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New Experience in Monofilament Fiber Tandem Sweeps Hole Cleaning Performance on Kharyaga Oilfield, Timan-Pechora Region of Russia

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Abstract

Drilling the 12 1/4" sections for the Kharyaga oilfield in the Timan-Pechora region of Russia has always been considerably complicated by wellbore instability and hole cleaning issues. These issues have been most serious when drilling through Triassic and Permian shales, sandstones, argillites and silts, followed by drilling Carboniferous limestones and dolomites. Unstable formations sloughing and packing off, wash outs and severe caving has resulted in many problems including drill pipe pack-offs, high torque and drag, the need for additional reaming operations, and difficulties in reaching bottom with casing.

Fluid treatments of swelling shales with chemical inhibitors helped considerably with shales hydration, but the problem of caving and packing off still persisted. High angles (up to 52.8°) and long section lengths (up to 2,707 m) aggravated the problems. The key remedy was determined to be effective hole cleaning. Cleaning efficiency of different types of sweeps was studied during drilling of 10 Kharyaga wells. Sweeps were pumped on a regular basis in drilling intervals of 100, 150, 200 and 300 meters, prior to pulling out of hole and when indications of packing off had been observed.

Pumped cleaning sweeps included high-viscosity or high-density single sweeps; tandem sweeps (low-viscosity following by high-viscosity or high-density sweeps); and sweeps with special additives (carbon-based LCM material or innovative monofilament fiber sweeping agent). Also, special attention was given to combined tandem sweeps, which are low-viscosity sweeps treated with a monofilament fiber sweeping agent followed by a high-density sweep (sometimes treated with carbon-based LCM material).

Investigation of different sweeps performance showed that the best hole cleaning results for Kharyaga field wells were achieved by circulating combined tandem sweeps, which are low-viscosity sweeps treated with a monofilament fiber sweeping agent followed by a treated or untreated high-density sweep.

Introduction

Effective hole cleaning becomes a vital part of operations when drilling deviated wells through unstable formations. Formational requirements to maintain appropriate equivalent circulation density (ECD), reduced mud weight (MW) and hydraulic pressure below the fracture gradient may complicate the engineering approaches of achieving effective cuttings transportation and hole cleaning.

Many factors can influence the hole cleaning practices. To achieve the best results, they can not be separated into individual components; it is always a system of actions.

When planning a hole cleaning program, engineering personnel should consider and work through the four main components of this system: (1) drilling program and well design; (2) hydraulic and rheology program; (3) fluid formulation program; and (4) cleaning sweeps pumping program. When these four components are put together into one system, effective hole cleaning can be achieved.

Modern hydraulics software allows us to perform hole cleaning procedure simulations at a very high and realistic level, and the application of innovative sweeping agents also helps considerably. However, it would not be a bad approach for new materials to be tested and studied operationally on every location on the particular wells under computer modeling before some systematic and synergetic approach for the hole cleaning is developed.

Background

When taking into consideration drilling program and well design components of hole cleaning, the following parameters can be listed and described:

Formation effect – there are formations that tend to slough and pack off, such as old lamellar shales or unconsolidated sands. Unstable formations may complicate hole cleaning considerably. An appropriate flow rate, higher rheological parameters, balanced mud weight, and effective filter cake development should be taken into consideration, and pumping cleaning sweeps on a regular basis should be practiced in this case.

Cuttings diameter – large cuttings are not necessarily more difficult to clean. Depending on fluid velocity and viscosity characteristics, small cuttings can be more difficult to remove than large size cuttings. Cuttings diameter is the function of formation effect as well as of the bit chosen and the rate of penetration (ROP).

Well angle (drill pipe eccentricity) – this is one of the main parameters. In vertical wells (eccentricity 0), cuttings bedding tendency is lower then in deviated wells (eccentricity 0 – 1). In horizontal wells (eccentricity 1), the highest cuttings bedding tendency is where drill pipe is lying on the lower side of the wellbore. In this case, if the flow regime, fluid rheology and sweeps pumping are not optimized, the cutting bed below the drill pipe can not be cleaned out at all. Cuttings beds also have a tendency to be accumulated in the so-called “dog legs” – quick angle changes during short drilling intervals [1].

Drill pipe rotation and reciprocation – pipe rotation and reciprocation are strongly recommended for successful hole cleaning. Drill pipe rotation and reciprocation can significantly improve the hole cleaning efficiency. Considerable cuttings beds removal can be observed due to their erosion by drill pipe orbital and translational motions [2].

Rate of penetration (ROP) – the higher the ROP, the more cuttings are being generated and the more complicated hole cleaning becomes. It’s good practice to maintain constant ROP, which is calculated from the hole cleaning modeling and simulation.

Annular diameters – it is more difficult to clean the cuttings from large annular diameters, as annular velocities are lower there in comparison with small diameters. Therefore, cuttings have a tendency to be accumulated in larger annular areas [3].

Connection time – during connection time, when no circulation is maintained, cutting are sedimentating down with the fluid rheology speed and cuttings weight. When connection time takes long and large cuttings volume has been generated before, they can settle down and pack-off the bit.

Circulation time – this is one of the most important parameters. Prior to connection, the hole should be circulated for several minutes to prevent cuttings from settling down and packing off the bit. Prior to pulling out, the hole should be circulated a few cycles bottoms up until no cuttings on surface are observed and they are not less then what is specified in Table 1, depending on section angle.

