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Challenging the Norm: Are Nonaqueous Fluids Truly Efficient in Modern Drilling Operations?

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Abstract

The drilling industry has traditionally relied on oil-based muds (OBM) for their superior performance in challenging conditions, particularly in micro-fractured rocks where drilling with adverse trajectories is required. However, questions remain regarding the true efficiency of OBM — especially when comparing high-performance invert emulsion fluids with conventional oil-based muds in terms of engineering complexity and formulation optimization.

This paper presents the engineering approach taken to optimize established invert emulsion fluid (IEF. By adjusting the base oil content and oil-water ratio (OWR) in 80-92-lb/ft3 high-performance invert emulsion fluids, the objective was to reduce initial mixing and maintenance demands while maintaining reliable performance across different lithologies.

Extensive HPHT laboratory validations proved effective to qualify new 65/35 OWR formulations for successful field applications, in contrast with the usual 80/20. The result was improved additive content, stable emulsion and consistent properties under surface and bottom-hole conditions; which aimed to reduce oil retention on cuttings and lower fluid costs without sacrificing operational integrity.

A series of wells were assigned for trial implementation, where the fluid delivered strong technical performance and notable cost savings. Compared to 75/25 OWR, the new system reduced overall fluid ownership costs by 20-25%, primarily due to decreased base oil and material consumption. Additional unquantified benefits included faster mixing, simplified logistics, and the elimination of pre-casing reaming operations in several wells.

Multiple 3,000-ft horizontal and build-up sections were drilled with zero fluid-related nonproductive time (NPT). This confirmed the formulation's reliability across varied formations. The fluid also allowed effective control of equivalent circulating density (ECD) with efficient hydraulics. With oil retention on cuttings reduced to just 2%, the system contributed to lower environmental impact and improved waste management.

Moreover, reduced material usage led to fewer mobilizations, lifts, and mixing operations. This meant improved operational efficiency and health, safety, and environmental (HSE) performance.

Introduction

Drilling fluid is critical for operational success and cost efficiency in wells, and can play a significant role in feasibility and overall results of the drilling campaign. A proper fluid design demands for detailed engineering work including adequately supported laboratory validations and the establishment of well-specific practices and performance indicators to mitigate risks. While failure to consider these criteria may derive in operational failures including nonproductive time (NPT), fit-for-purpose solutions shall always aim for optimization.

In the case referenced in this paper, a high-performance Invert Emulsion Fluids (IEF) to drill horizontal wells for over 20 years. The selection of mineral oil as base oil had helped reduce Health, Safety and Environment (HSE) concerns, while the organophilic clay-free formulations had proved to provide reliable properties and wellbore stability across limestone formations with presence of reactive shale particularly prone to swelling and dispersion; justifying its use over Water-Based-Mud (WBM) alternatives, despite the potential logistics, cost and waste management benefits associated to aqueous fluids.

However, after a solid usage record, these reliable IEF formulations were challenged by the industry's increasing global demand for efficiency, in a context of unstable hydrocarbon markets. The need was now to maintain the operational success obtained thus far, while bringing additional savings and improvement beyond the mere reduction of a single product concentration.

Initial Formulations and Properties

Two different types of IEF formulation had been normally implemented in this project: a barite-laden system was utilized to drill 12 1/4" intermediate sections, while a barite-free version was used exclusively for drilling the 8 ½" reservoir sections, in order to minimize formation damage, maximizing the synergy with delayed release filter-cake breaker systems prior to production. The referenced formulations are shown in Table 1.

Table 1 – IEF formulations used historically in the project. Slight adjustments applied were normally based on density requirements.

