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Field Results of Ultra-low Invasion Drilling Fluids Demonstrate Reduced Wellbore Instability, Reduced Mud Losses, Wellbore Strengthening and Improved Well Productivity

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Abstract

When the invasion of drilling, completion and workover fluids is reduced to as low a level as possible, problems with mechanically unstable formations, differential sticking and lost circulation are also greatly reduced. If invasion never occurs, or is stopped by the rapid formation of a seal, then rock mechanics considerations tell us that this is a viable route to wellbore strengthening. A properly formulated ultra-low invasion fluid (ULIF) will also reduce formation damage and so improve the prospects for optimum well productivity.

We describe the technology used to produce a class of ULIF and review the benefits that limiting fluid and pressure invasion brings to rock integrity, drilling performance and well productivity.

The paper then focuses on case histories. Log data are used to demonstrate that the ULIF reduces wellbore instability and fluid invasion. Evidence of wellbore strengthening is presented and the economic benefits of using ULIF are discussed.

Introduction

The ability to reduce the invasion of drilling, completion and workover fluids to the lowest possible level brings many benefits, including less formation damage, less differential sticking and the prevention of some types of mechanical instability. If transmission of the mud overbalance to the pore pressure is prevented or greatly reduced, the effective stress is not reduced and compressional failure of the rock may be avoided.

If the rock can be strengthened by some mechanism, higher fluid densities can be used without resulting in induced losses.

It is not surprising therefore that, in recent years, a considerable amount of effort has been expended in trying to find “zero fluid loss fluids” as well as fluids that strengthen the wellbore by stopping pressure invasion, consolidating rock or managing the stress distribution (including recent use of the “stress cage” approach).

In this paper we review one class of additives that are designed to limit both fluid and pressure invasion. These Ultra-low Invasion Fluids (ULIF) can be used as drilling, completion or workover fluids as well as cementing spacers. The additives described here are equally effective in water-based, oil-based and synthetic-based fluids. Many laboratory results to date show that, after a brief period of invasion, an extremely low permeability seal is formed that virtually eliminates further fluid ingress: once this happens, the formation is effectively protected from the consequences of further pressure or fluid invasion. An important feature is that this seal is formed extremely rapidly – in a matter of seconds after the rock has been exposed to the fluid. This rapid shutoff of invasion, depicted in Figure 1, is a key factor in achieving the excellent results seen in the field with the ULIF product.

The technology behind this class of Ultra-low Invasion Fluids will be briefly discussed and then several field examples will be described where the muds have successfully strengthened the wellbore to reduce wellbore instability and reduce or eliminate induced losses. We will also provide examples of much reduced fluid invasion into permeable sands. The ability of the ULIF approach to improve well productivity has been discussed elsewhere[1,2] and will not be greatly expanded upon in this paper.

Description of the ULIF Technology

The compositions and properties of the ULIF additives are described in detail in other publications[2,3] and so will only be briefly reviewed here.

The additives use a carefully controlled blend of low molecular weight polymers and fine solids. Both the polymers and the surfaces of the solids have been modified such that different components have different oil/water solubilities or wettabilities. These components are then blended in precise ratios to produce the ULIF additives.

When the ULIF blend is added to an aqueous fluid, the more hydrophobic entities are only poorly wetted and, in order to minimise the system energy, associate to form aggregates. The process is similar to micelle formation in surfactants, although the ULIF aggregates are much more poorly ordered than micelles and are largely insensitive to temperature, pressure and salinity.

When the ULIF product is added to an oil-based fluid, the same mechanism operates but it is now the more hydrophilic components that form the aggregates.

It is these aggregates that are the key to the formation of the very low permeability barrier at the surface of rocks with matrix permeability. This seal forms after an extremely short period of invasion and is shown in laboratory tests to be very effective at virtually eliminating further fluid invasion or pressure transmission. The aggregates are also able to seal and protect microfractures and bedding planes.

Particle size analysis of the aggregates in different liquids shows a d_{50} that ranges from about 60 to 140 microns, depending on the base fluid. The d_{10} varies from about 9 to 16 microns and the d_{90} from about 300 to 750 microns, again depending on the base fluid. With such a wide particle size distribution, it is easy to see how the same ULIF additive can seal a wide range of matrix pore sizes and small fractures.

The mechanism of action of the ULIF is shown pictorially in Figure 2. Figure 3 shows the ability of the ULIF to seal a 20/40 frac sand; the deep invasion of the base oil based mud into the sand is in strong contrast to the effective seal formed when only 5ppb of the ULIF is added to the fluid.

Why Limit Fluid and Pressure Invasion?

Invasion of the mud overbalance *pressure* into a rock matrix will elevate the pore pressure. If this increased pore pressure is unable to bleed away quickly enough (for example if the rock permeability is very low as in a shale or silt), the effective stress is reduced, taking the rock stress state towards the collapse limit[4,5]. This can cause the rock to fail and lead to wellbore instability.

Excessive *fluid* invasion can give rise to a number of problems:

- if a thick filter cake forms, the risk of differential pressure sticking increases
- invasion of whole mud or filtrate into producing formations increases the probability of formation damage
- invasion of fluid can occur into imperfections, microfractures or along bedding planes, particularly (but not exclusively) in shales, coals and other low permeability rocks. This may open and lubricate the planes of weakness, often leading to mud losses and/or wellbore instability

If pressure and fluid invasion could be stopped completely while drilling in overbalance, it is clear that many drilling problems would never occur and that most of the formation damage related to mud and completion fluids would be eliminated. However, at present there is no established technology that can completely prevent both forms of invasion and so the industry focuses on reducing them to as low a level as possible. In actual fact, considerations of chip hold down effects and the resulting low ROP suggest that some invasion will actually be beneficial, provided it can be stopped after a short period of time and distance. By substantially reducing invasion it is possible to remove, or at least reduce, the above problems: this will reduce non-productive time, make for more efficient operations and improve well productivity.