When describing hydraulic and rheology components, the following parameters should be defined:

Flow rate – this is one of the most important parameters in hole cleaning practices. The higher possible flow rate should be applied to provide better hole cleaning. Higher flow velocities provide better hole cleaning. But this parameter is limited by ECD, which is dependent on flow rate. Under high ECD, the formation may be fractured. Considerable shakers overflow also may be experienced under high flow rates [4].

Fluid rheology and fluid regime – these two parameters are interdependent. More turbulent flow regime (at less viscous rheological properties) provides better hole cleaning, especially for highly deviated and horizontal sections. But higher rheological parameters of fluid (laminar fluid regime) provide better cuttings transportation. So these two parameters should be pre-simulated using hydraulics software and balanced to achieve the synergic effect of hole cleaning [5, 6].

Fluid formulation can significantly contribute to the hole cleaning efficiency. The main fluid formulation parameters are:

Mud weight (MW) – mud weight force counteracts the cuttings gravitational force, and any increase in mud weight raises the cuttings removal efficiency.

Fluid formulation – successful fluid formulation with all the weighting, bridging, viscosity, pH, lubricity, shale swelling inhibition and fluid loss treatments balanced provides wellbore stability with good and tight filter cake development, which prevents unstable formations from sloughing, washing out and packing off [7, 8].

Drilling fluid sweeps generally are used in the drilling practice when regular fluid circulation is not sufficient for effective hole cleaning [9]. Sweeps application is very helpful for highly deviated and horizontal sections drilling, for sections being drilled with high ROP and for intervals with sloughing, caving and packing off formations. Sweep types generally are divided into the following categories: (1) high-viscosity; (2) high-density; (3) low-viscosity; (4) one of the above sweeps treated with special additives (lost circulation material LCM or sweeping agent); (5) tandem sweeps – combination of high-viscosity or high-density sweeps with low-viscosity sweep; and (6) tandem sweeps that also can be treated with special additives – LCM or sweeping agents.

High viscosity sweeps perform well in vertical and near vertical wellbores, but they are not the best option for deviated wells. High-viscous fluid requires an additional shear stress to be applied for flow to occur. That shear stress needs to exceed the yield stress of the fluid. In the narrow gap region of the annulus, the shear stress is low. If the fluid yield stress exceeds the prevailing stress conditions, no flow will occur in the low side of the annulus and thus minimal solids transport will occur.

Weighted sweeps provide more appropriate action for improved solids transport in deviated wellbores. The primary factor associated with improved solids transport efficiency is the buoyancy effect added to the system with weighted sweeps. This reduces the settling velocity of the drilled solids as well as allows the weighted fluid to penetrate more effectively the region below the drill pipe. But high-weighted sweeps also may induce losses downhole in sensitive formations [10].

Low-viscosity sweeps also are extremely helpful when washing cuttings beds out from the low side of drill pipe. Turbulent flow that is reached when pumping low-viscosity fluids can effectively wash the cuttings away from the most hidden places, such as area below tool joints, key-seatings and fractures. But pumping also should be balanced to avoid hole erosion and increased levels of filtrate invasion as filter cake is removed or fails to form [11].

Solids transport efficiency also can be improved through the addition of traditional LCM. Materials such as organic fibers or plant derived abrasive materials have been used with great success. In addition to improved hole cleaning, these materials also can reduce torque values in extended reach wells. Fibrous materials are useful for transporting large

particles while the abrasive materials are effective at eroding cuttings beds [12, 13].

It is important to highlight that the approach applied for fines removal is different to that for course material. Often in deviated wellbores, large solids are transported out of the hole easily with conventional circulation and rotation. Apparently stuck pipe can result from a build-up of fine solids. Field experience has established that circulating an abrasive LCM with a weighted sweep can remove this build-up of fines.

When pumping tandem sweeps, a synergetic affect can be reached when a turbulent flow of low-viscosity sweeps washes the cutting beds from the low side of the drill pipe and high-density sweep pushes and forces the cuttings beds out.

12 ¼ Section Drilling Program

In accordance with the customer's drilling program, 10 deviated wells (named KHA-1 thru KHA-10) were drilled on the Kharyaga oilfield. These include seven oil production wells and three water injection wells (KHA-3, KHA-4 and KHA-9). The wells have been designed as four-casing wells. The first casing – 20 7/8" conductor pipe – was driven to the approximate depth of 30 m TVD. The objective of the second 16" section was to set 13 3/8" surface casing at the average depth of 770 m TVD to cover the surface formations and to isolate the Jurassic aquifer from the deeper hydrocarbon bearing reservoirs. The casing shoe was set into the Upper Triassic shale. The objective of the third 12 ¼" section was to set 9 5/8" intermediate casing at the average depth of 2,500 m TVD to cover and isolate the hydrocarbon bearing reservoirs of Lower Triassic, Permian, Carboniferous and Upper Devonian. The casing shoe was set into Famennian basal shale just above the top of Devonian Frasnian shale limestones. The objective of the last 8 ½" section was to drill the reservoir in the Lover Frasnian and set 7" liner at average depth of 2,800 m TVD. The objective of the wells was to produce oil from Lower Frasnian reservoirs through single completion.

A lithological description for the 12 ¼" section is shown in Table 2.

Parker stationary top-drive drilling rig 236 was rigged up to drill the Kharyaga wells. The rig was completed with two Co Ems FB-1300 and one Co Ems F-1600 triplex rig mud pumps (12" stroke length, 5.5" liner length, 6" rod size, 120 spm max for Co Ems FB-1300 and 130 spm max for Co Ems F-1600, with 97% efficiency).

