

Increasing Drilling Performance for ERD Wells using New Generation Hydro-Mechanical Drill Pipe

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Abstract

Complex and extended reach drilling (ERD) profiles are continuously pushing the limits of the drill string. Drill pipe performance factors include high-torque connections and increased tensile strength-to-weight ratios are required to overcome frictional drag forces and to achieve improved hydraulic performance, higher rate of penetration, control of well trajectory and optimal hole cleaning. Those challenges are best addressed through a holistic approach of planning.

While hole cleaning is generally considered to be well understood when drilling deviated and horizontal wells, many drillers still have difficulty properly managing the entire process. Holes do not have to be 100% clean; they need to be kept clean enough to safely perform the next operation.

Experience reveals that less-than optimal hole cleaning can lead to non-productive time, poor bore-hole quality, and loss of drill string or even the well. Large boreholes drilled at high ROPs will usually require additional rig time for cleanup. Time spent on hole cleaning operations can be significant, but it is essential. A more in-depth analysis supported by key performance indicators (KPI) shows that using Mechanical Hole Cleaning Devices (MCD) in certain directional wells can achieve drilling efficiency gains with cost savings.

Introduction

This paper outlines a new drill pipe design which integrates hydro-mechanical features into the tool joint to increase hole cleaning efficiencies while drilling and addresses annular pressure issues associated with cutting transport prevalent in horizontal wells. The unique and innovative drill pipe enables drilling safer and faster, reducing time spent on hole cleaning operations, improving hole quality and reducing risks for Non Productive Time (NPT) without jeopardizing the performance of the drill string. Short of a case history application in a drilling environment with full Key Performance Indicators (KPI), performance improvements can be expected for the new generation hydro-mechanical drill pipe based on efficiency gains and performances achieved with the established Hydroclean™ tool in highly deviated well.

Understanding Hole Cleaning

Cuttings behaviors in highly-deviated wells have a natural tendency to avalanche and accumulate on the low side of the wellbore. As the flow velocity of the drilling mud becomes insufficient, cutting beds start to develop thus loading up the well. Large boreholes above 30° inclination and drilled at high ROPs are most critical and will usually require additional rig time and clean out procedures. Practically, the clean-out process includes a combination high rotational speed and flow rates with other operations such as reciprocating, pumping sweeps, wiper trips, circulating multiple “bottom’s up”, tripping, reaming and back reaming.

Hole cleaning issues have an impact on drilling performance. Land drilling operators are more inclined to accept addressing these issues with time consuming practices and procedures, which increase drilling cost and risk. Cuttings start to load up the well from the bottom up immediately after drilling has started and when everything seems to be going well. The paradox with maintaining cuttings to acceptable levels is that the build ups will go unnoticed until symptoms from the well signal a growing issue. If left unattended the problems become more obvious later when indicators such as reduced ROP, need for higher WOB, erratic drilling torque, non-uniform rate of cuttings over the shakers, pipe buckling, high annular pressures, Equivalent Circulating Densities (ECD) out of the window, drill string whirl and stuck pipe events present themselves. Remedies, which are also flags, simply include additional wiper trips, sweeps, long circulating times and other well rig practices.

Hole cleaning “rules” change in smaller hole sizes (less than 8½-in.) and specifically apply to horizontal wells. Excessive annular pressure and higher ECD can rapidly develop with cuttings tending to settle in Saltation and cutting beds forming on the low side of the well. This problem can be exacerbated by the increased horizontal length of the wellbore, particularly in ERD wells. The idea that pipe rotation and high pump rates will keep cuttings in suspension is generally flawed by a misconception that the cutting transport to the surface is uninterrupted with sufficient flow rate and pipe rotational speed. The universal laws of physics govern cutting behavior and transport with perhaps as little as

20% of the total cuttings in suspension at any given time. The evidence to that is seen by the irregular cutting volumes coming over the shakers, the tripping behavior of drill string and other indicators. A good approach to optimizing rig time is to incorporate good hole cleaning practices and procedures in the drilling program with continuous monitoring of the well. The consequences of poor hole cleaning often lead to problems difficult to solve, especially when the borehole quality is downgraded. Lost circulation commonly encountered in ERD wells is one example.

The industry recognized the impact of hole cleaning early on and estimated the global cost for the loss to be roughly \$800 million per year (Ivan et al, 2004). That cost is likely to have increased considering the nature of the more complex wellbores drilled today.