The class of additives described in this paper has been shown to produce very effective ultra-low invasion fluids. As described above, there is a brief period of invasion with these fluids until the extremely low permeability barrier is formed. Once this barrier is in place, there is very little further fluid invasion and the effects of pressure transmission through the barrier are greatly mitigated.

Case Histories

In previous publications[2,3] we presented laboratory and field evidence to demonstrate that the ULIF additives described here reduced the invasion of synthetic based mud in a sandstone formation in an offshore well in the Far East. Inductance logs indicated that without the additive, filtrate invasion of the base mud was approximately 90 inches while, in an offset well using the same base mud but containing the ULIF additive, invasion was reduced to less than 10 inches (this was the limit of the resolution of the inductance logging tool).

We have also stated elsewhere[3] that wellbore stability in fractured shales drilled with water based mud in Colombia, Latin America was improved and that well productivity was often increased by 20 to 25%.

In this paper, we expand on the field experience with the ULIF additive. We will present log data that reinforce our claims of reduced matrix invasion and improved wellbore stability. We also present data on wellbore strengthening from offshore wells in the Gulf of Mexico where there is clear evidence that the ULIF additive raises the fracture gradient and thereby reduces problems of induced mud losses: the economic benefits are discussed here along with the obvious technical advantages.

Further evidence of the ability of the ULIF products to protect and strengthen weak formations is provided by their use to drill the difficult Nahr Umr Shale in the Middle East, and in the use of the ULIF approach to drill a 500 foot long horizontal section in a coal bed in North America.

1/. Reduced Fluid Invasion and Wellbore Instability with ULIF Fluids

Colombia, Latin America

In the past 3 years a major operator in Colombia has drilled over 45 land wells using the ULIF additive. The product has been used in 5 different fields, exclusively in water based muds and generally in wells below 40 degrees inclination.

Results to date show that wellbore stability in fractured and bedded brittle shales has been markedly improved, and that filtrate invasion into reservoir sands has been reduced. The ULIF have typically given a 20 to 25% increase in well productivity in the cased and perforated completions used in the region.

The ability of the ULIF additive to improve wellbore stability and lower filtrate invasion is clearly demonstrated in the sections of well logs shown in Figures 4 and 5. The figures compare 2 wells in a field where the 8 ½" hole section contains brittle, unstable shales and a sandstone reservoir. Essentially the same water based mud formulation was used for both wells except that, in Well #B, 6ppb of the ULIF product was added. The typical mud formulations and properties are shown in Tables 1 and 2 respectively.

Figure 4 compares the well logs of the 2 wells in a part of the shale section. In the figure the depths of the portions of logs are offset to allow the gamma ray traces to be aligned: in that way, the effects of the 2 muds on the same formation are compared. It is clear from the caliper logs that the 8 ½" hole drilled without the ULIF (Well #A) is enlarged and uneven. The maximum caliper is 12 ½ to 13 inches. In well #B the effect of adding the ULIF is striking: the caliper is now close to gauge and never exceeds 9 inches.

Figure 5 compares the logs in the sandstone payzone of the same 2 wells - again the logs are offset in depth to align the same formations by the gamma ray logs. In the left hand image (Well #A without the ULIF additive), the resistivity log traces for different investigation depths are clearly separated: this indicates that at each depth of analysis the pore fluid has a different electrical conductivity. The conclusion must be that mud filtrate has invaded to around the deepest investigation depth of the log, if not deeper. The logging company estimates the depth of invasion to be about 40 inches.

In the corresponding log where the ULIF additive was used (Well #B), we see that the shallowest reading resistivity trace is distinct and separate, but all the others are virtually superimposed. The only plausible interpretation is that the ULIF has allowed the filtrate to invade a little but that, once past the shallowest investigation depth of the log, only uncontaminated reservoir fluids are present. The logging company estimates the invasion depth with the ULIF additive is of the order of only 4 inches.

If, for the sake of argument, we assume that some formation damage has occurred over most of the invaded depth – and remembering that the wells are completed by cementing and perforating – it is easy to see why the well productivity is improved with the ULIF. 4 inches or less of damage from the Ultra-low Invasion Fluid will be largely bypassed by the perforation tunnels, but most (or all) of the perforations in the offset well that did not use the additive will be in the invaded section - and therefore quite possibly in damaged permeability.

The recommended method of engineering this ULIF system is to use the sand bed test described earlier to ensure the ultra-low invasion properties are maintained. Details of the test are given elsewhere[3] but, in brief, the aim is to keep mud invasion into a graded 20 / 40 mesh sand bed to less than 5 centimetres in a 30 minute test carried out at 100 psi overbalance. If the invasion starts to increase beyond this depth, this is a clear indication that there is insufficient ULIF additive in the fluid and that a maintenance addition should be made.

Figure 6 gives an excellent demonstration of the need to maintain an effective concentration of the ULIF additive in the mud. As the well using the ULIF neared TD, the concentration of the ULIF additive was not maintained properly, the additive depleted, and the active concentration fell below that required to maintain a good seal. When the logs were later examined we can see that as the ULIF additive depleted, the invasion into the sand increased: a comparison of the well without the ULIF and the well where the ULIF additive had depleted shows that they were now virtually indistinguishable. When the caliper logs in the sandstone section of the ULIF well are compared (right hand images of Figures 5 and 6) there is also evidence that the filter cake thickness has increased as the ULIF additive concentration depleted below an effective level.