Solids control equipment consisted of four shale shakers (three screens, linear screens layout), one desander unit (two cones, 12" cone size), one inline desilter unit (12 cones, 4" cone size) and two centrifuges (DMNX 418FT and DMNX 418VT, 3 200 RPM nominal, 80 Lpm max feed rate).

The circulation and mixing system contained one 8 m^3 trip tank, eight reserve mud tanks (4 x 22 m^3, 1 x 12 m^3 and 3 x 25 m^3), two mixing mud tanks (20 and 9 m^3), six active tanks (2 x 47 m^3, 3 x 22 m^3 and 1 x 16 m^3) and one 7 m^3 sand trap. Two mud hoppers were supplied – one for mixing sacked polymers, the other for mixing big bagged materials.

KCl/Polymer/PHPA/Glycol inhibited drilling fluid was used to drill this interval for all Kharyaga wells. Fluid formulation was modified during drilling of all 10 wells to help overcome the issues experienced during drilling operations. The last fluid formulation applied for Kharyaga 12 ¼" section drilling (KHA-10 well) is shown in Table 3.

Due to the high tendency of Triassic and Permian shales to swell, high concentrations of different shale dispersion inhibitors were used. Mud weight at the beginning of the interval was raised up to 1.20 SG. Mud weight up to 1.30 SG was applied in some cases to increase borehole stability mechanically as well conditions dictated. To provide better fluid lubricity in swelling shales under high angles, high concentrations of lubricants were used. The interval was spudded with a lubricant concentration of 5.0% vol, further maintaining the concentration at the 3.0% volume level to reduce torque and drug as conditions dictated. Reserve LCM materials in case of mud losses, Caustic Soda to maintain pH in Serpukovian anhydrites and H2S scavengers in case of H2S occurrence – were kept in stock. Recommended fluid properties for the 12 ¼" section (KHA-10 well) are shown in Table 4. All of the fluid parameters were tested under API Recommended Practice 13B-1 (ANSI/API 13B-1/ISO 10414-1) – Petroleum and natural gas industries – Field testing of drilling fluids – Part I – Water-based fluids.

Hole Cleaning

The most complicated sections for tripping, which included continuous reaming and backreaming operations for almost all of the wells, proved to be Lower Permian and Upper Carboniferous intervals, beginning from the Ufimian grey silts and shales down to Serpukovian anhydrites, dolomites and limestones (1,600 to 1,970 m TVD). Signs of packing off were experienced mainly in Lower Triassic red shales and grey silts (830 to 900 m TVD) and Tatarian, Kazanian and Ufimian grey shales and silts (1,490 to 1,640 m TVD).

Shales intervals have been drilled with very high ROP's – 13 to 17 m/hour – and rather often – up to 20 to 25 m/hour. Long deviated (up to 38° to 53°) sections being drilled with high ROP through unstable formations with large volumes of cuttings generated required outstanding hole cleaning efficiency. Numerous hydraulic and cleaning simulations were performed to develop satisfactory hole cleaning recommendations.

The 12 ¼" hole cleaning optimization modeling was performed for the following basic well design and drilling parameters (see Picture 1):

- 13 3/8" surface casing set at 1,200 m MD / 992 m TVD
- hole angle growing up to 53° - 55° (angle development is shown on the picture)
- rotary drilling ROP – 14 m/hour (3/4 of a stand length)
- sliding ROP – 6 m/hour (1/4 of a stand length)
- cuttings diameter – 0.4".

This modeling was performed to 2,680 m MD / 1,862 m TVD where ROP was 6 to 14 m/hour before changing the formation to cherts.

Software modeling helped to reveal that under a reasonable pipe rotation of minimum 200 rpm and 2.7 m^3/min flow rate, hole cleaning performance proved to be satisfactory (see the first column on the picture that shows percentage of cuttings load on different sections of the wellbore. Everything inside

the 3% zone is satisfactory). ECD achieved also avoided fracturing of the formations being drilled (see the two graphs on the picture. The left one is ECD for cuttings-free fluid, and the right one is ECD for fluid loaded with cuttings). It was recommended to circulate for two minutes minimum before every connection to clean the hole (see the red line marked with "HC" in the "Transport Efficiency" column. It shows the improvement in hole cleaning after the short circulation prior to connection is made).

The pump rate of 2.7 m^3/min was just under the shakers overflow, especially when fluid was loaded with cuttings. The flow rate had to be decreased to 2.5 m^3/min when drilling or reaming through Triassic shales and when shakers overflow was considerable while pumping at higher rates due to severe plugging of the shaker screens.

In accordance with the simulation results, hole cleaning performance was satisfactory during drilling operations; however, the cuttings load simulation was quite substantial for some sections (cuttings load exceeded 3% recommended by drilling practice). Thus, to prevent considerable cuttings bedding, pumping tandem cleaning sweeps on a regular basis was proposed. On the first Kharyaga wells, tandem sweeps were pumped every 300 m of drilling, then every 200 m when ROPs got higher. The final best practice established was to pump tandem sweeps every 100 m in shales and every 150 m down to the 12 ¼" section TD below shales. Sweeps were pumped at a constant pump rate without stopping drilling. The basic tandem sweeps design proposed was to pump minimum of 8 m^3 of low viscosity sweep followed by 10 m^3 of high density sweep (1.60 to 1.80 SG). This mud weight for cleaning sweeps was allowed, as fracture gradient from the offset wells was determined to come to 2.13 SG EMW.

