

## Gliding Through Extended Laterals with Water-Base Fluids

Gabe Manescu, James Friedheim, Valentin Visinescu, Weiqing Huang, M-I SWACO, a Schlumberger company

Copyright 2016, AADE

This paper was prepared for presentation at the 2016 AADE Fluids Technical Conference and Exhibition held at the Hilton Houston North Hotel, Houston, Texas, April 12-13, 2016. This conference is sponsored by the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individual(s) listed as author(s) of this work.

### Abstract

Shale plays present various challenges by combining the requirements of a reservoir and a shale interval. Across North America, operators mostly use invert-emulsion fluids for drilling extended lateral sections for overall improved drilling performance when compared to water-base fluids. However, invert-emulsion fluids are more expensive and have a greater environmental impact. Recent tight economics govern many shale plays and have little room for using high cost oil-base and premier high-performance water-base drilling fluids, including transportation and disposal costs. Ancillary costs can go as high as 50% of total drilling fluid cost. Using a water-base fluid matching or exceeding the rate of penetration achieved with oil-base fluids would virtually eliminate most of these ancillary costs.

This paper presents a fast-drill water-base drilling fluid, the associated development phase laboratory testing, and the successful field trial results. This water-base drilling fluid addresses the issues encountered with the build and extended lateral sections: minimizes torque and drag, reduces shale swelling and dispersion, and mitigates environmental impact on land. The system does these at a lower total cost for the operator than by using the alternative. The fluid system focus is on improved drillability during the build and lateral section. The synergy of a specially screened-for-performance lubricant and the additives offering shale inhibition and minimizing shale dispersion provide reduced torque and drag, and lead to an increased rate of penetration.

Laboratory results show that the fast-drill water-base drilling fluid outperformed the referenced high-performance water-base drilling fluid with performance matching the diesel-base drilling fluid at a fraction of a total cost of ownership.

Field trials in the Permian basin proved successful. Extending its applicability to higher temperatures and various base brines, this new fast-drill water-base drilling fluid offers a potential solution to minimizing well construction cost in North America.

This fast-drill water-base drilling fluid provides an entirely different approach to shale play drilling primarily by focusing on an increased rate of penetration while maintaining wellbore stability through fit-for-purpose shale inhibition.

### Introduction

Balancing cost and performance has always been a challenge for drilling engineers on a quest to improve drilling rates while leaving behind a smooth wellbore ready for completion on a limited budget. Drilling fluids and associated services present a significant part of the cost to drill a well, therefore choosing the proper fluid is an important decision for the drilling team.

Invert-emulsion drilling fluids, more commonly referred to as oil-base muds (OBM), are the fluids of choice when drilling extended-lateral wells in the shale plays of North America. The perception is that these wells require a highly inhibitive fluid to minimize interactions between the fluid and water-sensitive formations (shale); a fluid capable of insuring high rates of penetration (ROPs) coupled with good lubricity and low potential for stuck pipe. The fact is that each shale play is different and the fluid should be tailored for each formation's characteristics. Shale plays are usually less reactive than claystone and shale formations, but are micro-fractured and can be very easily destabilized by fluid or filtrate. They do require a fluid to drill faster, but not all require very high shale inhibition. OBM may appeal to operators who are risk adverse, but the total cost of ownership when drilling with an OBM is much higher than a WBM option.

The additional cost of drilling with OBM is summarized as:

- Increased logistical requirements for bulk fluid transfers
- High unit cost of fluid, especially when mud losses are encountered
- High unit cost of base fluid (diesel) for maintenance
- High cost of environmental compliance: OBM cuttings haul-off and disposal to landfill
- Increased cost of contingency materials due to higher chance of mud losses
- Health and safety compliance cost: spill containment and operator liability for rig personnel.

Several high-performance water-based muds (HPWBM) have been developed over the past fourteen years (1) with the goal of approaching the drilling performance of an OBM. Land operators in North America have trialed inhibitive WBM for replacing OBM in order to minimize the above OBM ancillary cost, but highly inhibitive HPWBM proved to be cost prohibitive for land drilling due to high unit cost of fluid.

The development of a cost-effective water-based drilling fluid, which could exhibit similar drilling characteristics to

OBM for the shale play land drilling, seemed inevitable. The following sections in the paper present the fast-drill water-base mud (FDWBM) research and development phase, and the successful field trials results.