2/. Wellbore Strengthening

a). Gulf of Mexico

The ULIF additive has been used by one operator in over 30 wells drilled in the Gulf of Mexico. Here, the large majority of applications have been in diesel invert muds where the ULIF is used in intermediate hole sections to raise the fracture gradient and reduce induced mud losses.

A typical problem faced by the operator in this region is that the fracture gradient is lower than the mud weight required to provide effective well control and wellbore stability. In many wells, influxes are taken or cavings are observed, but when the mud weight is raised to combat these problems, substantial losses are induced: in some wells upward of 25000 barrels of oil mud have been lost. These uncontrolled losses can result in subsurface kick/loss situations that can take many days to solve. Wells often need to be sidetracked or have casing set

early.

Three examples of the use of the ULIF approach in this region are given below:

- Well 1

  After setting the 13 3/8" casing at 6,630 feet, the offset well used for comparison (i.e. without the ULIF) experienced heavy mud losses which could not be cured with conventional lost circulation treatments. After losing over 2,000 barrels of oil mud, a string of 11 7/8" casing was run to 9,196 feet and drilling restarted using a 10 5/8" bit. Heavy losses were again encountered and these were finally controlled after pumping 3 cement plugs. It was decided to sidetrack the hole at 8,619 feet and a 9 5/8" liner was finally set at 16,142 feet. It had taken 154 days to drill from the 13 3/8" shoe.

  In the next well, the ULIF product was added to the oil based mud at the start of the 12 ¼" section (the 13 3/8" casing was this time set at 6,700 feet). No mud losses were detected and the section was drilled smoothly to 16,614 feet in 54 days. This represented a saving of 96 days over the offset well, despite the fact that an additional 400 feet of hole was drilled. Casing was run to bottom and cemented without problems. This was the longest string of 9 5/8" casing ever run by this operator.

  A preliminary economic analysis suggests that the use of the ULIF saved the operator over US$4.2 million on this hole section.

  A summary of the wells is given in Table 3.

- Well 2

  An offset well had used oil mud to drill from 9,304 to 15,800 feet in 117 days. The upper part of the interval was drilled with continuous partial losses and then an influx of formation water was detected in the mud. The drill string showed snatches of high torque suggesting stuck pipe was imminent. As a result of these problems a cement plug was set and the well sidetracked.

  While at 11,309 feet, simultaneous losses and a water flow were detected. An LCM pill was placed but total losses were experienced and attempts to cure them were unsuccessful. In all, some 25,000 barrels of oil mud were lost to the formation and it required 4 trips from shore by the supply boat to make enough mud available to keep the well full.

  On a subsequent well, the ULIF product was added at the start of the 12 ¼" section (8,425 feet) and was maintained in the system until TD at 16,027 feet. A leak off test (LOT) was made at the 13 3/8" shoe with old water based mud before switching to the ULIF oil mud: the LOT value was 15.7ppg.

  Drilling commenced with the ULIF at a density of 15.0ppg but this was increased to 15.3ppg when a pressure transition was encountered at 9,196 feet. In the next 6 days, drilling progressed to 10,157 feet, with the mud continuing to be weighted up as the well went further into the high pressure zone. The static mud weight finally reached 16.6ppg. Even though this gave a calculated ECD of 18.53ppg below the 13 3/8" shoe that had previously shown a LOT of 15.7ppg, no losses were observed despite the high mud weight.

  Using the ULIF approach, the operator had drilled over 650 feet deeper into the high pressure zone than on any previous well.

  Unfortunately, having made a bit trip, the string was run back in the hole to just below the 13 3/8" shoe and circulation was established by bringing the mud pumps up to speed rapidly, rather than rotating the pipe and bringing the pumps in slowly. The resulting pressure surge broke down the 13 3/8" shoe and about 3,700 barrels of mud were lost before the loss zone was sealed with a dilatant LCM pill.

  Drilling recommenced once the losses were controlled but the hole was unintentionally sidetracked. This sidetrack was drilled without problems to 9,678 feet using the ULIF. 9 5/8" casing was set at 11,302 feet and, continuing with the same ULIF system, the hole was deepened to 16,027 feet and 7 5/8" casing run and cemented without problems.

  Despite the lost circulation incident and the unintentional sidetrack, this section was drilled in 69 days with the ULIF, compared with 117 days for the offset well using conventional invert OBM. Although there were induced downhole losses totaling 5,700 barrels of mud, this volume was significantly lower than the 25,000 barrels lost in the offset well. It is estimated that, compared with the offset well, around US$3.2 million was saved by using the ULIF additive.

  A summary of the wells is given in Table 4.

- Well 3

  In November 2004, the operator was having severe problems with induced losses of an 80/20 invert OBM in the 6" section of an offshore exploration well.

  Trouble had started in the 8½" section which had been drilled with WBM. Here, due to

hole problems and mud losses, the section was terminated at 12,395 feet instead of the planned 12,796 feet. The 7 5/8" liner then became stuck at 11,496 feet, some 900 feet above bottom and about 1,300 feet short of the planned TD.

These problems in the 8½" hole meant that there was a long rathole exposed while drilling the 6" section and the total length of this lower section needed to be extended if the planned casing point was to be reached.