Prior to each trip, 8 m^3 of low-viscosity sweep plus 10 m^3 of high density sweep, followed in 15 minutes by 8 m^3 of low-viscosity sweep were pumped to confirm the cleaning efficiency. Minimum two bottoms up circulation cycles with pipe reciprocation and rotation at maximum rpm were performed for hole cleaning prior to pulling out of hole. These data were received from the hole cleaning simulations, which showed that constant almost cuttings-free ECD could be received after approximately 1.7 cycles of circulation (for 2,680 m MD / TVD 1,862 m). Further circulation did not decrease ECD considerably.

Pumping tandem sweeps also was recommended during difficult reaming and back reaming operations. When back reaming, especially when the well showed signs of packing off, it was recommended to run several meters down, establish full circulation and pump cleaning sweeps at a constant increasing pump rate.

To mix high-density sweeps, the necessary volume of active circulation mud was transferred to the mixing pit and weighted-up with barite to MW 1.60 to 1.80 SG. In some cases the sweep was treated with 80 kg/m^3 of carbon-based LCM material to cure seepage mud losses in Carboniferous vuggy and porous dolomites and limestones and to provide additional lubricity for sliding under high angles.

For all the first Kharyaga wells (KHA-1-7), low-viscosity sweeps were mixed from water treated with 60 to 80 kg/m^3 of potassium chloride (to prevent shales swelling in fresh water) and with 8 kg/m^3 of wetting agent (a blend of water soluble anionic surfactants) to counteract the sticking tendencies of clays and thereby reduce well packing, bit balling and formation of mud rings. But for the last three wells (KHA-8-9-10), drilling practice with a new innovative sweeping agent – a specially treated monofilament fiber – was developed and proposed. Thus, low-viscosity sweeps for the last three wells (KHA-8-9-10) were prepared with additions of 60 to 80 kg/m^3 of potassium chloride, 12 kg/m^3 of modified potato starch to maintain the filtration properties of the drilling fluid (this material does not induce increase in viscosity) and 0.3 kg/m^3 of monofilament fiber sweeping agent. Such a low concentration of monofilament fiber is used when downhole mud motor is installed in the drilling string and this concentration is still effective for hole sweeping purposes. Fiber in such a concentration is harmless for downhole mud motors, as sweeps pumping practice showed. A wetting agent was not added.

Prior to pumping monofilament fiber sweeps, fine protective screens were removed from the mud pumps, as they could get severely plugged with the fiber. Also when fiber-containing sweeps were coming at surface, sensitive mud logging tools and fluid gas analyzer sucking hoses were removed from the possum bellies, as this equipment also could be plugged and damaged with the fiber.

When tandem pills are being pumped, the first low-viscosity monofilament fiber treated sweep is moving in a turbulent regime and is washing the cuttings beds from the lower side of the wellbore in a deviated hole (see Picture 2). Monofilament fiber helps to lift cuttings particles, associate them together and sweep them out from out-of-the-way places of the wellbore. The low-viscosity, high-density sweep pushes all the cuttings out of hole by the buoyancy effect and by additional force given by the higher mud weight (in comparison with the circulation system mud weight). This additional force also assists in washing out the residual cuttings from the lower side of the wellbore. Large sweeps volumes prevent them from total intermixing with active circulation fluid and help to deliver large volumes of cuttings to surface.

Pumping low-viscosity and high-density tandem sweeps at constant pump rates without mud pumps stopping, together with drilling pipe translational motion and rotation at the highest possible rpm, results into a synergetic effect of hole cleaning.

Sweeps Performance Investigation

At the calculated time when sweeps should have appeared on surface, their performance was observed by the customer representative and fluids engineer on shakers. They noted the shakers coverage with fluid and coming cuttings quantities and composition before and during sweeps. On the rig floor, the driller also was supposed to observe and note sweeps performance using such drill string weight and torque parameters as Free Rotating Weight (FRW), Free Rotating Torque (FRT), Pick Up Weight (PUW) and Slack Off Weight (SOW) before and after each sweep pumping.

For Kharyaga wells KHA-6-7-8-9, each tandem sweep performance was registered in a special Sweep Performance

Sheet indicating:

- Depth
- Reason for pumping
- Flow rate
- Sweeps volumes and composition (monofilament fiber or carbon-based LCM materials added)
- Shakers coverage and cuttings volumes prior and during sweeps coming on shakers
- FRW, FRT, PUW and SOW prior and after sweeps pumping.

FRW and FRT were registered at 60 rpm with circulation. PUW and SOW were registered without rotation.

All the sweeps performance information collected for Kharyaga wells KHA-6-7-8-9 is gathered in Tables 5 through 8. A very high percentage of cuttings volume increase for some cases could result from very low initial cuttings flow (0.2 L/min) followed by considerable cuttings flow increase when sweeps coming on shakers (5.0 L/min), giving 2,400% cuttings volume increase.

