration.

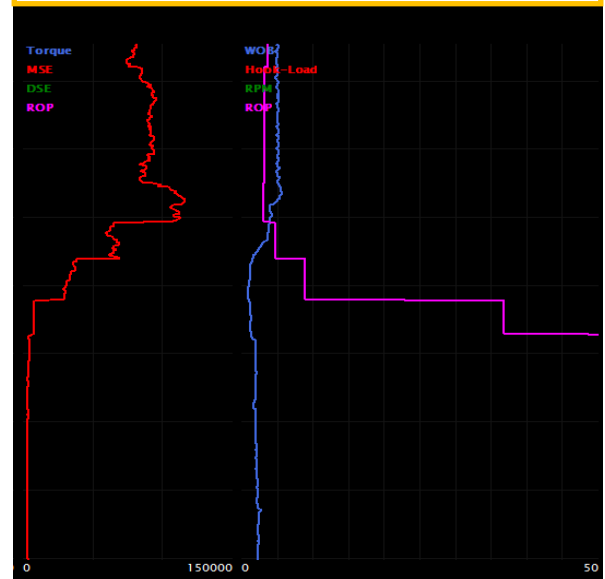


Fig. 11) Real-Time MSE analysis, during Casing Drilling operation, for identifying and mitigating Bit Balling

In the Louisiana Haynesville, at another Casing Drilling operation, real-time MSE analysis was used to drill at or near the founder point. More specifically, quantitative analysis of excess MSE and correlative analysis of wasted or misused MSE were used to identify the development of conditions in which the transfer of energy from the bit to the rock is constrained. Upon positive and early identification of performance limiters, linear and multi-variable regression and Dynamic Drill-Rate tests were used to mitigate the “vibrational founder,” overcome bit balling, and to optimize Depth of Cut.

The implications of recent Casing Drilling operations, findings, and lessons learned suggest transference of energy that is greater than 40% from the bit to the rock. However, the focus of this paper is not the qualitative or quantitative justification of this energy transference – such discussion is reserved for inclusion in another paper.

Casing Drilling Successful Case Studies

Wells with drilling problems are primary candidates for Casing Drilling. Below is a brief review of recent case studies where Casing Drilling has been able to overcome lost circulation, wellbore instability, well control problems, and create a better wellbore quality:

Askew et al. (2011) summarized their 5-year experience of Casing Drilling campaigns working with 4 operators in 13 fields in Gabon. The application has been in top-hole sections where unconsolidated sands have been washed away, leading to wellbore instability. Total losses can also occur due to the existence of hard fractured carbonates. 49 out of 50 runs were successfully set at the lowest minimum depth and cemented in place. All the 49 drillable bits were drilled out successfully. They have also noticed that total losses had little influence on the average penetration rate. This is due to Casing Drilling's benefits which enable continued drilling with fewer total losses.

Sanchez et al. (2010) reported the success of Casing Drilling in the most challenging environments of Oman. In their studies, two surface sections were drilled successfully with large OD casing strings through UeR and FIQA formations notorious for hole instability, lost zones, and reactive shale problems. Sanchez et al. also made several observations with regard to Casing Drilling's benefits, stating, for instance, "Casing Drilling reduced the drilling phase 40-45% in comparison with the field average. The exposure time of FIQA to aqueous environment was reduced considerably eliminating conditioning trips and NPT associated with wellbore instability. The total volume of pumped cement recovered at surface reached up to 98% of pumped excess (versus 25% in the Field), which is an indication of the good quality of the borehole. Casing Drilling will allow future wells to utilize 'slim' top holes allowing drilling/casing much deeper sections in less time preventing the FIQA from collapsing and avoiding the use of more expensive oil-based mud," (Sanchez et al. 2010).

Lopez et al. (2010) presented a case study of successful Casing Drilling application in the Cira Infantas field in Colombia. This field is crossed by faults and is characterized by depleted and shallow gas-bearing formations that resulted in challenging drilling operations with both loss circulation and well control issues. Lopez et al. observed that utilizing Casing Drilling reduced NPT associated with wellbore instability due to the Plastering Effect formed around the wellbore (Lopez et al. 2010).