Additive	Intermediate Sections 90 pcf (75/25)	Reservoir Sections 80 pcf (70/30)
Mineral base oil	0.57	0.51
Emulsifier 1	9	9
Emulsifier 2	2	2
Lime	3	3
Fluid loss control agent	2	2
Rheology modifier 1	2	2
Rheology modifier 2	2	2
Calcium chloride brine	0.21	0.25
Fine marble (density)		158
Sized marble (bridging)	15	20
Resilient carbon material	5	
Barite	215	

As a comprehensive revision took place, focused on the Oil/Water Ratios (OWR) of both initial formulations. This property defines the proportion of oil versus water in an IEF, which is associated with chemical additive dispersion, and has a significant impact over many other fluid properties such as emulsion stability, rheology profile, chemical titrations, among many others. In general, a lower OWR translates into a reduced requirement of base oil and barite - two of the costliest components in the IEF- making this approach greatly desirable due to its optimization potential. Unfortunately, it is not always possible to maximize OWR reductions due to the expected detrimental effect on the fluid's properties, observed especially when conventional OBM are utilized.

Both IEF used in the project (barite-laden and barite-free) showed OWR ranging from 75/25 to 80/20, as shown in Table 2. This range, although in line with many other operations worldwide, was found to leave room for optimization. It was decided to start validating 65/35 OWR alternatives via laboratory work, taking advantage of the low solids content and absence of organophilic clay to minimize impact on rheology.

Table 2 – Typical IEF properties

Properties	Intermediate Sections	Reservoir Sections
Density, lb/ft3	90	80
OWR	75:25	70:30
Plastic Viscosity, cP	≤35	≤33
Yield Point, lb/100ft2	20-25	18-22
LSRYP, lb/100ft2	6-10	5-8
Tau0, lb/100ft2	6-9	5-8
WPS, mg/l CaCl2	250k-260k	250k-260k
Electrical Stability, volts	≥250	≥250
HPHT Fluid Loss, 500 psi, 250°F, ml/30min	≤3	≤3

Oil/Water Ratio Adjustment Validations

Before a formulation was deemed ready for execution, an extensive set of tests was required to understand the new fluid's properties and ensure adjusted property targets had been met at surface and downhole conditions.

Emulsion Stability

The initial step was to assess the initial impact of the higher proportion of aqueous phase in the system. It was prioritized the evaluation of emulsion stability to initiate treatments accordingly. Poor emulsion stability can be associated with unstable properties due to the separation of the aqueous phase - particularly in HPHT, static conditions- low electrical stability (ES) and water wetting of the solids in the drilling fluid.

It was possible to maintain an adequate emulsion stability by adjusting emulsifier concentrations. As an example, the initial drop in OWR to 65/35 for the barite-laden fluid resulted in reductions of ES from the 420-volt average, ending in an average of 320 volts. Gradual adjustments in the emulsifier concentration to 13.5 ppb were found to provide optimal emulsion stability, becoming the second adjustment in the IEF formulations, as shown in Chart 1. The effect of this increase was observed at surface conditions (BHR) and after dynamic ageing (AHR) at Bottomhole Temperature (BHT).

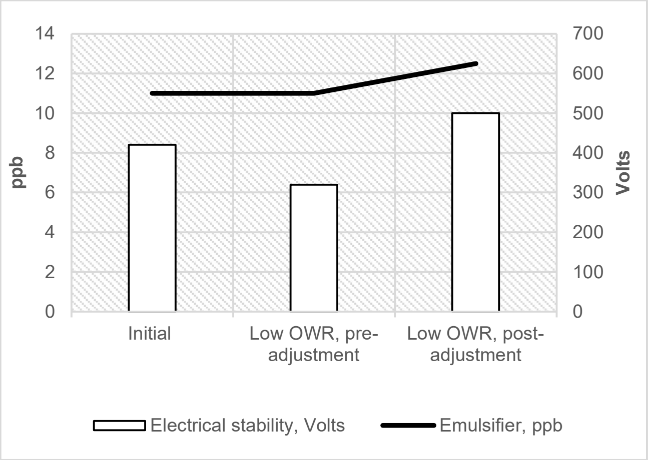

Chart 1 – Summary of ES trends for Barite-laden IEF

Another indicator of poor emulsion stability is the presence of free water in the HPHT filtrate. Free water entering reactive formations may end up in wellbore instability, and operational issues. Although initially observed after OWR reduction in barite-laden IEF validations (Image 1 and Chart 2); the adjustment in emulsifier concentration was found to be adequate to correct this trend and restore full-oil filtrate in subsequent tests.