Addressing Hole Cleaning

In many respects, the first approach to hole cleaning can look quite simple when only considering cuttings behavior by rotation of the drill string and cuttings displacement by the circulation of the drilling fluid. Mud rheology is deemed to play a major role, but mud is only one part of an engineered approach requiring all the factors to be addressed in concert. Analyzing cuttings ground by rotation of the drill string and cutting rates over the shakers is a first step towards developing hole cleaning KPI. Efficient cuttings transport and keeping the well clean enough for trouble free operations usually dictate how much time is spent on cleaning the hole. Evaluation and performance analysis for drill string optimization, flat times, ECD, Torque & Drag are also commonly used for setting targets. The execution at the wellsite usually requires the drilling team to manage pre-established rig practices and procedures to achieve real-time performance improvement by monitoring the wellbore. PUV (Pick Up Weight) is one of the performance indicators measured while tripping in and out of the hole and reciprocating the drill string. Measurement of PWD (Pressure While Drilling) is routinely applied for monitoring cutting bed height equilibrium close to the bit and mostly used as an indicator of "out-of-control" hole cleaning. Major sources of NPT can result from tight hole situations to the extreme of losing the drill string or the well; i.e. stuck pipe, wellbore instability, loss of circulation, fishing jobs and technical sidetracks, all of which are more prevalent in ERD wells.

The most effective approach to address hole cleaning is to use a holistic and engineered system approach. An in-depth performance analysis review of the entire drilling process focusing on lessons learned and with emphasis on mitigating risks and maximizing drilling time is key for planning. When economically justifiable, Mechanical Hole Cleaning Devices (MCD) can enhance performances and have already shown to be effective achieving drilling efficiency gains in long holes (12 ¼") sections and highly deviated wells. Misconceptions about MCDs remain and, therefore their use is still too often overlooked or under-utilized.

Using Mechanical Hole Cleaning Devices

When effectively used and adequately configured in the drill string, mechanical hole cleaning devices such as the Hydroclean™ are like a tool in the shed. Their justification and use is primarily offshore to drill 17½-in. and 12¼-in. directional and deviated hole sections. The tool gradually erodes cutting beds height starting at low RPM's by mechanically scooping cutting beds buildup where they cannot be avoided under normal drilling conditions. Cuttings are continuously scooped to a position above the drill pipe and sustained for transport in the high fluid velocity area of the annulus. As a result, increased performance can be achieved with less time spent cleaning the hole.

Despite worldwide experience with MCDs, very few studies have been conducted showing how drilling performances can be improved with an all-inclusive system approach and measurable KPIs. Mixed results have also been reported ranging from total success to disappointments but generally lacking substantiating data. Such outcome is usually predictable because of the need to follow a blue print from planning to execution. A hole cleaning management system approach for the well is needed with defined expectations and measurable deliverables on the well site. The flow chart process should have planning, execution and a post job review analyses with lessons learned and quantifiable objectives for continuous improvement. For example, there is a minimum quantity of tools required to be spaced in the drill string and a minimum RPM (60-80) to achieve effective mechanical scooping of cutting beds. Additional cleaning scooping efficiency is achieved by increasing RPMs above the threshold of "viscous coupling" between the pipe and the drilling fluid with procedures to be followed to maintain effective hole cleaning while rotating. A common mistake is to use fewer than the minimum tools required which is typically due to cost and thus defeat the purpose of the entire exercise. A few publications have demonstrated the value proposition of the Hydroclean™ technology in highly deviated wells.

Hydroclean

The tool features fit-for-purpose bladed scallops and grooves producing a number of hydro-mechanical effects to increase the cleaning efficiency of the drill string. The Hydroclean™ has two separate design configurations, one in the form of a drill pipe joint (HDP) and the other in the form of a Heavy Weight Drill Pipe (HHW). Both tools need to be configured and spaced as add-on to the drill string. Safer and faster drilling can be expected. Consequently less rig time is needed for cleanups.

The Hydroclean™ provides full and immediate degradation of cutting beds while keeping more cuttings in suspension on the high side of hole where fluid velocities are the highest. The hydro-mechanical hole cleaning functions are achieved through the combination of three distinct hydro-mechanical effects:

- **Scooping:** Cuttings deposited on the low side of the hole are mechanically eroded at low RPMs avoiding cutting bed build ups around the drill pipe.
- **Recirculation:** Once lifted, cuttings are recirculated up to the high side of the hole and above the pipe.
- **Transportation:** Regardless of the energy input exerted on the cuttings during the recirculation stage they will only travel a certain distance and will eventually resettle on the low side of the hole due to gravity. A “conveyor belt” has to be established to maintain transport cuttings to the surface.