Investigation and comparison of hole cleaning efficiency for monofilament fiber (MFF) containing tandem sweeps and tandem sweeps not containing the sweeping agent show that monofilament fiber sweeping agent treatments are more favorable. If we were to compare the hole cleaning efficiency by geological intervals using the cuttings load on shakers parameter, this investigation would show the double increase of cuttings when pumping monofilament fiber sweeps in Triassic and Carboniferous formations: 87% (without MFF) and 177% (MFF) cuttings increase in Triassic sandstones and silty shales; and 204% (without MFF) and 399% (MFF) cuttings increase in Carboniferous limestones and dolomites). It would also show an 18% cuttings increase in Permian argillites, shales, siltstones and limestones (245% without MFF and 295% with MFF); and nearly 7 times cuttings increase in Devonian dolomitic and shaly limestones (232% without MFF and 1,583% with MFF cuttings increase).

If we were to compare hole cleaning efficiency of single low viscosity (MFF-treated) sweeps pumped with tandem (MFF-treated) sweeps by geological intervals using the cuttings load on shakers parameter, this investigation would show 57% cuttings increase when pumping low viscosity sweep (196% cuttings increase) in comparison with pumping tandem sweep (125% cuttings increase) in Triassic sandstones and silty shales; but 1.6 times cuttings increase when pumping tandem sweep in comparison with low viscosity sweep (344% and 214% cuttings increase respectively) in Carboniferous limestones and dolomites; 1.75 times cuttings increase when pumping tandem sweep in comparison with low-viscosity sweeps (503% and 289% cuttings increase respectively) in Permian argillites, shales, siltstones and limestones; and 3.3 times cuttings increase when pumping tandem sweeps in comparison with low-viscosity sweeps (1839% and 550% cuttings increase respectively) in Devonian dolomitic and shaly limestones.

Hole cleaning performance differences between tandem sweeps treated and non-treated with monofilament fiber are shown on Picture 3, and tandem and low viscosity monofilament fiber treated sweeps hole cleaning performance is shown on Picture 4. Geological intervals are described as follows: Triassic – 1, Permian – 2, Carboniferous – 3 and Devonian – 4.

Higher single low-viscosity sweeps efficiency in Triassic sandstones and silty shales may be explained by the frequency of pumping low viscosity sweeps in the upper intervals while tandem sweeps were pumped more seldom to remove the residual cutting beds left after low viscosity sweeps pumping. In all the remaining cases, tandem sweeps have shown higher efficiency in comparison with single low-viscosity sweeps.

Single high-density sweeps were not pumped for these wells.

Investigation of pipe torque and weight drilling parameters (FRW, FRT, PUW and SOW) changes before and after sweeps pumping does not show cuttings load on shakers; but nevertheless sweeps performance tables indicate torque decrease and weight changes in many cases, showing the cutting beds removal and good hole cleaning.

Conclusions

1. An innovative monofilament fiber sweeping agent was first applied in Russia for drilling 12 ¼" sections of production wells on Kharyaga oilfield (Timan-Pechora region).
2. A monofilament fiber sweeping agent has been found to be of high hole cleaning efficiency for drilling these intervals.
3. Hydraulic and hole cleaning software simulation and modeling was performed to investigate drilling and fluid parameters to increase hole cleaning performance for drilling deviated Kharyaga wells.
4. Optimal fluid composition recommendations to achieve good 12 ¼" section hole stability and cleaning for drilling Kharyaga wells were developed.
5. Different types of single and tandem sweeps were pumped, studied and described to investigate their hole cleaning efficiency.
6. Tandem low-viscosity monofilament fiber treated / high-density sweeps were discovered to be of the best hole cleaning performance for Kharyaga wells.
7. Sweeps hole cleaning efficiency was discovered to be dependant on geological intervals and formations being drilled or swept out.

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Table 1: Circulation Times for Efficient Hole cleaning

Deviation	Circulation Factor for Open Hole Diameters, x Bottoms Up		
	17 ½ and 16"	12 1/4"	8 1/2"
Vertical	1.5	1.3	1.3
10 – 30°	1.7	1.4	1.4
30 – 60°	2.5	1.8	1.6
60° +	3.0	2.0	1.7

Table 2: Lithological description for 12 ¼" section of Kharyaga wells

Era Epoch	Age	TVD, m	Lithological Description
Triassic	Lower	820 – 1,359	Shales with alternations of sandstones and silts. Alternations of multi-colored shales, grey sandstones and silts. Alternations of brown-grey shaly sandstones, red silty shales and grey shaly silts.
Permian	Tatarian	1,359 – 1,549	- Grey calcareous and porous sandstones. - Dark grey platy shales. - Grey silts. - Dark grey calcareous argillites
	Kazanian	1,549 – 1,557	
	Ufimian	1,557 – 1,683	
	Kungurian	1,683 – 1,683	Argillites, dark grey siltstones with fine grained sandstone layers.
	Artinskian	1,683 – 1,716	Argillaceous and silty limestones.
	Asselian	1,716 – 1,755	Grey fine-grained porous limestones, recrystallised.
	Sakmarian	1,755 – 1,855	
Carboniferous	Upper Indiffer.	1,855 – 1,855	Detrital recrystallised limestones, slightly porous.
	Moscovian	1,855 – 1,870	Porous limestones, occasionally argillaceous.
	Serpukovian	1,870 – 1,970	- Anhydrites - Alternations of vuggy dolomites with porous vuggy limestones.
	Visean	1,970 – 2,081	Fine-grained limestones with dolomitic layers, vuggy limestones.
	Toumaisian	2,081 – 2,134	Shales at bottom.
Devonian	Famennian	2,134 – 2,494	Dolomitic limestones with inclusion of anhydrite and gypsum. Dolomitic limestones with shaly and marly streaks.
	Frasnian	2,494 –3,540	Shaly limestones, porous and vuggy limestones with shaly and marly streaks. Shales with sandstones layers.