In the 6" section, the WBM was displaced to OBM and drilling went ahead with problems of cavings, tight hole, pack-offs and partial to severe mud losses. A kick was taken at 12,467 feet that required the mud to be weighted to 13.3ppg: this induced more mud losses. In all, about 6,300 barrels of mud were lost downhole.

No progress was made for 18 days while several unsuccessful attempts were made to stop the losses (averaging over 250 barrels / day).

The operator believed that it was impossible to continue drilling with the standard OBM formulation and was considering either abandoning the well or running a 5" liner and then continuing in 4" hole in an attempt to reach the planned well TD at 13,878 feet. It was at this point that it was decided to try a low invasion OBM formulated with the ULIF additive before going to one of the more extreme options.

The bit was pulled back to the shoe and the OBM treated with 6ppb ULIF product which, from the sand bed test, was shown to be sufficient to convert the OBM into an Ultra-low Invasion Fluid. After one circulation of the ULIF-treated mud, losses were greatly reduced. A further 1ppb treatment was made to replace that ULIF additive consumed by the LGS in the mud and within the next 24 hours the losses stopped completely.

Drilling was restarted and the low invasion properties of the fluid maintained by making maintenance additions of the ULIF additive as indicated by the sand bed test. The drilling operation continued without further problems until the well was 130 feet from TD when a drop in the ULIF concentration through depletion resulted in a small loss of mud to the formation. The optimum ULIF concentration was re-established and the losses stopped.

A coring programme was then carried out without incident and the well drilled to the planned TD. The well was then cased and cemented without problems.

b). ULIF in WBM, Offshore United Arab Emirates

A KCl/Polymer ULIF system was used to drill the 12¼" section of a well offshore UAE. The major concerns in this section were wellbore instability, mud losses and stuck pipe in the difficult Nahr Umr Shales. The section was 4,763 feet long and had an average angle of 24 degrees. Approximately 400 feet of weak, unstable (and possibly microfractured) Nahr Umr Shale was drilled in addition to shallower shales and marls, and a thick fractured limestone sequence below.

The section was drilled in only 6.3 days, with an average ROP of about 760 feet/day. This compared with 290 to 660 feet/day in the offset wells used as comparisons. The target time for drilling the 12¼", as set by the operator, was 10 days. No wellbore instability, pack offs or mud losses were noted while drilling the Nahr Umr. Much less back reaming was required than on the offset wells, and bit balling was reduced and confined to the marls above the normally problematic Nahr Umr.

On entering the limestones below the Nahr Umr, 3 stuck pipe incidents were recorded. However, analysis showed that these problems were caused by mobile blocks of rock that trapped the pipe, and by key seating or ledges. None of the sticking incidents could be attributed to differential pressure sticking due to failure of the ultra-low invasion mud. The pipe was successfully freed after each sticking event

Casing was run and landed on bottom in 18 hours; 2 hours less than the target of 20 hours set by the operator, and considerably less than the 40 hours commonly taken in this field. The subsequent cement job was performed without losses and with full returns to surface. Typically, cementing losses are experienced in this area and the fact that the well drilled with the ULIF system was cemented trouble-free supports claims that the mud strengthens formations and prevents their breakdown.

c).Horizontal Well in Coal Beds, North America

In 2005, a 500 foot long horizontal section was drilled in a coal seam in a North American Coal Bed Methane well. A water based mud containing the ULIF additive was used.

Laboratory testing had confirmed that the additive did not cause formation damage to the tight, cleated coal. This result, combined with positive field results using a ULIF derivative in spacers to strengthen coals ahead of cement[3], gave the operator the confidence to try the ULIF additive in a full mud system. Offset wells had suffered severe problems with hole instability and mud losses.

The well was drilled with a low weight ULIF system with as simple a formulation as possible: Xanthan Gum,

starch, 7ppb of the ULIF additive, caustic soda and soda ash. The mud yield point was about 19 lb/100 sq ft and the plastic viscosity was around 25 cPoise. Special emphasis was given to maintaining enough ULIF additive in the mud to give a tight seal in the sand bed test, as well as ensuring the rheology and hydraulics would give good hole cleaning should any of the coal become unstable and cave into the hole.

The coal beds in this region are normally drilled with unweighted water-base mud, using fine screens and centrifuges to keep the low gravity solids content as low as possible. If the LGS is allowed to build up, the increased mud weight and ECD causes induced fracturing, losses and, sometimes, hole collapse. On the ULIF well it was decided to take advantage of the ability of the additive to aggregate low gravity solids (in this case coal fines) and remove them from the system on relatively coarse shaker screens. 100 mesh screens therefore replaced the normal 180-200 mesh, and the centrifuges were not used. As expected, the ULIF kept the LGS content low and the mud stayed in good condition.

The well drilled with the ULIF mud reached TD without any detectable downhole mud losses and with very few of the blocky cavings that are normally characteristic of these wells. On reaching TD, the well was cleaned out and a slotted liner run to bottom with little resistance.

At the time of writing this paper, no production data were available to allow the low damaging properties of the ULIF additive to be confirmed.

Conclusions

The ability to reduce fluid and pressure invasion into formations to ultra-low levels will bring benefits in terms of reduced mud losses, reduced formation damage, a lower risk of differential sticking and improved wellbore stability in many types of potentially unstable formations. The use of the ULIF approach is a simple and effective method of providing wellbore strengthening.

By using an approach where there is a small amount of initial invasion, followed by the formation of an extremely low permeability seal, the ULIF additives described in this paper are shown to be effective at minimizing the above problems.