The Hydroclean upset is composed of two distinct sections:

- The **hydro-cleaning** zone provides optimum scooping effect while variable helix angles accelerate the lift.
- The **hydro-bearing** zone protects the wellbore from the blades and provides optimum friction characteristics for sliding and rotating by keeping the drill string more centralized due to the increased OD.

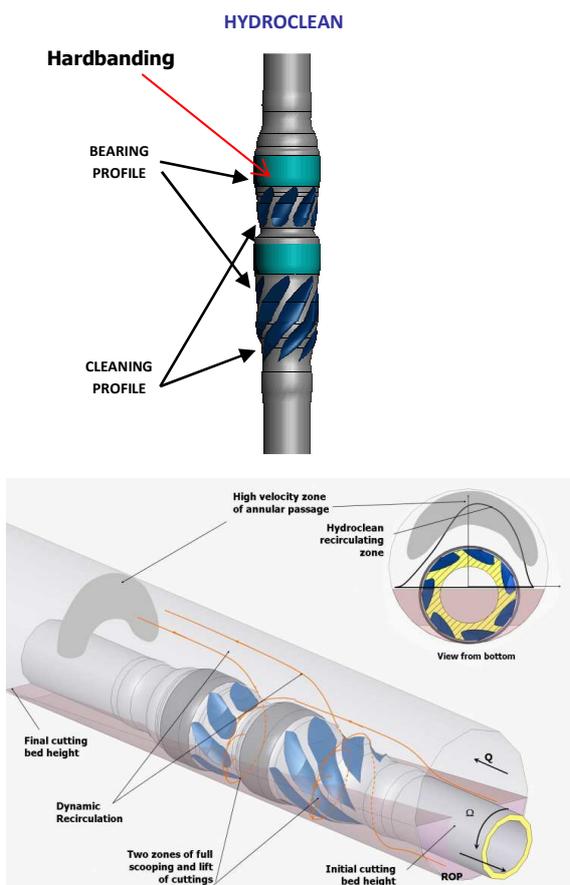


Fig 1 Hydroclean G1 design

Flow Loop Test

Tests have been carried out in a large-scale flow loop with an 8-in. transparent test section. Three different drill pipe sizes were considered for evaluation. Results were evaluated to obtain the overall effect of operating parameters on annular cuttings concentration and to develop correlations. Results shows that flow rate and inclination angle have the most significant impact. The correlations are useful to develop an analytical model for designing and optimizing drilling systems with Hydroclean™ for operating parameters or spacing.

a) Effect of inclination angle

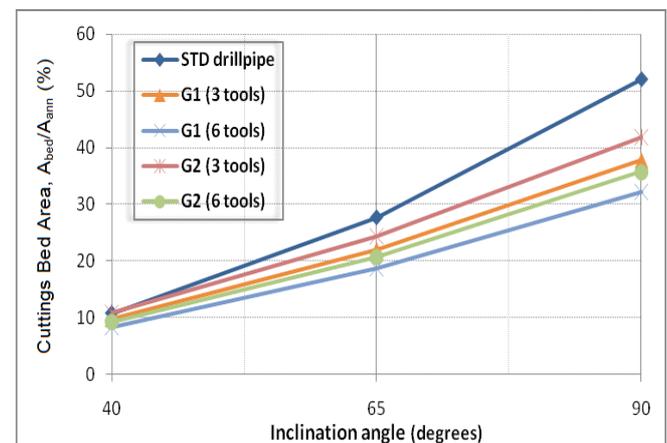


Fig 2 4.5" × 8" annulus, 90 rpm, 300 gpm, 40 ft/hr ROP

Fig 2 compares standard drill pipe versus Hydroclean showing the effect of inclination angle on cuttings bed area for different types of tools (Generation G1 & Generation G2) and spacing's. G1 tool is the first design featuring a different blade and bearing profile. The maximum cuttings accumulation occurs in the horizontal configuration in all cases. Cuttings bed area decreases steadily with reduction of inclination angle.