Table 3: Kharyaga 12 ¼" Section Best Fluid Formulation

Product Name	Product Description	Concentration, kg/m3
Caustic Soda	Alkalinity Control	1.0
Potassium Chloride KCl	Shales Swelling Inhibitor	60 – 80
Modified Starch	Filtration Control Agent	11.4
Polyanionic Cellulose	Filtration Control Agent	5.7
Xanthan Gum	Viscosifier	1.4 – 2.8
Glycol	Shales Swelling Inhibitor	3% vol
Hydrocarbon Powder	Shales Swelling Inhibitor	8 – 12
PHPA Liquid	Shales Swelling Inhibitor	8.55 equiv to 2.8 kg active (as conditions dictate)
Lubricant Solution	Lubricant	Up to 3% vol (as conditions dictate)
Microbiocide Solution	Biocide	0.4 (or as required)
Barite	Weighting Agent	To mud weight 1.20 – 1.27 SG

Table 4: Kharyaga 12 ¼" Section Recommended Fluid Properties

Fluid Properties	Values Recommended
Mud Weight, SG	1.20 – 1.25 (as conditions dictate)
Plastic Viscosity, cP	ALAP
Yield Point, lb/100 ft^2	25 – 35
API Filtrate, ml/30 min	< 5
pH	9.0 – 9.5
MBT, kg/m^3	< 40
Calcium Hardness, mg/L	< 200

Table 5: KHA-6 Well Hole Cleaning Sweeps Performance

Depth (MD), m	Activity	Flow rate, L/min	Sweeps Volumes, m3		Sweep Performance			
			Low-Vis	Hi-Wt	ΔFRW, %	ΔFRT, %	ΔPUW, %	ΔSOW, %
1,133	Drilling	2,800	4.0	4.0	0	31	12	5
1,275	Drilling	2,800	10.0	4.0	0	0	0	0
1,618	Sweep hole before POOH	2,800	4.0	5.0	0	22	0	0
1,850	Drilling	2,800	4.0	4.0	-2	0	2	4
2,136	Drilling	2,800	7.0	4.0	0	6	0	0
2,258	Sweep hole before POOH	3,000	7.0	5.0	0	0	0	0
2,437	Drilling	2,800	7.0	5.0	0	0	0	0
2,453	Drilling (problems to slide)	2,800	5.5 (Nut Shells)		0	0	0	0
2,460	Drilling (problems to slide)	2,800	5.5 (Nut Shells)		0	0	0	0
2,465	Drilling	3,000	8.0	4.0	0	0	0	0
3,288	TD Sweep hole	2,720	10.0	8.0	0	0	0	0

Table 6: KHA-7 Well Hole Cleaning Sweeps Performance

Depth (MD), m	Activity	Flow rate, L/min	Sweeps Volumes, m3		Sweep Performance				
			Low-Vis	Hi-Wt	ΔFRW, %	ΔFRT, %	ΔPUW, %	ΔSOW, %	ΔCutt, %
934	Drilling	2,500	10.0	5.0	0	0	0	0	150
1,505	Drilling	2,500	10.0	3.5	0	6	-9	-12	43
1,610	Circulating	2,500	10.0	4.0	0	-7	0	3	67
1,725	Drilling	2,500	9.0	4.0	-1	0	-3	0	129
1,276	Reaming on the way out	1,800	9.0		0	2	2	0	0
1,070	Reaming on the way out	2,400	10.0	4.0	5	12	3	0	overflow
1,725	Drilling	2,500	9.0		-1	0	-3	0	567
2,073	Drilling	2,700	10.0		-6	0	0	2	250
2,273	Drilling	2,780	10.0		0	-8	0	17	180
2,366	Drilling	2,700	10.0		-1	21	-2	-1	200
2,404	Drilling	2,700	10.0		0	0	2	-2	150
2,424	POOH	2,700	10.0	4.0					300
2,424	POOH, bit @ 1990	2,500	10.0						600
2,424	Drilling	2,700	10.0		0	0	0	0	257
2,507	Circulating before POOH	2,700	10.0						400
2,590	Drilling	2,770	7.0	3.0	-2	0	2	8	250
2,750	Circulating before POOH	2,750	7.0	5.0					300
2,750	After RIH	2,740	7.0	7.0	0	17	-2	-3	300
2,900	Drilling	2,899	7.0	4.0	0	0	0	0	167
3,096	Drilling	2,880	7.0		8	8	4	0	150
3,220	Circulation before POOH	2,800	9.0	9.0					900

