



## Optimizing Single Interval Drilling and Drill-in – Two Fluids: A Case Study

Jack Reeve and Tom Jones - INTEQ Drilling Fluids, Gary McNair and Hu Jia Pin, CACT Operators Group, Shekou, China

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### Abstract

An Offshore China/South China Sea operator wanted to optimize the use of rotary steerable drilling assembly, simplify and reduce operational steps, and provide a larger reservoir wellbore. The operator elected to drill a single 8.5" wellbore and, in order to address a variety of issues and potential problems, change from a Cloud Point Glycol Drilling Fluid to a Drill-In Fluid (DIF) at the reservoir entry point.

### Introduction

Effectively addressing numerous potentially compromising elements within a plan to optimize both reservoir production and utilization of new drilling technologies can be achieved through Reverse Sequence Solution Engineering (RSSE).

Reservoirs with shale layers can cause serious problems during drill-in and completion operations. Reactive shales can lead to borehole instability during the drilling phase and, if not controlled, may plug gravel and screens in the completion phase. Further, DIF return permeability and lift off properties may be seriously impaired, resulting in reduced hydrocarbon production. Without properly sequenced well planning and fluid design, high rates of filtrate invasion, circulation losses, differentially stuck pipe and low production rates may result.

In order to minimize forming or accumulating unforeseen problems while a project is underway, it is sometimes critical to originate the planning sequence from the point of view of the desired end result. This paper attempts to provide an overview of a RSSE approach, which allowed incorporation of numerous new ideas, products, processes and technologies into an existing successful process. In addition, the details from a successful field test using the new elements will be presented.

### Background

The operator had drilled a total of 12 wells culminating in horizontal sections in a variety of sandstone

reservoirs at depths varying from 2000 to 3000 m TVD, with the deeper wells reaching nearly 4200 m MD. Of

these, 4 were new wells while the remaining 8 were sidetrack re-entries. In all sidetrack cases, whipstocks were set inside existing 9.625" casing, and 8.5" sidetrack wellbores were exited from the casing. These 8.5" holes were drilled to designated reservoir entries, culminating at or very near a 90° angle. Then, 7" liners were run to isolate the entire 8.5" tangent wellbore. On some of the wells, following hanging and cementing the liner, 7" tiebacks were performed. The wells were then drilled horizontally into the reservoirs with conventional directional drilling assemblies using a water-based DIF containing a calcium carbonate bridging component. Depending upon reservoir characteristics, completion methods varied from open hole completions, to slotted or perforated liners, to pre-packed screens.

The operator had accumulated a history of consistently exceeding hydrocarbon production expectations when the reservoir was drilled using a specifically engineered DIF. Not surprisingly, the operator wanted to retain this DIF component in future wells.

Ten of the 12 wells, including all the sidetracks, were drilled with a platform rig that had initially been designed for workover purposes only. As a result, the rig was pushed to operational limits in drilling mode, with the primary limitations being overall string weight (top drive, draw-works and mast), pump pressure and output, top drive torque and speed, fluid handling and mixing capabilities, as well as fluid storage and circulating volume (Figures 1 and 2).

Regardless of these limiting factors, drilling progressed, with the directional profiles, depths and step outs reaching very challenging levels.

In an effort to further increase efficiency, enhance hole cleaning and to reduce lost-in-hole risks, the operator introduced a rotary steerable drilling assembly to drill the tangent sections of the wellbores. This technology step change became necessary when hole angle,

azimuthal trajectory and measured depth combined to create well geometry profiles which were approaching conventional directional drilling assemblies and methodologies.

Further analysis and consideration showed that drilling a single hole size to TD would streamline liner and completion operations, reduce drilling time and benefit hydrocarbon production. It was here, from a fluids point of view, that the need to engineer the required wellbore environments began.

### Reservoir Completion Phase

The first sequence for fluid selection began with the borehole environment at TD. The operator planned an open hole completion with a pre-perforated liner. To avoid needing chemical treatment options for wellbore clean up, it was decided that skin removal should occur naturally by allowing the well to produce the filter cake after displacement to brine. For this to happen, the following post drill-in specifications were agreed upon:

- undamaged reservoir from the drill-in process
- low-solids content (internal and external) filter cake
- a thin, tight filter cake across all pore variations
- minimal filter cake break-through pressures upon flow-back
- a gauge hole with good lubricity
- wellbore stability

This operator had previously utilized a proven carbonate-based drill-in fluid on numerous applications within the existing field for less challenging applications. The production results, in each case, were satisfactory. Therefore, the base formulation for the drill-in fluid did not require a change, but due to the shaley path to the pay zone, the system required non-damaging modifications.