Image 1 – Presence of water if HPHT Filtrate observed after OWR reduction for barite-laden system

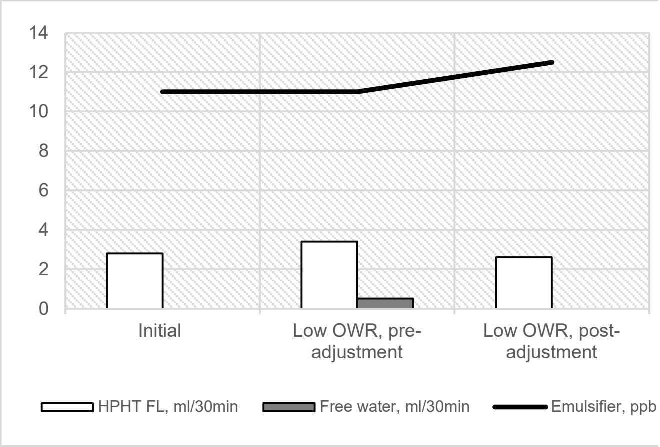

Chart 2 – HPHT Fluid Loss trends during validations

Static Sag

Attention was also given to the sag tendencies of solids in the formulation, especially for the barite-laden IEF, as an adequate suspension is required to avoid settling-related issues during static periods at downhole temperatures. Static sag was found to be below maximum acceptable value of 0.53 after 48 hours under BHT conditions (200°F), as shown in table 3 in line with the industry recommendations (Basfar et al. 2015).

Table 3 – Sag results

Static Sag at 200°F	Intermediate Sections 90 pcf	Reservoir Sections 80 pcf
24 hours	0.521	0.523
48 hours	0.528	0.529

Rheology Adjustments

As laboratory testing progressed, a reduction in viscosifier concentrations was necessary to maintain properties within desired specifications, as shown in Chart 3. Resulting rheology was in line with initial values, minimizing the potential effect on Equivalent Circulating Density (ECD) and the risk of induced lost circulation.

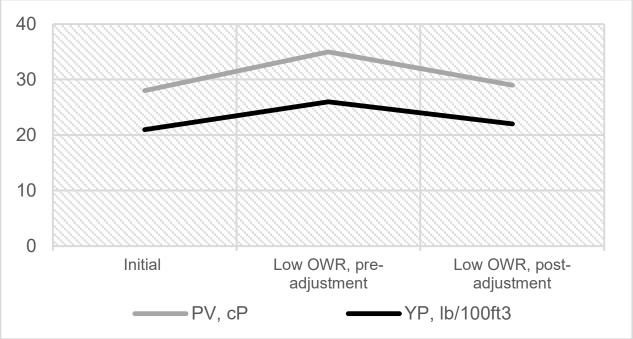

Chart 3 – Rheology trends during validations of barite-laden fluid

Approved low OWR Formulations

Tables 4 and 5 summarize the final formulations and resulting properties for both the barite-laden and barite-free systems for an initial stage of 65/35 OWR.

Table 4 – Low OWR IEF formulations designed for the project.

Additive	Intermediate Sections	Reservoir Sections
Mineral base oil	0.49	0.48
Emulsifier 1	12	11
Emulsifier 2	1.5	1.5
Lime	3	3
Fluid loss control agent	1.5	1.5
Rheology modifier 1	1.5	1.5
Rheology modifier 2	1.5	1.5
Calcium chloride brine	0.3	0.29
Fine marble (density)	-	147
Sized marble (bridging)	15	20
Resilient carbon material	5	-
Barite	196	-

The reduction of viscosifier concentrations had a positive effect on improving final properties, while also reducing the IEF's cost per barrel.