Dawson et al. (2010) reported the recent success of Casing Drilling in Angsi field in Malaysia. Formations in this area are soft, unconsolidated, and have a history of wellbore

instability issues and severe losses. Dawson et al. concluded that "Casing Drilling brought the additional advantage that if mud losses did occur; the mud system could be switched to seawater while continuing to drill ahead. No time was expended to mitigate incurred losses. The fine drilled solids and continuous drilling of the Casing Drilling process has been effective in combating the wellbore instability issues and essential to the successful application of the Casing Drilling technology," (Dawson et al. 2010).

Another study was done by Gallardo et al. (2010) on fluid loss mitigation in the Cashiriari field in Peruvian jungle. Total or partial fluid losses in shallow sections turn conventional drilling into a non-cost-effective way to drill this area. Gallardo et al. stated, "The main purpose in using Casing Drilling in these shallow hole sections was to drill the upper intervals quickly and minimize hole problems resulting from wellbore instability issues. Casing Drilling improves the mechanical seal in the borehole due to the Plastering Effect. The Casing Drilling application was able to meet the planned objectives of drilling the shallow hole sections in a total loss scenario uneventfully," (Gallardo et al. 2010).

Beaumont et al. (2010) reported another successful Casing Drilling application in Peruvian fields. According to Beaumont et al., "The main problem in this area was time-consuming gumbo events in the intermediate hole. Severe drag and tight spots led to high risk trips out-of-hole requiring extensive back-reaming and near-lost hole events in offset wells (severe pack-offs while tripping out). Potential problems associated with hole instability, clay swelling, stuck pipe, hole cleaning, gumbo, surface equipment downtime and seepage losses were entirely mitigated with Casing Drilling application," (Beaumont et al. 2010).

Watts et al. (2010) demonstrated that the Plastering Effect of Casing Drilling allows successful drilling through unstable loss zones. Watts et al. posited that "if wellbore strengthening can be systematically achieved, then wells can be drilled in known loss areas without contingency strings of casing." They add that "wells drilled in mature fields, where producing horizons have altered pressures, either from depletion or pressure maintenance, can be drilled with fewer casing strings," (Watts et al. 2010). Furthermore, their study showed that a significant improvement in fracture gradient can be achieved with the right clearance between the hole and the casing and the proper sized particles added to the mud system. With confidence that strengthening can be achieved to the levels of improvement demonstrated, wells can be evaluated with significant cost savings by eliminating casing strings and preserving hole size for completions or further drilling (Watts et al. 2010).

Avery et al. (2009) completed a study on high angle directional drilling with 9 5/8-in. casing in offshore Qatar, and made the following conclusion: “The problem was that the interface between the shale and pay zone formation is often a point where highly conductive faults are encountered. Severe losses of drilling mud often occur at this interface, thus resulting in a dramatic reduction of hydrostatic pressure as the wellbore annulus fluid level falls. This pressure loss causes the unstable formation to collapse in on the drill string and BHA, packing it off and making it practically impossible to retrieve. A potential solution to this problem was to drill the section with casing and a retrievable BHA,” (Avery et al. 2009). The operation was successful and effective due to Casing Drilling.

Conclusions

- Often conventional “best practices” need to be adjusted for the unique conditions of Casing Drilling.
- Casing Drilling allows for more flexibility in drilling hydraulics design.
- Drilling parameters should be reconsidered for Casing Drilling to achieve the most optimum performance.
- Field parametrical data suggest that Casing Drilling yields more efficient energy consumption.
- Transient MSE analysis can be used as a guidance tool during Casing Drilling operations.
- Quantitative MSE analysis suggests that input energy transference from the bit to the rock is greater with Casing Drilling in comparison to drilling conventionally.
- Even though the Plastering Effect has not yet been theoretically proved, the benefits of Casing Drilling are observable in terms of reduced mud loss.

Nomenclature

BHA: Bottom Hole Assembly
DOC: Depth of Cut
ECD: Equivalent Circulating Density
HPHT: High Pressure High Temperature
OD: Outside Density
NPT: Non-Productive Time
MSE: Mechanical Specific Energy
PSD: Particle Size Distribution
TD: Total Depth

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