Numerous laboratory tests designed to measure a drill-in fluid's tendency to maximize production have been performed and used as the basis for the operator's DIF selection. It is widely accepted that a thin, producible filter cake is necessary for higher production, especially if chemical clean up is not planned. The need for cake quality is evident when comparing laboratory measured break-through pressures with return permeability as shown in Figure 3.<sup>1</sup>

To promote low break-through pressures, the deposition of drill solids in the filter cake was to be minimized by controlling the concentration of solids incorporated in the DIF. A relatively clay-free filter cake was also required to provide a non-sticky wellbore surface for drilling operations and later and running the liner. To maximize the rate of desired cake deposition and minimize the clay content in the filter cake, the

excessive risk levels if drilling were to continue using

industry-recognized method of selecting an appropriate concentration and blend of sized calcium carbonate was used.<sup>2</sup> For the application discussed in this paper, a blend of two grind sizes was selected initially based on general reservoir characteristics as well as performance on previously wells drilled in the field.

Laboratory testing of successful drill-in fluid formulations that have incorporated varying amounts of drilled solids suggests that drill solid concentrations between 4 and 5 % in the fluid can have a direct effect on the quality of filter cake. As the concentration increases, the filter cake becomes sticky and less friable. Fluids having higher concentrations of clay deposited in the filter cake tend to require higher net break-through pressures. This trend is illustrated in Figure 3 and represented by the low return permeability and high break-through values.<sup>1</sup>

To avoid this type of formation damage, it was decided that the MBT of the drill-in fluid must be kept below 5 lb/bbl (bentonite equivalent). Field engineering procedures, such as whole mud dilution and the use of shale stabilizing additives, have been effective in this regard. It is worth noting that minimizing the concentration of clay particles in the filter cake also has an effect on the filter cake thickness and overall lubricity of the wellbore wall.

From a filter cake quality perspective, an MBT value of 5 lb/bbl or less was to serve as a gauge for minimizing the static (external) filter cake thickness. This is particularly an issue during displacement to completion fluid or brine. When the drill solid content or MBT rises, the static cake is more difficult to remove because the additional clay particles create unwanted adherence within the cake matrix, resulting in elevated break-through pressures and "sheeting". As Figure 4, indicates, a completion fluid or brine requires a Critical Transport Fluid Velocity (CTFV) of between 5-6 ft/sec to clean the horizontal and tangent section.<sup>3,4</sup>

In the horizontal section, the displacement rate can help scour away the static filter cake and carry debris to surface. However, when the filter cake is thick or sticky, the CTFV may not be capable of cleaning the hole sufficiently for an open-hole completion. An amine complex shale-stabilizing additive was selected to manage and control the drill solids build-up in the DIF without having to use excessive whole fluid dilution.

### Reservoir Drill-in Phase

The primary objective of the drill-in phase was to preserve the integrity of the producing reservoir by minimizing damage. The choice of the base drill-in fluid was a simple decision and based on previous successes. The reservoir interval in the subject well

was different from other field drill-ins in that the open-hole was to be exposed to lengthy sections of reactive shale, especially in the tangential section above the producing interval. This reactive shale, if not controlled, would severely affect depositional quality of the primary (internal) and static (external) filter cakes, and impact wellbore stability.

In order to avoid compromising hydrocarbon recovery in the reservoir, the shale-stabilizing additive was thoroughly tested with the base drill-in fluid. Laboratory studies have concluded that the amine complex was effective in stabilizing shale. Accordingly, this product was also studied in the formation damage laboratory to ensure that drill-in fluid concentrations used were completely non-damaging. Table 1 below shows typical laboratory results of this additive in the polymer/carbonate base drilling fluid used in this project.