Table 5 – Low OWR IEF properties found acceptable for the project

Properties	Intermediate Sections	Reservoir Sections
Density, lb/ft3	90	80
OWR	65:35	65:35
Plastic Viscosity, cP	≤35	≤33
Yield Point, lb/100ft2	20-25	18-22
LSRYP, lb/100ft2	10	8
Tau0, lb/100ft2	9	8
WPS, mg/l CaCl2	250 k-260 k	250 k-260 k
Electrical Stability, volts	≥450	≥450
HPHT Fluid Loss, 500 psi, 250°F, ml/30min	≤3	≤3

Conventional OBM rheology behavior

As a reference, it was validated a conventional OBM Mix to define whether a conventional, organophilic clay-based system could tolerate such OWR reduction and maintain a required rheology profile.

In this case, the resulting rheology increase was significantly higher. Although reductions were possible thanks to emulsifier concentration increases, and viscosifier reductions, the overall performance failed to comply with the required rheology profile; unlike the results observed with the high-performance IEF. Based on these observations, the team decided to drop validations of conventional OBM.

Risk Assessment and Operations Program

The resulting properties and risks associated with the change were assessed. Mitigations and contingencies set in place included increased visibility and monitoring of key service delivery aspects such as property trends from mixing to execution, to allow joint decision making on treatments and recommendations, evaluation of cuttings integrity, ECD, and SPP. Contingencies considered increased availability of treatment additives, especially emulsifiers, to allow prompt treatments, and additional typical formulation volumes at Liquid Mud Plant (LMP) to allow full well displacements, as last resort.

Field Execution

The optimized formulations were successfully utilized in a total of 35 well sections -the initial scope of the project-, covering a density range of 80 to 92 lb/ft3, across heterogeneous lithologies, including shale, sand, siltstone, and reservoir limestone formations. Overall, results were found to be satisfactory with operational highlights in combination with savings.

Wellbore Stability

The increased water content did not pose any additional challenges regarding wellbore construction and stability. Shale shakers were closely monitored throughout drilling and circulation operations to identify cavings or signs of instability. Cuttings observed on the shakers were reported to exhibit normal shape and size, with good integrity maintained; with no issues associated.

Image 2 – Example cutting sample, excellent integrity and no cavings

Hole cleaning

Hole cleaning posed a significant challenge in both the critical-angle buildup intervals and the extended lateral sections. Inefficient cuttings transport in these sections increased the risk of cuttings bed development and pack-off. Under such conditions, inadequate hole cleaning could lead to elevated torque and drag, increased standpipe pressure, and an increased risk of stuck pipe. Consequently, maintaining stable and robust drilling fluid parameters—particularly rheological properties tailored to the well geometry and inclination—was essential to mitigate these risks (Sandeep et al. 2017).

Simulations were run using specialized hydraulics software to assess the fluid's efficiency in removing drill cuttings under normal operational parameters as shown in Chart 4. The highest cuttings load estimation in the annulus was 2.00% v/v. Transport efficiency (cuttings velocity vs annular velocity ratio), on the other hand, was found above 50% for the majority of the well, as enough cuttings removal allowed for reduced risk of bedding.

Finally, simulations estimated differences between ECD and ESD to be below 5 pcf, in line with the expectation of high-performance IEF, and within acceptable values per the formation's fracture gradient data (Mena et al. 2020). Similarly, the ECD simulations performed on the proprietary software followed very closely the data obtained via pressure-while-drilling (PWD) measurements during the operation. No induced fracture events were reported in any of the 35 well sections including 23 intermediate holes (61,966 ft total) and 12 reservoir holes (41,588 ft total).

