

CRACKING A GEOLOGICAL OBSTACLE COURSE

Abdullah Al-Ajmi, Kuwait Oil Co., Kuwait, Lucio Monferone, Newpark Drilling Fluids, Italy, and Victor Barsoum, Impact Fluid Solutions, UAE, shed light on how a water-based fluid was able to improve wellbore stability in challenging Kuwaiti fields.

Within the industry there has existed a long-held perception that oil-based drilling fluids are the only option for landing wells fraught with downhole hazards such as severe loss-prone zones, highly reactive shales and pressure variances. However, a recent development drilling campaign in North Kuwait has provided evidence that challenges this belief.

Wells constructed through the North Kuwait development programme represent diverse sets of shale and sand sequences that pose distinctive and costly drilling challenges. At the start of the project, the use of conventional water-based drilling fluids to drill weak and highly depleted shale and sand sequences proved unsuccessful in maintaining wellbore stability. The operator experienced excessive non-productive time (NPT) and unforeseen costs due to downhole complications, including intermittent tight hole and wellbore enlargement, hole collapse, stuck pipe and logging tools, low-quality logs and poor primary cement jobs. Nevertheless, in keeping with a self-imposed edict to reduce its environmental footprint, the operator assigned drilling fluid designers the task of formulating a water-based mud (WBM) capable of drilling the extremely problematic wells without the fluids-related NPT and cost overruns encountered previously.

Taking into account the specific formation conditions, a wellbore stability study was initiated that resulted in the formulation of a customised high-performance water-based mud (HPWBM). The design incorporated an ultra-low fluid invasion (ULFI) additive to shield the micropores and microfractures found in sandstone, thereby reducing instability and improving hole integrity. This combination enabled the successful drilling of highly depleted, high-overbalance development wells with zero instances of differential sticking.

The subsequent application of the customised HPWBM in the Kuwait development drilling programme demonstrated that highly troublesome wells can be drilled safely and cost-effectively, while still reducing the environmental impact.

Geological obstacle course

Operators have historically faced wellbore instability challenges in the reactive shales comprising the Zubair formation. However, before reaching the Zubair, operators must drill through the Shuaiba formation and its vugular limestone. The Shuaiba is predisposed to fracturing and losses so severe that some drilling programmes in neighbouring Iraq have been abandoned when NPT-related costs became unsustainable.¹

Adding to the complexity, the unstable Ahmadi, Wara and Burgan shale sequences are traditionally drilled in the same interval as the troublesome Shuaiba. Therein lies a significant challenge for drilling fluid programmers, as the Shuaiba demands a lower mud weight to prevent fracturing and loss returns – invariably inducing wellbore instability in the overlying shales requiring higher mud weights. At worst, the subsequent loss of hydrostatic pressure means drilling blind through the Shuaiba, where low mud density often leads to wellbore instability, necessitating multiple wiper trips. Prior to entering the Shuaiba, wellbore instability also compromises openhole logging in the Lower Burgan section of every well, depriving the development team of vital geophysical characteristics.

Blind drilling also magnifies wellbore instability issues and increases the degree of severity during wiper trips, raising the risk of stuck pipe – and even the loss of the bottomhole assembly (BHA). To cure losses, operators must set multiple cement plugs, which are costly and require additional rig time.

The difficulties of drilling the Shuaiba and the Zubair transition zone are compounded by the heightened possibility of landing casing shorter than the programmed depth. Consequently, with the Shuaiba and its propensity for losses, operators must account for unplanned casing strings or conduct cement squeezes to effectively perform a formation integrity test (FIT). Casing integrity, likewise, becomes a concern as losses while cementing often result in poor cement bonds above the loss zone. This problem manifests itself in corroded casing caused by the cross flow across the Lower Burgan.

Well designs and mud challenges

In the North Kuwait development programme, the operator's various well designs added to the challenge of reaching programmed depth and meeting objectives using conventional water-based drilling fluids.

With the aim of increasing oil production, the operator decided to drill high-inclination slant and horizontal wells in the Zubair sand zones. Sequential changes in the well design included drilling an 8 ½ in. hole and commingling different layers of the Zubair shale-sand sequence. Alterations to the well profile had increased NPT on offset wells when stressed interbedded shales were drilled with high-angles and low-reservoir-pressure conditions in high-permeability sand. Wellbore instability issues led to downtime caused by differentially stuck pipe and hole cleaning problems (in sandstone where there is permeability and hence the need for ULFI). Lacking a viable alternative to ensure casing zonal isolation, the operator needed a drilling fluid formulation that could prevent the severe losses encountered in prior wells and effectively drill and complete the reservoir.

For wells targeting the Lower Burgan reservoir, the operator drilled a long 12 ¼ in. intermediate section in the Mutriba formation, transitioning from a vertical to a low-inclination profile. Attempts to run a

conventional WBM were unsuccessful, given the subsequent instability of the reactive Ahmadi and Wara formations and slow drilling. In addition, vibrations in the upper Mutriba resulted in rotary stalling and eventually, stuck pipe.²

Particularly challenging for a traditional WBM are wells landed in the prolific Mauddud limestone reservoir through an 8 ½ in. interval from the Tuba limestone in the minimum stress direction. Along the way, the Wara shale requires excessive mud weight to avoid wellbore instability issues; however, running a high-density mud when entering the depleted Mauddud raises the possibility of differential sticking or induced losses.