Test results of the final DIF formulation indicated that the shale stabilizing amine additive had no detrimental effect on regain permeability. Clay dispersion tests demonstrated that the additive was an excellent overall choice to minimize excessive intrusion of clay solids into the DIF and filter cake.

The massive shale (tangential) section, initially exposed during the pre-reservoir drilling phase, was to remain exposed during the drill-in phase. The plan called for an open-hole displacement after the wellbore was drilled to a horizontal position. It was anticipated that with time and drill string rotation and vibration, the shale would have a tendency to slough into the circulating fluid and further affect the quality of the filter cake. This was another reason to maintain adequate concentrations of the amine complex in the DIF.

#### Tangential Drilling Phase

The fluid selected for the upper open hole interval was based on several criteria. As before, the number one concern was long-term shale stability. This section would be exposed during the drilling and drill-in phase because casing was not planned. There was a real risk that long-term exposure could be exacerbated by typhoon delays. It was decided that the best approach to long-term shale stabilization was to minimize the pore pressure transmission (PPT) effects in the long angle-building interval.

Much as been written about the effect of cloud point glycol/polymers systems and their ability to stabilize wellbores.<sup>5,6,7</sup> A water-soluble cloud point glycol, based on the BHCT and a 5-7% KCl brine, was selected. The approach taken by the planning team was to stabilize the shale with a high performance WBM (KCl, polymer and glycol) and extend the shale stability with the amine complex after displacement to the drill-in fluid. PPT testing (Figure 5) has confirmed

that this fluid formulation, if engineered properly with respect to cloud point and BHCT can effectively stabilize shale by preventing pressure transmission.<sup>6</sup>

As the rotating drill string mechanically destabilizes sections of the shale, they would be released into the wellbore and the freshly exposed formation would require renewed stabilization. The amine complex additive, purposefully included in the reservoir drill-in, would serve this all-important function.

#### Fluid Selection Summary

In summary, the open hole section, which was to be drilled with a rotary steerable drilling assembly, would require long-term stabilization throughout the drilling phase, the open-hole displacement, and the drill-in and completion phase. The final proposal for long-term stabilization called for a salt-polymer-glycol system followed by an amine complex additive included in the DIF. Throughout the drilling operation, the primary objective would be to minimize reservoir damage caused by filter cake contamination. Secondary issues requiring address would be wellbore stability and reduced drill solids invasion into the drill-in fluid. Once drilled and displaced properly, the pay zone interval then would require a thin, pliable, easily produced filter cake. This would be made possible by maintaining a low MBT level in the drill-in fluid and utilizing a specially blended calcium carbonate bridging material. The field results discussed below confirm that the drilling program followed provided a clean, undamaged and above average, producible reservoir with minimal problems and costs.

#### Field Case History

Drilling began using the rotary steerable assembly, beneath the 9.625" casing shoe, at an initial angle of 39°, at depths of 1702 and 1601 m, MD and TVD, respectively. Following a relatively planar SSW to NE "pregnant lady" profile, the wellbore gradually dropped through vertical, then built to 90° at the reservoir entry point, at 2753 and 2324 m, MD and TVD, respectively.

A wiper trip was performed to ensure that the wellbore was as free of cuttings or excess filter cake as possible. When the assembly was back on bottom, the displacement operation began. First, a 20 bbl KCl (≈ 120 m of annulus) brine pill weighted to the same density as the existing drilling fluid in the well was pumped, followed by a 50 bbl (≈ 300 m of annulus) high rheology push pill composed of DIF viscosified with xanthan gum. This was followed by the DIF. This entire displacement sequence was circulated at the maximum possible rate, giving annular velocities in the range of 285 ft/min (87 m/min). Returns at surface showed distinct and easily recognized interfaces, with very little fluid mingling.

Drilling progressed through the reservoir section to TD, with MBT values reaching a maximum of 3.75 ppb bentonite equivalent, well within optimum levels. Following a wiper trip, the well was circulated clean, with the DIF processed through fine shakers to minimize the solids content and particle size.

A 7" liner was run, with a perforated section extending approximately 50% into the reservoir interval. An external casing packer was inflated just above the reservoir, and the liner was cemented to isolate the reservoir interval.

Upon putting the well on production, the operator reported that hydrocarbon output was better than modeling had anticipated.