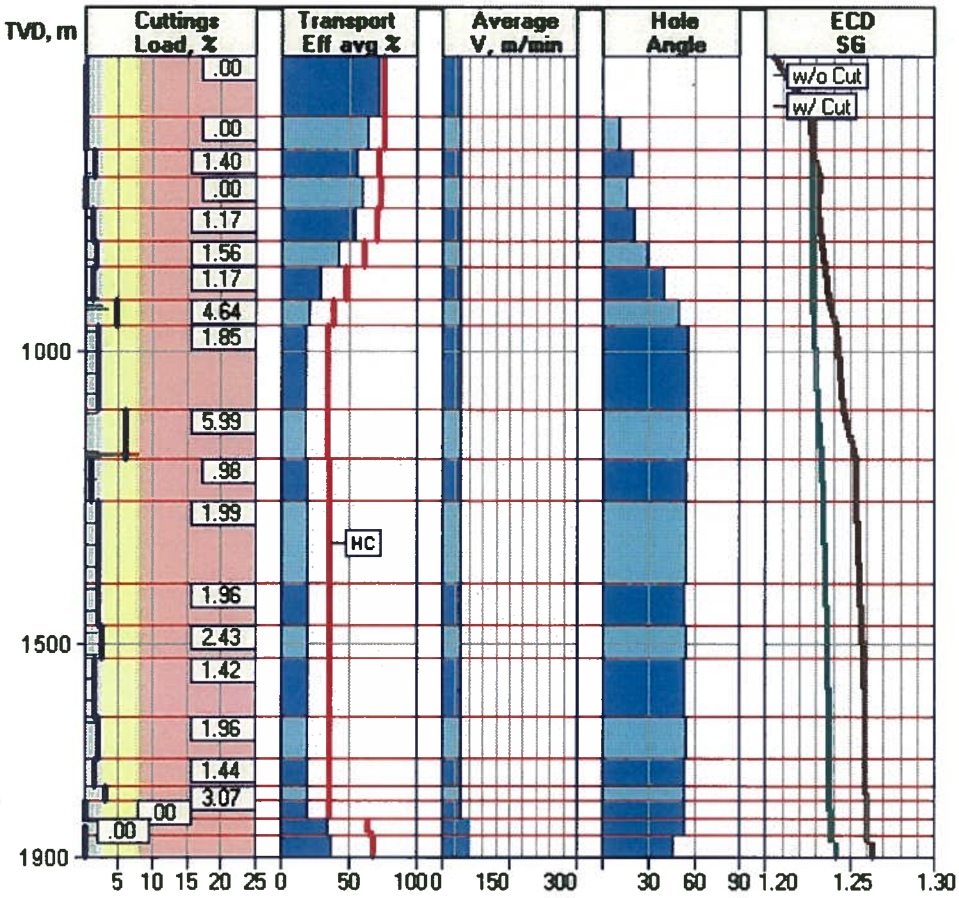
Table 7: KHA-8 Well Hole Cleaning Sweeps Performance

Depth (MD), m	Activity	Flow rate, L/min	Sweeps Volumes, m3		Sweep Performance				
			Low-Vis	Hi-Wt	ΔFRW, %	ΔFRT, %	ΔPUW, %	ΔSOW, %	ΔCutt, %
1,046	Drilling	2,500	8.0		0	0	25	9	Overflow
1,216	Drilling	2,500	5.0	10.0 (MFF)	0	26	0	-9	Overflow
1,378	Drilling	2,500	8.0		-4	0	3	4	75
1,558	Drilling	2,500	8.0	10.0 (MFF)	0	0	0	0	200
1,758	Drilling	2,500	8.0 (MFF)		0	0	0	4	275
1,903	Drilling	2,500	8.0 (MFF)		-3	0	2	0	275
2,043	Drilling	2,500	6.0	8.0 (MFF)	0	-1	-2	4	700
2,159	Circulating before POOH	2,500	8.0+8.0 (MFF)	8.0 (MFF)	0	5	3	0	900
2,160	Circulating before drilling	2,500	8.0 (MFF)		3	0	4	-7	233
2,288	Circulating before POOH	2,800	8.0 (MFF)	10.0	0	0	0	0	400
2,388	Drilling	2,800	8.0 (MFF)	8.0	0	0	0	0	400
2,588	Drilling	2,800	8.0 (MFF)	8.0	-1	4	-2	0	233
2,758	Drilling	2,800	5.0 (MFF)		0	0	0	0	133
2,867	Circulating before POOH	2,800	5.0+6.0 (MFF)	10.0	0	0	0	0	233
2,445	Trip out of the hole	2,000	6.0 (MFF)						200
2,872	Circulating before POOH	2,600	5.0+6.0+6.0 (MFF)	10.0	0	0	0	0	1,700 - 3,900

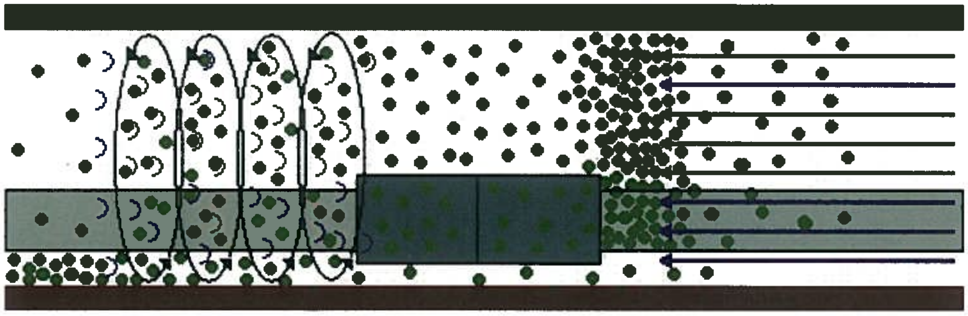
Table 8: KHA-9 Well Hole Cleaning Sweeps Performance