Hydroclean™ has the greatest impact on cutting bed erosion at 90° compared to standard drill pipe. Below 40° inclination it has limited benefits compared to standard drill pipe.

b) Effect of flow rate

Flow rate (GPM) is considered to be a main component of hole-cleaning as it provides the only physical means of achieving transportation of solid particles to surface. Achieving the proper flow rates can be difficult because other compromises are needed to maintain wellbore integrity. Improper flow rates can degrade the hole, cause hole enlargement or caving, produce equipment wear or create high standpipe pressure. Testing included G1 and G2 tools.

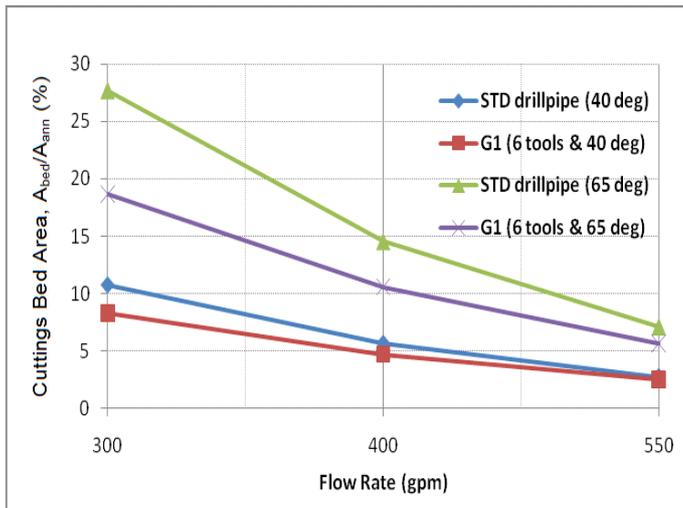


Fig. 3 4.5" × 8" annulus, 110 rpm, 40 ft/hr ROP

Fig 3 compares standard drill pipe versus Hydroclean™ showing the bed area as a function of the flow rate at 110 rpm and 40 ft/hr cuttings injection rate and for 2 inclinations, 40° and 65°. At low flow rate, Hydroclean™ allows much better hole cleaning than standard drill pipe.

At low inclination angles (i.e. $\alpha = 40^\circ$), the flow rate is expected to be the dominant parameter influencing the accumulation of cuttings in the annulus and reducing the impact of the tools. This is because most of the cuttings are already in suspension and the cuttings beds being much thinner. As a result, the effects of the Hydroclean™ diminish as the inclination angle decreases below 40°. (SPE 134269 was presented during the SPE Annual Technical Conference and Exhibition in Florence, Italy, 19–22 September 2010)

c) Effect of flow rate

Rotational speed (RPM) is the second most well-known parameter, usually considered to increase hole-cleaning with higher rotation above the threshold of “viscous coupling” which is hardly achievable below 60 or 70 rpm. Although increasing pipe rotation improves cuttings recirculation, rotational speed cannot by itself fully clean the hole and may increase the risk of casing wear, drill string fatigue and dynamic vibrations.

d) Effect of flow rate

Mud rheology plays a significant role in hole-cleaning as it impacts cuttings suspension in the mud flow. Mud rheology is not usually considered as an optimization parameter because the mud properties are mainly adapted to the formation and well profile.

An efficient hole-cleaning process combines the full bed

erosion action with a “conveyor belt” mechanism that transports the maximum amount of cuttings to the surface. However, even with a fully optimized hole cleaning system, it may still be impossible to clean the hole sufficiently with the drilled pipe alone and achieve the desired drilling performance. The Hydroclean™ will provide a “mechanical” boost enabling increased hole cleaning efficiency and improve drilling performances.

The Hydroclean™ comes in range 2 and 3 and is integrally machined over the full length. A portion of the tool joint bearing section is machined to a larger OD with a profile to reduce friction. The dual OD configuration provides several advantages.