### Summary

The drilling of this well generated some significant performance milestones for the operator in this field including:

- longest footage drilled per day
- longest horizontal section in 8.5" hole size
- drilled the entire 1783 m interval in one run
- 7.5 days vs. 30 days (AFE)
- a clean and stable wellbore throughout
- validation of dual fluid concept
- validation of RSSE

In this instance, successful incorporation of several new elements into an existing functional operational sequence was best accomplished through reverse sequence solution engineering. Beginning planning from the point of view of a clean, undamaged and productive wellbore allowed for appropriate address of the new operational elements desired and of the potentially detrimental effects generated by the changes.

### Nomenclature

*DIF = drill-in Fluid*

*CTFV = critical transport fluid velocity*

*BHA = bottom-hole assembly*

*BHCT = bottom hole circulating temperature*

*ROP = drilling rate of penetration*

*PPT = pore pressure transmission*

*WBM = water-base mud*

*BHCT = bottom-hole circulating temperature*

*MBT = methylene blue test*

### Authors

1. Jack W. Reeve received his initial training in drilling fluids in Calgary in 1976, and has held positions in drilling and completion supervision, solids control and production equipment design, as well as numerous positions in drilling fluids operations,

technical services, sales and marketing both domestically and internationally. Jack is currently a Marketing Specialist with INTEQ Drilling Fluids in Houston.

2. Tom Jones received his B.S. in Biology and Chemistry from Southwest Texas State University. He began his career in the oilfield as a Milchem mud engineer in 1978 and has held various positions in operations, technical services, and engineering since. Currently, Tom is the Product Line Manager of Hydrocarbon Recovery for INTEQ Drilling Fluids.

### Acknowledgments

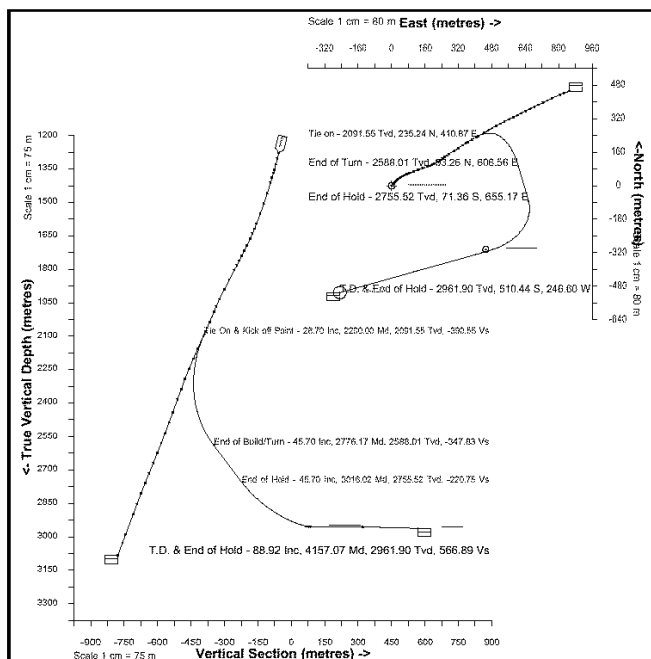
The authors thank CACT Operators Group for allowing the authors to write and publish this paper.

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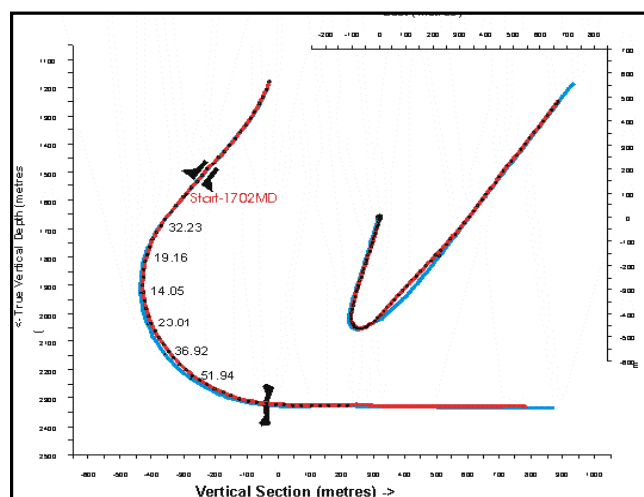
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Lab Test #	Shale Stability % Retained Screens	%Kr	Break-Through psi
1	97.4	93.5	8.8
2	95.6	96.6	9.3