Depth (MD), m	Activity	Flow rate, L/min	Sweeps Volumes, m3		Sweep Performance				
			Low-Vis	Hi-Wt	ΔFRW, %	ΔFRT, %	ΔPUW, %	ΔSOW, %	ΔCutt, %
1,109	Drilling	2,500	6.0		0	-2	4	6	Overflow
1,275	Drilling	2,500	8.0		2	4	0	0	0
1,473	Drilling	2,500	6.0	8.0	0	0	4	0	33
1,627	Drilling	2,700	8.0 (MFF)		0	0	0	0	200
1,789	Drilling	2,700	8.0 (MFF)	10.0	0	19	0	0	25
1,957	Drilling	2,600	8.0 (MFF)		0	0	0	0	233
2,100	Drilling	3,000	8.0 (MFF)	4.0	0	0	0	0	233
2,266	Drilling	2,600	8.0 (MFF)		0	19	3	0	122
2,410	Drilling	2,700	8.0		0	0	0	0	100
2,560	Drilling	2,900	6.0 (MFF)	8.0	4	2	2	-4	700
2,610	Circulating	2,600	8.0		5	-2	4	0	700
987	Stuck pipe	3,000	6.0 (MFF)						700
1,101	Circulating before POOH	2,600	7.0 (MFF)		0	41	0	0	67
1,407	Hole Pack-Off	2,600	7.0 (MFF)		0	0	0	0	100
1,558	Drilling	2,800	8.0 (MFF)	5.0	0	0	3	-5	200
1,671	Drilling	3,000	8.0 (MFF)		0	0	3	-5	100
1,832	Drilling	3,000	8.0 (MFF)		24	0	0	0	100
1,910	Hole Pack-Off	3,000	8.0 (MFF)	5.0	0	0	0	0	186
2,015	Circulating before wiper trip	2,800	8.0+8.0 (MFF)	5.0	0	0	0	0	200
1,528	Back Reaming	2,800	8.0 (MFF)						Overflow
1,245	Back Reaming	2,700	5.0 (MFF)						200
1,065	Back Reaming	2,700	7.0 (MFF)						100
2,159	Drilling	2,750	5.0 (MFF)	10.0 (MFF)	0	0	0	0	200
2,273	Drilling	2,750	8.0 (MFF)	5.0	0	0	0	0	186
2,418	Drilling	2,900	8.0 (MFF)	5.0	0	0	0	0	100
2,561	Drilling	2,720	5.0 (MFF)	10.0	0	0	0	0	186
2,701	Drilling	2,700	8.0 (MFF)	8.0					150
2,842	Drilling	2,700	8.0 (MFF)	6.0					500
2,882	Circulating before POOH	2,750	6.0 (MFF)	10.0 (LCM)	0	0	0	0	Overflow
2,282	Circulating	1,300	6.0 (MFF)						100
2,886	Circulating before POOH	2,360	8.0 (MFF)	7.0					650
2,894	Drilling	2,700	5.0 (MFF)						400
2,899	Drilling	2,700	6.0 (MFF)	5.0					200
2,966	Circulating before POOH	2,470	8.0 (MFF)	7.0					400
2,781	Back Reaming	2,470	8.0 (MFF)						400
3,158	Drilling	2,840	8.0 (MFF)	7.0 (LCM)					2,400
3,244	Drilling	2,650	8.0 (MFF)	7.0 (LCM)					2,400
3,305	Circulating before POOH	2,650	8.0+8.0 (MFF)	7.0 (LCM)					1,900
1,783	Reaming	900 / 2,500	5.0 (MFF)						Overflow
1,800	Reaming	2,200	8.0 (MFF)	8.0					150
1,832	Reaming	2,000	6.0						300
2,012	Washing Down	2,460	6.0						300
2,219	Washing Down	2,500		5.0					100
2,409	Washing Down	2,450	5.0						200
2,600	Washing Down	2,460		5.0					100
2,810	Washing Down	2,480	5.0						100
3,012	Washing Down	2,460		5.0					100
3,205	Circulating	2,450	8.0	7.0					100

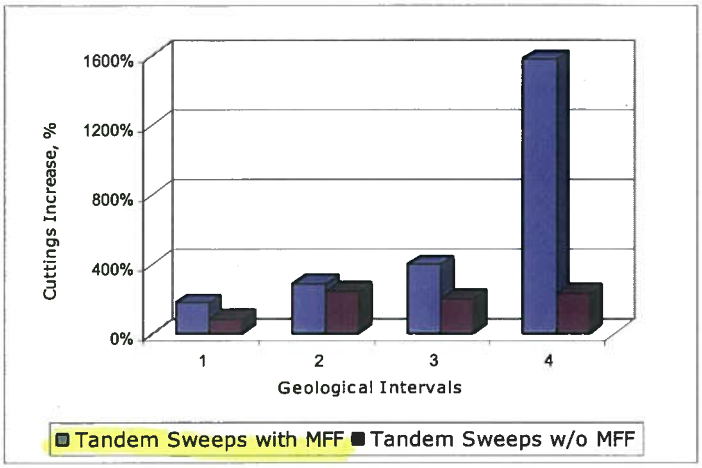
Picture 1: Kharyaga 12 1/4" Section Hole Cleaning Performance Simulation



Picture 2: Low-Viscosity Monofilament Fiber / High-Density Sweeps Hole Cleaning



Picture 3: Efficiency Comparison of Tandem Sweeps with MFF and without MFF using Cuttings Load Increase on Shakers Parameter



Picture 4: Efficiency Comparison of Tandem Sweeps with MFF and Low-Viscosity MFF Sweeps using Cuttings Load Increase on Shakers Parameter