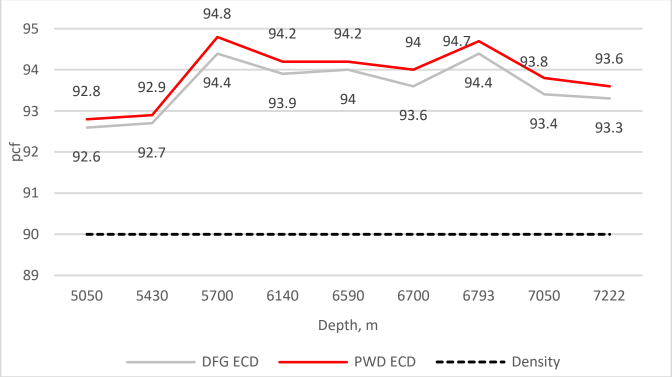

Chart 4 – Example of simulated and PWD ECD vs MW in execution

Lost circulation and differentially stuck pipe

The potential for downhole fluid losses and differential sticking represented additional operational challenges, driven by the presence of permeable formations and the sensitivity of the wellbore to variations in fluid rheology and bridging performance. The adjusted fluid succeeded in achieving zero differentially stuck pipe events, while downhole losses were limited to naturally fractured intervals. In this latter context, lower OWR (lower cost/barrel) fluid helped maximize savings.