The hurdles are similar for wells landed in the Upper Burgan, where the 12 ¼ in. section from the Mutriba to the top of the Mauddud is especially problematic if a high exit angle is programmed for the intercepted Wara. Drilling the 8 ½ in. interval from the top of the weak Mauddud limestone to the Upper Burgan means penetrating multiple depleted layers. Consequently, the 7 in. liner may be unable to hold a FIT to enable the next slant section to be drilled in the Upper Burgan shale-sand sequence.

Given the severe wellbore instability issues, a customised HPWBM and reservoir drill-in fluid (RDIF) system were engineered with the key

objectives of reducing both NPT and the operator's environmental footprint. Designed in conformance with chemical and mechanical properties, the drilling fluid and RDIF incorporated a specially formulated wellbore sealing synthetic co-polymer, field-proven to stabilise the weakest and most loss-prone zones.

HPWBM and ULFI synergy

The water-based drilling fluid system was formulated with a combination of synthetic co-polymer and organic shale inhibitors. This design effectively stabilised hydratable and dispersible shale, plugging pore throats and minimising fluid invasion, as verified by particle/permeability plugging tests and linear swell meter tests under downhole conditions.³

The HPWBM included an ULFI additive, referred to as 'wellbore shielding technology', comprised of proprietary cellulosic material engineered to form small but tough filter cake. By producing an extremely low permeability barrier at the fluid-rock interface, the additive delivers an equally low invasion area across a broad range of permeability and microfractures. The ULFI additive has been proven to effectively control fluid invasion at concentrations as low as 3 – 10 ppb.

The wellbore shielding technology effectively restricts the transmission of destabilising wellbore pressure to the pore fluid, in turn reducing filtrate invasion

Table 1. Lithology sample in Kuwait

Age	Formation	Thickness (ft)	ROP (ft/hr)	Mud WT (ppg)	Est.pp (ppg)	Main lithology	Others
Tertiary	Kuwait Ser.					Sand	Interbeds of limestone and clay
	Dammam	663 – 668	37 – 138	8.8 – 8.9	8.6	Dolomite	Streaks of limestone and shale and minor anhydrite
	Rus	391 – 488	10 – 28	9	8.6	Anhydrite	Minor streaks of dolomite
	Radhuma	1662 – 1725	43 – 44	8.6 – 8.7	8.6	Dolomite	Minor streaks of anhydrite and shale
Upper Cretaceous	Tayarat	879 – 917	15 – 21	8.9	8.6 – 8.7	Limestone	Minor streaks of anhydrite beds at basal part
	Hartha	275 – 277	10 – 14	8.8 – 8.9	8.6 – 8.7	Limestone	Streaks of shale
	Sadi	684 – 820	45 – 59	9.1	8.6 – 8.7	Limestone	
	Mutriba	442 – 443	12.4 – 9.5	9 – 9.1	8.6 – 8.7	Limestone	Streaks of shale
	Mishrif	175 – 180	16 – 27.5	9 – 9.1	8.7	Limestone	Streaks of shale
	Rumaila	344 – 360	8.6 – 15.7	9 – 9.1	8.7	Limestone	Streaks of shale
Lower Cretaceous	Ahmadi	193 – 275	15 – 20.7	9 – 9.1	8.7	Shale	Minor limestone and siltstone
	Wara	107 – 202	19 – 60	9 – 9.1	8.7 – 8.8	Sandstone and sand	Streaks of shale
	Mauddud	5 – 7	12 – 35	9 – 9.1	8.7 – 8.8	Limestone	Minor shale
	Burgan	991 – 1243	21 – 56	9.1	8.7 – 8.9	Sand and sandstone	Interbed of shale, siltstone and limestone
	Shuaiba	165 – 185	9.3 – 22	9 – 9.2	8.7 – 8.9	Dolomite	
	Zubair	1240 – 1276	11.7 – 26	9.1 – 9.8	8.7 – 8.9	Sandstone	Streaks of shale, sand and coal vein
	Ratawi Shale	270 – 332	5.5 – 12	9.7 – 10	8.6 – 9.8	Shale	Interbed with sandstone, siltstone and limestone with sandstone
	Ratawi L. St	338 – 395	5 – 5.7	9.8 – 10	9 – 9.4	Limestone	
	Minagish	789 – 862	6 – 14	9.9 – 10.5	9.3 – 9.8	Limestone	
Makhul	819 – 1065	4.7 – 11.7	10.5 – 11.9	9.8 – 10.6	Limestone	Interbed of shale and anhydrite	

into the matrix permeability and microfractures.⁴ The impenetrable shield essentially raises the fracture initiation pressure by isolating the mud pressure in the wellbore from the geology, effectively inhibiting the fracture propagation process. By restricting the transmission of wellbore pressure into the geology, this sealing mechanism reduces fluid influx in the microfractures, minimises the risks of formation breakdown and effectively stabilises weak shales.