- Offset the bladed section from the borehole wall
- Improve mud flow pattern around the pipe OD
- Less torque & drag than a standard tool joint
- Increase wellbore stand-off

Benefits

- Reduced circulating time
- Fewer wiper trips
- Less or no back-reaming
- Elimination of sweeps
- Better and faster hole cleaning
- Lower annular pressure
- Trouble-free BHA trips
- Smooth casing runs
- Bigger cuttings
- More time spent drilling
- Higher ROP
- Extended service life of the drill string

Placement in the drill string

Tool spacing is critical for achieving effective Hydroclean performance and hole cleaning. Placement in the drill string is based on field experiences. Joints should be placed starting from the 30 / 40° inclination depth in the well profile and spaced at regular intervals to ensure continuous cuttings transportation known as the conveyor belt. The conveyor belt effect applies the same way whether in open hole or cased hole. The Hydroclean™ provides additional benefits such as torque and drag reduction, improved sliding behavior of the drill string, better weight on bit transmission and casing and equipment wear reduction. Field experience has shown that the most common spacing is one joint every two or three stands of drill pipe. Software is also available to calculate the optimum number of joints needed. Reduction in tool spacing (i.e. increasing the numbers of joints per length of wellbore) improves the performance of the system.

Application example

12 ¼ Hole size

Parameters

- Inclination above 30 degree
- Flow rate: 1050 GPM
- RPM : 80 - 140
- Drill Pipe: 5 1/2"
- Interval spaced with Hydroclean 2265 ft
- **Qty Hydroclean DP : 15 jts**

Recommendations were made to use one Hydroclean every two stands (R2) from 40° inclination starting at 1760 ft to 4665 ft. BHA length: 134ft. The first Hydroclean shall be placed just above the BHA.

8 ½ Hole Size

Parameters

- Inclination above 40 degree
- RPM : 90 - 130
- Flow rate: 650 GPM
- Drill Pipe: 5"
- **63 Hydroclean DP + 2 Hydroclean HWDP**

Recommendations were to use one Hydroclean every three stands from 40° inclination (1760 ft MD). The composition of the BHA is different from the 12 ¼ section. It was also recommended to replace all standard DP and HWDP by Hydroclean products in the BHA or about 640 ft with 21 jts of HDP and 2 jts of HHW.

Hole cleaning efficiency index

Hole cleaning efficiency index is a comparison between a drill string with and without Hydroclean™ tools. To facilitate the understanding of the hole cleaning efficiency index, the assumption was made to give index 100 to the value obtained with Hydroclean™ tools. The following tables show the comparison between using Hydroclean™ in the drill string and standard drill pipe

12 ¼ hole

Parameters

- Flow rate 1050 GPM
- 80 RPM
- 60° inclination
- Mud density 1150 kg/m3

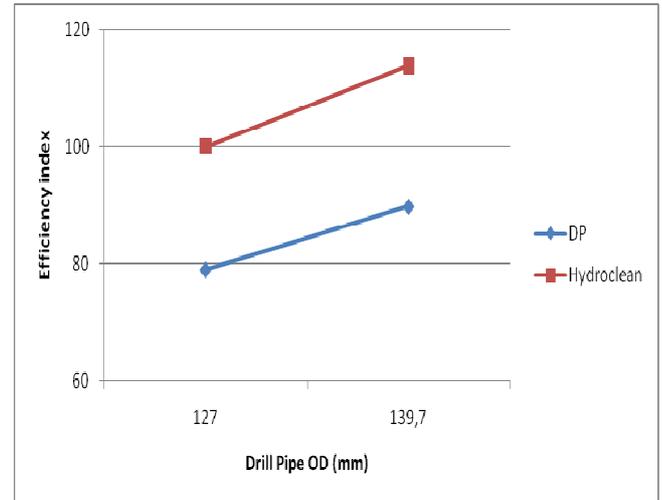


Fig.4 Efficiency index (100% corresponds to Hydroclean 5" OD)

The analytical model developed at the University of Tulsa was used to evaluate this index. Assuming that the 5" or 127mm OD Hydroclean has an index of 100, we can draw the following conclusion:

- The use of 5" drill pipe has an efficiency index more than 20% below the Hydroclean index

By increasing the OD from 5" to 5 ½ or 139,7mm, the efficiency index is 15% higher.

8 ½ hole

Parameters

- Flow rate 650 GPM
- 80 RPM
- 60° inclination
- Mud density 1120 kg/m3

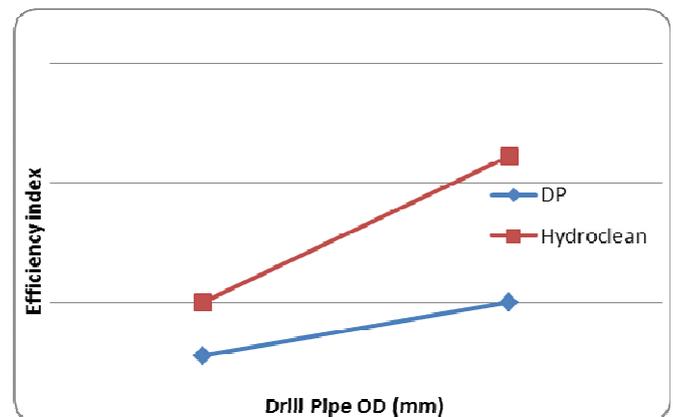


Fig.5 Efficiency index (100% corresponds to Hydroclean 5" OD)