We present several field cases to show the benefits of using the ULIF additive:

- Log data from Colombia show how ULIF systems can protect brittle shales and prevent hole enlargement. The logs also show how filtrate invasion in the sandstone payzone is reduced from about 40 inches to 4 inches by using the additive.
- Three case histories are presented for offshore wells in the Gulf of Mexico where the ULIF additive is being used in invert oil muds to strengthen the wellbore and prevent induced losses. The fluids have produced considerable reductions in drilling costs and non-productive time.
- In the Middle East, the ULIF approach has been used successfully to drill the difficult Nahr Umr Shale.
- In North America a mud containing a ULIF additive was used to drill a 500 foot long horizontal section in a coal seam. The product was effective at preventing the induced losses and hole instability seen on offset wells.

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Table 1: Typical mud formulations used in Colombia, Latin America (Field Case History 1)

PRODUCT	Well #A, No ULIF	Well #B with ULIF
Bentonite	5	0
Biopolymer	1.44	1.3
$CaCO_3$, 40-100 Grade	6	0
$CaCO_3$, 200 Grade	34	35
Polysaccharide FLA	4.3	3.1
Starch FLA	6	4.4
Lubricant	6	6
ULIF Additive	0	6

All concentrations are in pounds per barrel

Table 2: Typical properties of muds used in Colombia (Field Case History 1)

PROPERTY	Well #A, No ULIF	Well #B with ULIF
Density	8.7 – 9.0 ppg	8.8 - 9.0 ppg
Plastic Viscosity	20 – 24 cPoise	17 – 22 cPoise
Yield Point	31 – 35 lb/100sqft	17 – 26 lb/100sqft
Gels (10 sec / 10 min)	7/11 – 9/12	7/9 – 8/11
pH	9.5 – 10	9.2 – 10.3
API Fluid Loss	3.6 – 4.2 mL	3.9 – 5.1 mL
Sand Bed Invasion (cm)	Total; uncontrolled loss	3.5 – 10 cm*

* Target sand bed invasion depth in Well #B was < 5 cm. Invasion increased above 5 cm when the ULIF depleted towards the bottom of the section, as described in the text.

Table 3: Summary of offshore Gulf of Mexico well 1

WELL	Offset Well	Well With ULIF	Difference
Interval	6630-16142 feet	6700-16614 feet	
Feet drilled	9512 feet	9914 feet	+ 402 feet
Mud Volume Lost to Formation	3164 barrels	0	- 3164 barrels
Days on Location	154	58	- 96
Rig Day Rate	US$ 39,500	US$ 39,500	0
Interval Rig Cost	US$ 6,083,000	US$ 2,291,000	- US$ 3,792,000
Cost of Sidetrack	US$ 180,000	US$ 0	- US$ 180,000
Cost of Fluids*	US$ 1,137,000	US$ 859,000	- US$ 278,000
Interval Cost	US$ 7,400,000	US$ 3,150,000	- US$ 4,200,000

* Includes mud costs, cost of cement plugs and LCM

Table 4: Summary of offshore Gulf of Mexico well 2

WELL	Offset Well	Well With ULIF	Difference
Interval	9304-15800 feet	8425-16026 feet	
Feet drilled	6496 feet	7601 feet	+ 1105 feet
Mud Volume Lost to Formation	24987 bbl	5748 bbl	- 19239 bbl
Days on Location	117	69	- 48
Rig Day Rate	US$ 39,500	US$ 39,500	0
Interval Rig Cost	US$ 4,621,500	US$ 2,725,500	- US$ 1,896,000
Cost of Sidetrack	US$ 180,000	US$ 0	- US$ 180,000
Cost of Fluids*	US$ 2,930,500	US$ 1,746,100	- US$ 1,184,400
Interval Cost	US$ 7,732,000	US$ 4,471,600	- US$ 3,260,400