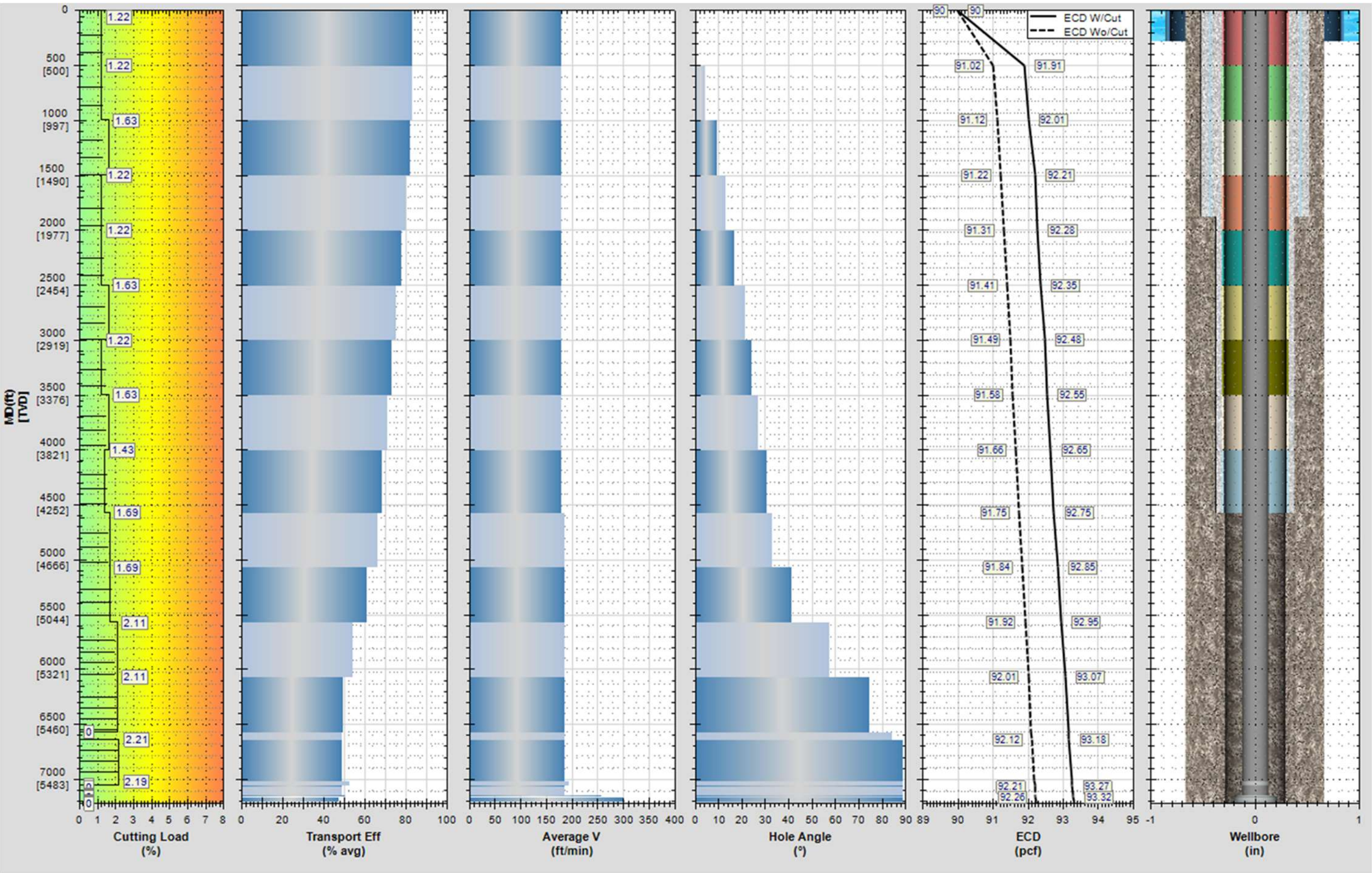

Chart 5 – Example hole cleaning and ECD simulation summary for 12 ¼" hole using barite-laden IEF (execution). From left to right: Maximum cuttings load: 2.19%, Average transport efficiency >50%, Fluid velocity > 150 ft/min, hole angle >75°, and ECD with cuttings estimated at 93.32 pcf Eq on bottom, compared to a 90 pcf Mud Weight.

Retention of Oil on Cuttings (ROC)

The low OWR systems achieved an overall reduction of ROC for both the 12 ¼" and 8 ½" hole sections; averaging 8.37% w/w and 15.91% w/w respectively, compared to the previous averages of 10.26% w/w and 19.48% w/w values. This represents a reduction in retained oil on cuttings of approximately 18.4% on a weight basis, minimizing environmental impact of waste generated while drilling.

Beyond the environmental benefits, the observed reduction in ROC delivered tangible cost savings. Lower oil retention on cuttings reduced the volume of base fluid lost with drilled solids, directly decreasing fluid replacement requirements and overall mud consumption. In addition, improved cuttings dryness reduced waste handling, transportation, and treatment costs, while enhancing solids control efficiency and minimizing nonproductive time associated with surface processing.

The consistently lower ROC achieved across the tracked sections confirms that the low OWR fluid system provides a repeatable and cost-effective alternative to conventional OWR designs. By simultaneously improving environmental compliance, reducing drilling fluid losses, and lowering waste management costs, the low OWR system contributed to enhanced operational efficiency and overall well construction economics without compromising drilling performance.

Overall cost comparison

Across several tracked intervals, the low OWR system achieved an average 25–50% reduction in formulation products only, resulting in lower overall IEF fluid costs without compromising operational efficiency or performance.

Conclusions

Research carried out allowed the customization of a well-established IEF formulation used to drill wells, by significantly reducing base oil requirements in 8-14 %. Concentrations of products in the formulation -particularly emulsifiers and rheology modifiers- were adjusted to maintain properties within desired ranges.

The execution of the adjusted formulations in the 35 well sections proved no negative impact over any of the key operational performance areas identified, including wellbore stability, hole cleaning, lost circulation and stuck pipe. No nonproductive time events associated to drilling fluid were recorded for these jobs.

Overall, the optimization initiative has brought the operator savings by 22% overall cost reduction, associated to decreases in both base oil and adjusted formulation and treatment costs (Ripa et al. 2017).

Furthermore, the optimized formulation contributed to environmental benefits, reducing oil retention on cuttings by approximately 18.4% on a weight basis and 18.3% on a volume basis, indicating more efficient fluid separation and cleaner cuttings at surface.

It is well known that Invert Emulsion Fluids are not the least expensive option on a cost per barrel basis. However, the results obtained from this initiative made it evident that room for improvement remains available. Engineering and collaboration helped answer the question of this investigation: Nonaqueous fluids can be truly efficient and cost effective to face the challenges posed by modern operations.

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