With the 5" OD Hydroclean has an index of 100; the following observation can be made

- The 5" (127mm) OD drill pipe has an efficiency index 10% lower than the Hydroclean
- By increasing the OD from (5") 127mm to (5 ½) 139,7mm, the efficiency index of the Hydroclean is 25% higher than the drill pipe.

Conclusion

The Hydroclean™ MCD tools have better hole cleaning characteristics and are expected perform better than the standard drill pipe on hole cleaning efficiency in all geometries and hole sizes.

Hole cleaning improves with the increase in drill pipe size because of the increase in annular velocity (flow rate/effective flow cross-sectional area) and better viscous coupling characteristics.

Equivalent Circulating Density

Equivalent circulating density's shown below are calculated for the 8 ½ hole section with a clean well, with both 5" (127mm) API drill pipe and 5" (127mm) Hydroclean drill pipe using one joint of Hydroclean per 3 stands. The equivalent circulating density in a clean hole increases about 1.5%. However, with better hole cleaning the Hydroclean drill string is expected to offset this increase and maintain an overall lower ECD while drilling compared to the API drill pipe.

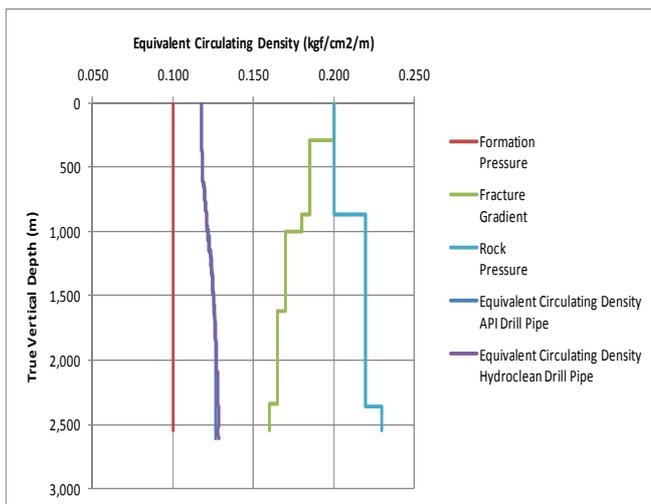


Fig.6 ECD comparison with & without Hydroclean for 5" OD drill string

With one 5 ½ Hydroclean used per 3 stands, the equivalent circulating density in a clean hole increases about 5.5%.

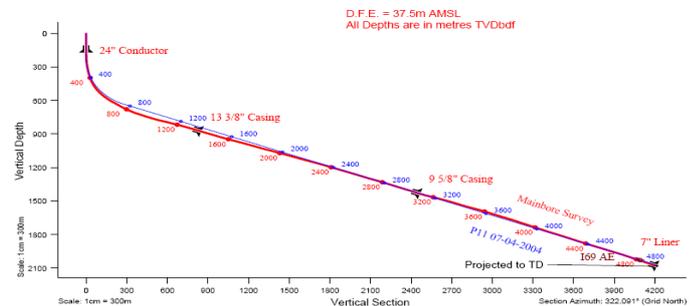
Conclusion

A generalized correlation was developed based on dimensional analysis using correlations showing that:

1. Hydroclean is effective in cleaning highly deviated and horizontal wellbores.
2. In horizontal wellbores, the use of the tools improve hole cleaning regardless of the bed area in the annulus.
3. The effect of variations of "rate of penetration" on the annular bed area is minimal. Flow loop experiments simulate only the effect of cuttings generation rate at the bit, which is directly related to the ROP.
4. Annular bed area is sensitive to differences in tool spacing when a small number of tools per length of the wellbore are used.

Experience

More than 500 Hydroclean™ operations have been carried out worldwide, emphasizing the need of hole cleaning technology in highly deviated wells. The following is a case study from a 12 ¼ application with KPI's and is referenced in our publications.