* Includes mud costs, cost of cement plugs and LCM

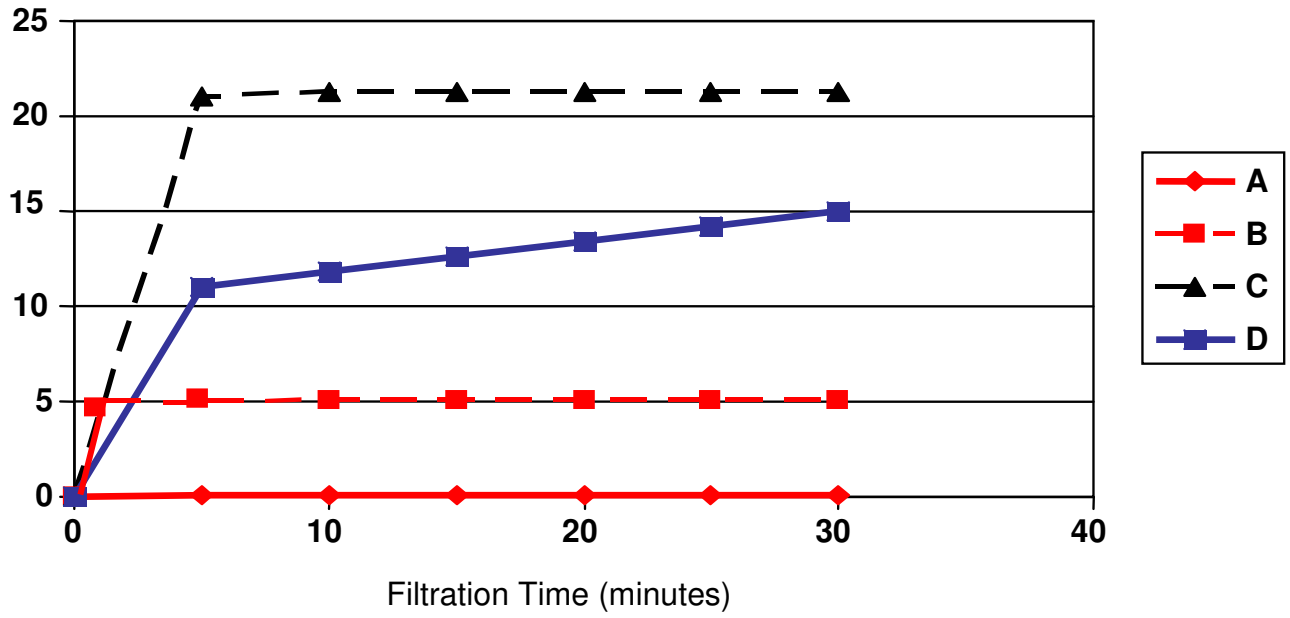


Figure 1: An illustration of the theoretical dynamic filtration behaviour of different drilling fluids. The preferred situation is that, after a short spurt phase, a seal is formed so that no further invasion occurs. The fluid described by line “B” fulfils this requirement. The vertical axis is cumulative fluid loss in milliliters.

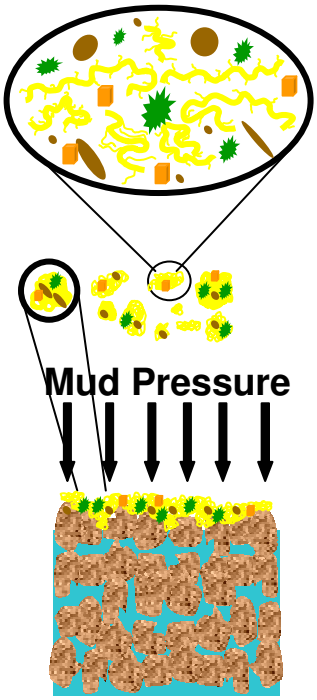


Figure 2: A schematic representation of the ULIF polymers and solids forming aggregates in solution. The aggregates form the low permeability, deformable barrier near the rock surface in the very early stages of mud filtration.

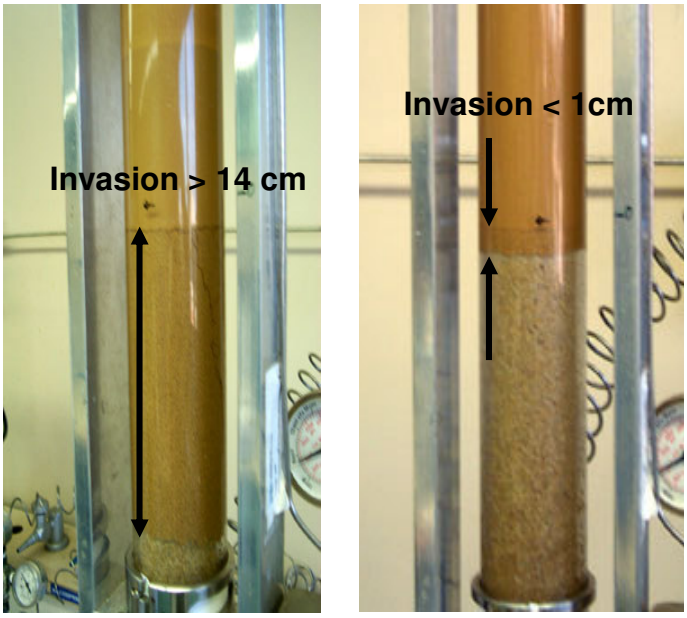


Figure 3: The left hand figure shows deep Invasion of a field oil-based mud into a 20/40 grade sand bed. The right hand figure shows the same mud with 5ppb of the ULIF additive present. The barrier at the sand surface can be seen just below the top arrow.