During the design process for the HPWBM with ULFI technology, chemists considered area-specific factors related to the density profile prediction, pore pressure transmission, shale inhibition, hole cleaning and bridging characteristics.

The predicted density profile was cross-checked with offset wells, focusing on the recorded instabilities across the Zubair shale. In most of the offsets studied, instability was largely blamed on the use of an improperly low mud weight at the onset, generating insufficient hydrostatic pressure. Addressing this issue required more mud weight than actually needed to maintain wellbore stability. Depending on the programmed inclination, mud weights between 11.5 – 12 lb/gal. were recommended when drilling the Zubair shale in the maximum stress direction; 11.8 – 12.2 lb/gal. was recommended when drilling in the minimum stress direction, again depending on angle and proximity. Well behaviour, however, dictated the final mud weight.

Fractures induced by filtrate invasion in weak and depleted zones increase pore pressure, in turn aggravating the decline in effective overbalance. Reduced overbalance usually destabilises the wellbore and promotes sloughing. The ULFI additive was incorporated to prevent filtrate invasion and reduce previously high pore pressure transmission by mechanically bridging the micropores and microfractures within the shale matrix. Using linear swell meter testing, fluid scientists also examined several shale inhibitor formulations before confirming a package to include in the final mud design.

An equally customised bridging package was formulated to offset the challenges of using calcium carbonate (CaCO_3) as the primary bridging agent. Due to its tendency to degrade, CaCO_3 is unable to efficiently and economically bridge the micropores intrinsic to the North Kuwait development programme. To address these shortcomings, the deformable ULFI agent was employed in conjunction with sized CaCO_3 to further reduce the permeability of the seals formed across fractures and – by depositing a thin filter cake – provide protection against differential sticking in permeable formations.

For the critical hole cleaning component, recommended drilling practices received nearly the same consideration as the fluid design during the development programme. Therefore, it was essential for the mud to maintain low shear rate rheology to ensure desired carrying capacity for dispatching cuttings from the wellbore. Additionally, to assist solids lifting with a rotary steering

assembly, the operator would follow the recommended practice of maximising pump rates and rotating drillpipe at a minimum of 120 – 130 rpm. The pumping of hole cleaning pills would be dictated by real time drilling parameters, such as pump pressure fluctuations. For example, a 20 – 25 bbl pill earmarked for the 6 ½ in. hole section – with a density 2 lb/gal. above the active mud weight – would be pumped as conditions warranted to ensure thorough cleaning of the openhole.

Well recaps

In an Upper Burgan well, an 11.6 – 12 lb/gal. customised HPWBM system was used to successfully drill a 6 ½ in. slant section at an inclination of 75° to total depth (TD) – now with a stabilised wellbore. At a concentration of 6 – 7 ppb, the ULFI additive effectively reduced fluid invasion by sealing and bridging porous and permeable sand in combination with sized CaCO_3 . The shale inhibition efficiency of the tailored mud and ULFI additive was reflected in the dry and firm shale cuttings at surface.

Elsewhere, the high-angle 8 ½ in. interval of a Mauddud well was also drilled without any fluids-related NPT, from the top of the Tuba to planned TD. In drilling the 1235 ft section, the operator built from a 45° to an 89° angle through the Wara shale with a 12.5 – 12.9 lb/gal. HPWBM – again, with a stabilised wellbore. A 2 – 3 lb/bbl ULFI agent, along with sized CaCO_3 and resilient graphite, effectively reduced fluid invasion. No differential sticking tendency was observed while sustaining 2500 psi overbalance across the depleted Mauddud formation.

In a low-inclination Lower Burgan well, 2772 ft of the 12 ¼ in. section was drilled with an 11.1 – 12 lb/gal. customised KCl polymer mud without any trace of wellbore instability. The HPWBM incorporated the wellbore shielding additive at a 2 – 3 lb/bbl concentration. Even while sustaining 1300 – 2000 psi overbalance through porous and permeable sand, no differential sticking tendency was observed. The HPWBM maintained wellbore stability despite lengthy exposure to the formations while tripping.

Conclusion

Controlling wellbore instability in troublesome formations is a key element of successful drilling in North Kuwait. Operators can adapt field-proven solutions, such as the HPWBM with ULFI technology, to enhance wellbore stability when faced with a variety of geological challenges – lowering and even preventing fluid-related NPT altogether. ■

Note

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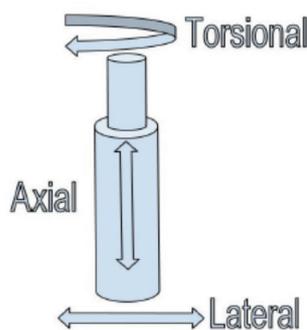


Figure 1. Free body model for primary vibration modes.¹