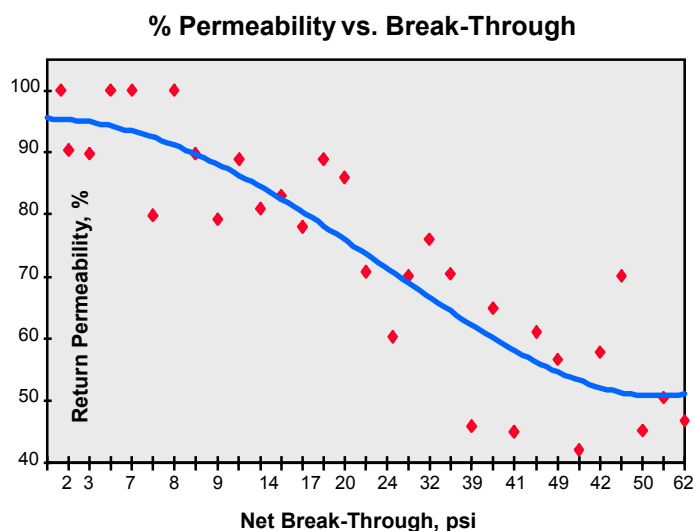
**Table 1- Effectiveness of Shale Control Additive based on the % of shale retained on a screen after hot rolling and its influence on return permeability.**



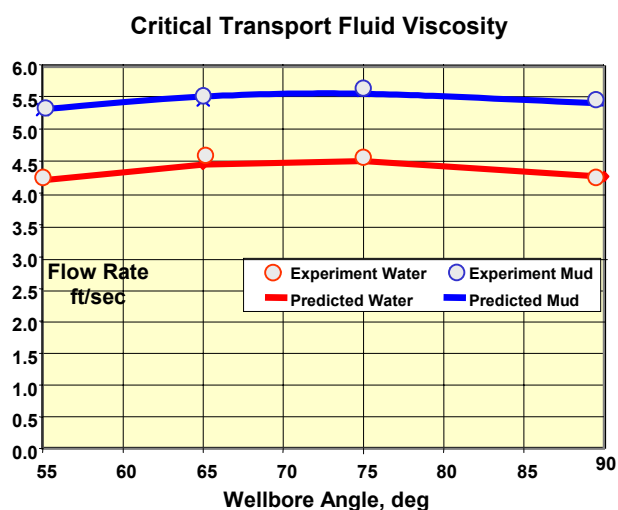
**Fig. 1 -Typical field re-entry wellbore profile**



**Fig. 2 -Subject well designed and actual profiles**

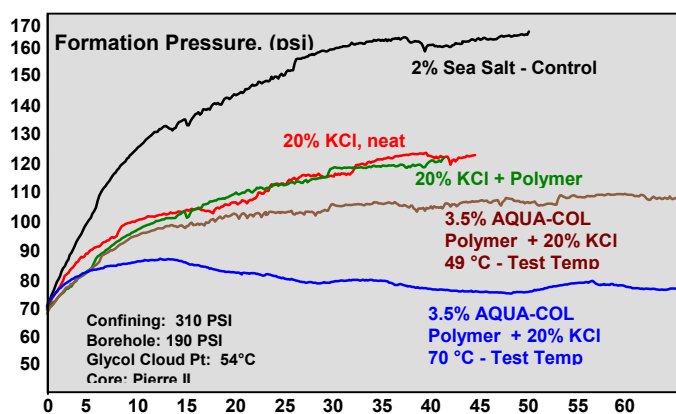


**Figure 3 -The effect of skin damage on break-through pressures and its corresponding effect on return permeability.**



**Figure 4 –The Critical Transport Fluid Viscosity required to remove drilled solids and filter cake debris (potential damage) is ~ 5 ft/sec (300 ft/min).**

### Pore Pressure Transmission Testing



**Fig. 5 –When the cloud point of a water-soluble glycol is properly engineered in a salt-polymer-glycol fluid, the PPT can be controlled effectively and the shale mechanically stabilized with hydrostatic fluid pressure.**