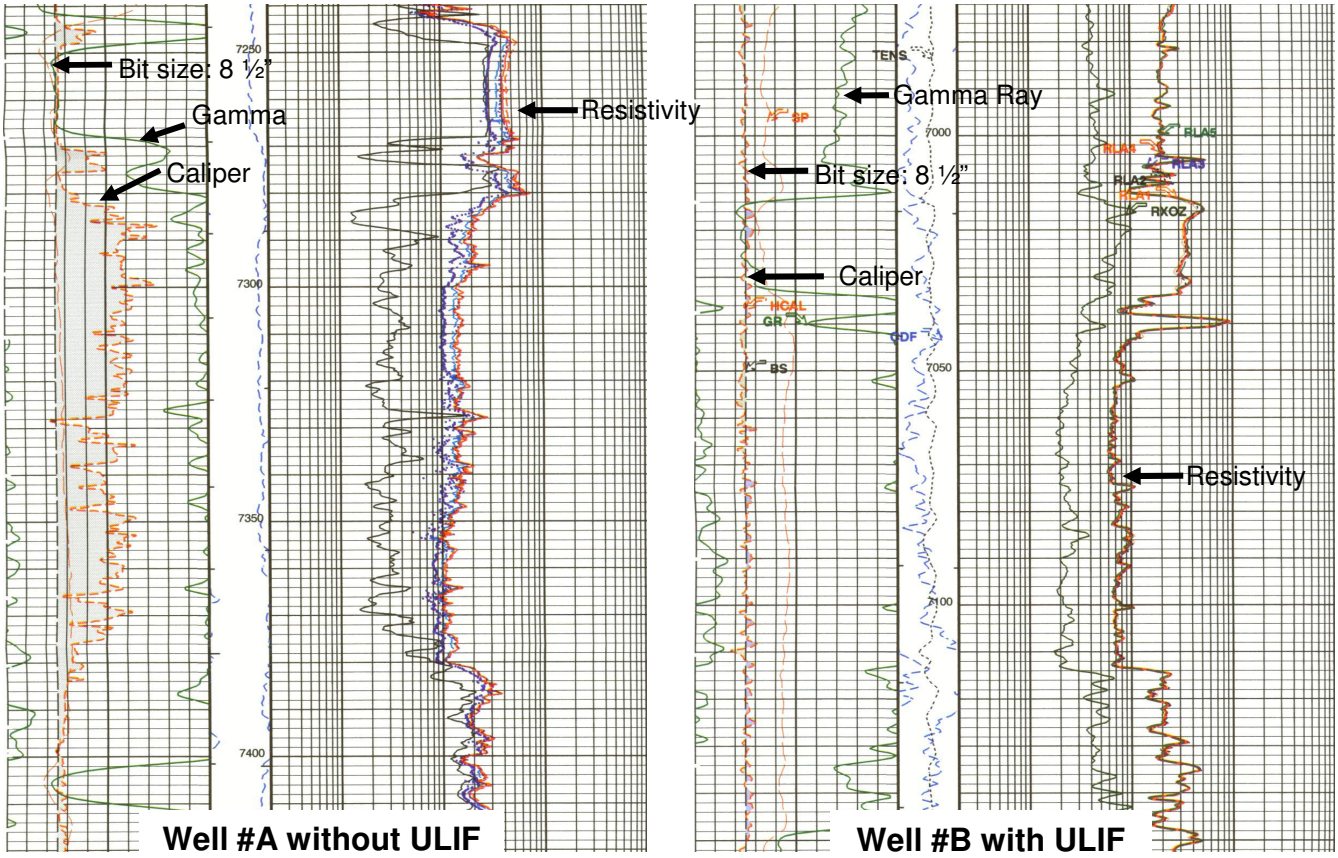


Figure 4: Logs from shale section of Colombian wells drilled with water-based muds. The left hand image shows severe hole enlargement in shales (high gamma denotes shale) drilled without the ULIF additive. In comparison, the right hand image shows the near-gauge hole obtained in the same formation drilled with the ULIF system.