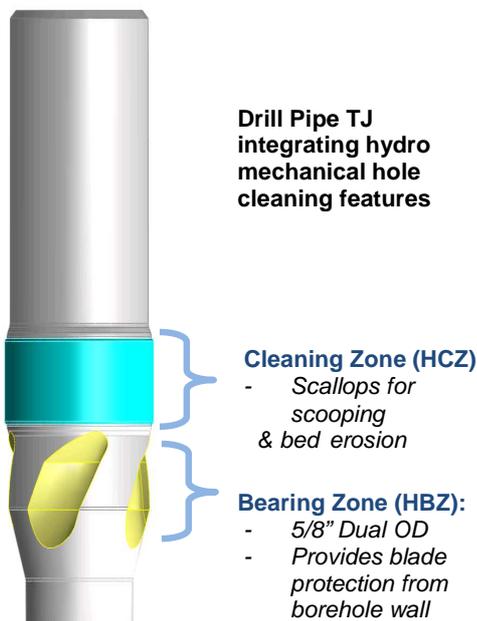


1st Performance Class / Cleaning Efficiency KPI i's:	
Increase cutting size indicator	+14%
Decrease circulating time indicator	-52%
2nd Performance Class / Time Saving KPI i's:	
Decrease in tripping time indicator	-49%
3rd Performance Class / Operational Safety KPI i's:	
Decrease in TD friction factor	-60%
4th Performance Class / Well Bore Quality & Stability KPI i's:	
Decrease in backreaming time indicator	-75%

Fig.7 Key Performance Indicators achieved in 12 ¼ hole

New Generation Hydroclean™ Drill Pipe

A new drill pipe design integrating hydro-mechanical cleaning features in the tool joint has been developed to increase hole cleaning efficiencies and address annular pressure challenges in horizontal and ERD wells. The new design also overcomes some of the limitations of the Hydroclean™ in ERD wells. The new Hydroclean™ Drill Pipe incorporates patented technology designed to enhance hole cleaning performance of the new drill pipe compared with a standard drill pipe. This innovation addresses ECD issues commonly encountered in smaller horizontal holes and extended reach wells. The new drill pipe incorporates specially designed bladed scallops in each tool joint without compromising the performance of the drill string.



Pipe Size (in)	Dual OD (in)	TJ OD (in)	ID (in)
3 1/2	5 3/8	4 3/4	2 3/4
4	5 5/8	5	2 11/16
4 1/2	6 5/8	6	3 1/2
5	7 1/8	6 1/2	3 3/4
5 1/2	7 3/8	6 3/4	4
5 7/8	7 5/8	7 1/4	4 1/4

Fig.8 New Hydroclean Drill Pipe Sizes

Test run with prototype

A test with 80 joints of the prototype 5" Hydroclean Drill Pipe has been run in a horizontal test well to evaluate to behavior of the new pipe compared to 5" API standard drill pipe. No drilling was performed. The test conclusions were as follows:

- 5" Hydroclean Drill Pipe prototype was successfully run in a granite test well

- Test was not representative of drilling conditions but both drill strings operated similarly without surface handling issues

- No issues with Torque & Drag in horizontal

- Cutting size observed to be 10 – 15 % larger with Hydroclean Drill Pipe (cuttings were pumped from surface through the drill pipe)

- KPI's could be not fully assessed

CONCLUSIONS

1. A new Hydroclean™ Drill Pipe incorporating hydro-mechanical hole cleaning in the tool joint has been developed.
2. The new drill pipe aims at :
 - Increasing hole cleaning efficiencies while drilling
 - Reducing total cleanout time & operations
 - Addressing annular pressure challenges prevalent in smaller horizontal hole sizes and ERD wells
3. Performance expectations and benefits are based on the established Hydroclean™ technology
4. A prototype string was run in a test well
5. Measurable gains are expected in 4 key performance areas:
 - Cleaning efficiency,
 - Time saving,
 - Operational safety,
 - Wellbore quality.
6. The Hydroclean™ Drill Pipe can be used both offshore and onshore and is also economically justifiable for conventional and unconventional drilling operations

Acknowledgement

We want to extend our tanks to the American Drilling Association of Drilling Engineers for the opportunity to present this paper.

Other colleagues from VAM Drilling, namely Christopher ROHART, Thomas DIDRY and Jean BOULET ought to be recognized for their contributions in providing valuable inside information to this paper.

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