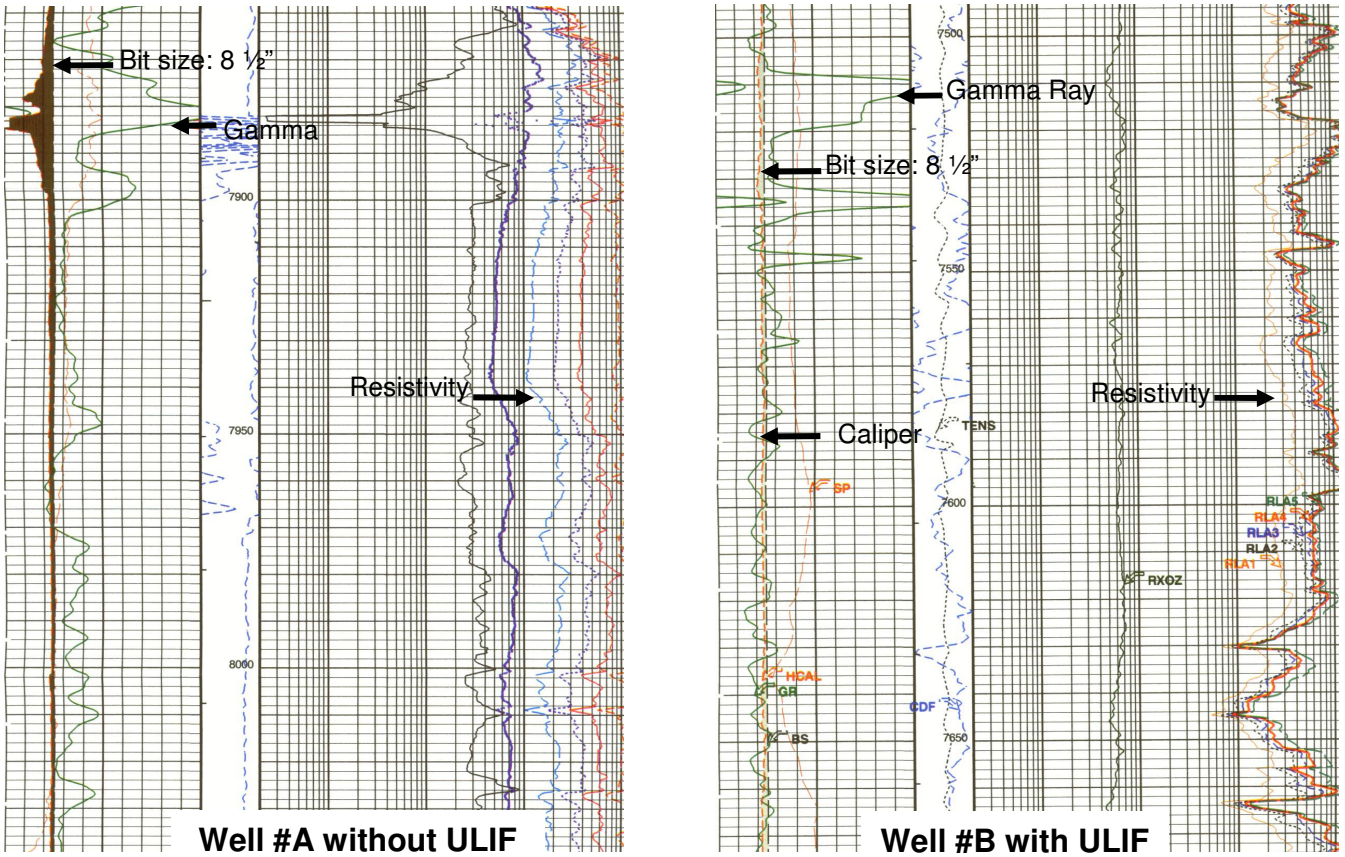


Figure 5: Logs from sandstone reservoir section of Colombian wells drilled with water-based muds. The left hand image shows resistivity data in the sand (low gamma denotes sandstone) drilled without the ULIF additive. The different resistivity values at different depths in the formation indicate deep invasion: approximately 40 inches. The right hand image shows the same formation drilled with the ULIF system: here all but the shallowest reading rate traces are largely superimposed, indicating much less invasion. The logging company estimated only 4 inches of invasion with the ULIF.

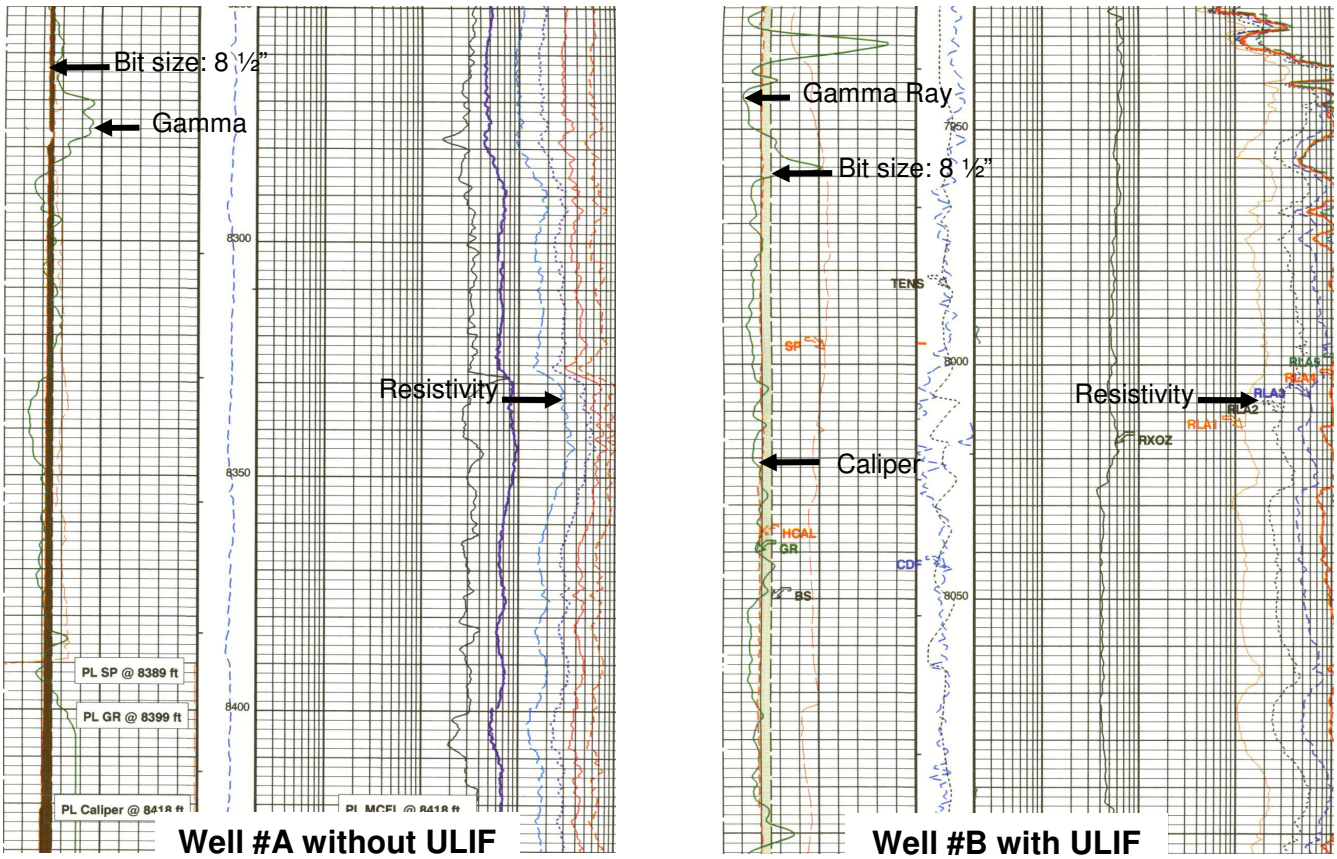


Figure 6: Logs from sandstone reservoir section of Colombian wells drilled with water-based muds. Designations are as in Figure 5. Here, the concentration of ULIF was allowed to deplete to an ineffective level and the invasion, as shown by the resistivity logs, increased to that of the mud without the ULIF additive. The contrast with Figure 5, where an effective concentration of ULIF was present, is clear. There is also the suggestion from caliper logs that the filter cake thickness has increased as the ULIF additive was allowed to deplete (compare the right hand images of Figures 5 and 6).