## Fluid Development

The main requirements of the new FDWBM for fit-for-purpose shale play drilling were increased ROP during the horizontal section, good wellbore stability, and sufficient shale inhibition for the build section. The scope was to provide a drilling fluid solution that:

- Drives performance, matching or exceeding the one achieved with OBM
- Reduces overall cost for the drilling phase
- Minimizes environmental impact

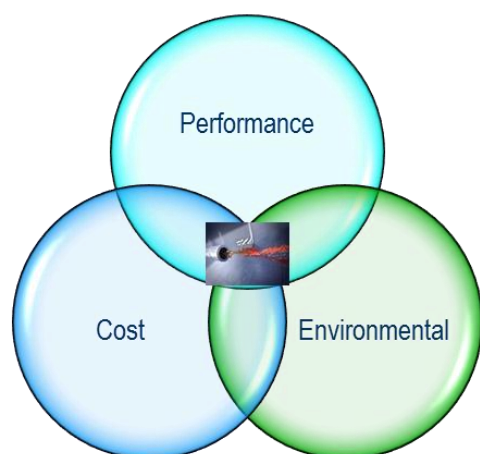


**Fig. 1**—Cost effective WBM developed to improve performance without the environmental liability.

Performance, cost and environmental factors were concurrently considered on screening different chemistries for the main components of the new FDWBM.

Learning from the previously developed HPWBM deemed critical throughout the development, with the focus maintained on the entire performance spectrum of an OBM and HPWBM at a lower cost per unit. The differentiation from the HPWBM was by switching focus from high shale inhibition, not always required for the shale play drilling, to increased lubricity for minimizing torque and drag and allowing ROP matching or exceeding those provided by an OBM.

The following were determined to be the key criteria:

- Highly lubricious system
- Similar rheology to OBM and referenced HPWBM for improved hole cleaning
- Fit-for-purpose shale inhibition
- Environmentally acceptable for land drilling

To this end, a development project matrix was set up for a short-term development project. The selection of the most appropriate chemistries for the fluid main components were chosen from previous research work involving HPWBM development. The test matrix involved the combination of four

shale suppressant inhibitors, three clay dispersion reducers, and seven lubricant / accretion inhibitor chemistries.

The formulated fluids were subject to fluids performance testing (filtration, rheology, contamination tolerance lubricity, shale inhibition, clay dispersion, and accretion potential) to evaluate their overall performance.

Testing was conducted on shale play core substrate (moderate reactivity), and used a variety of inhibition test methods (shale hardness, shale dispersion, shale accretion) combined with lubricity testing. The test methods are described in details by Stephens et al in 2009 (6).

The test results of the FDWBM compared against the baselines, a referenced HPWBM and an OBM typically used in the targeted area, Permian basin, West Texas.

The result of this development project was a new FDWBM that exhibited laboratory performance characteristics in the realm of those achieved by OBM and the referenced HPWBM. This fluid was then field trialed successfully in the Permian basin, which are detailed later.

## Overall fluid properties

The overall properties of the developed fluid were targeted to be comparable to the referenced fluids used for drilling in the area considered for a potential field trial. The data presented in **Table 1** displays the properties of the fluids after hot rolling at 150°F. Stress testing with fluids exposed to temperatures up to 250°F showed similar excellent results.

**Table 1**—Properties comparison for reference fluids and the newly developed FDWBM system at 9.5 lb/gal mud weight.

| Fluid                            | OBM   | HPWBM | FDWBM |
|----------------------------------|-------|-------|-------|
| Rheology                         | 120°F | 120°F | 120°F |
| 600                              | 72    | 74    | 64    |
| 300                              | 46    | 54    | 47    |
| 200                              | 37    | 46    | 38    |
| 100                              | 25    | 33    | 28    |
| 6                                | 10    | 10    | 8     |
| 3                                | 9     | 8     | 6     |
| 10" Gel (lb/100ft <sup>2</sup> ) | 11    | 8     | 7     |
| 10 Gel (lb/100ft <sup>2</sup> )  | 19    | 11    | 9     |
| PV cP                            | 26    | 20    | 17    |
| YP (lb/100ft <sup>2</sup> )      | 20    | 34    | 30    |
| API FL (ml/30 min)               | 0.5   | 6.8   | 6.5   |
| HTHP FL @250°F (ml/30 min)       | 1.6   | 17.6  | 16.8  |

## Lubricity Testing

For lubricity testing, an OFI lubricity meter was used. Unlike the typical measurement performed in the industry at only 150 in-lbs torque, the lubricity variation under several loads was assessed. The torque values at which the lubricity was tested were 150, 200, 300, 400, 500, and 600 in-lbs.

The raw data recorded during the test is presented in **Fig. 2**, which displays the calculated coefficients of friction (CoF) charted versus corresponding direct load.

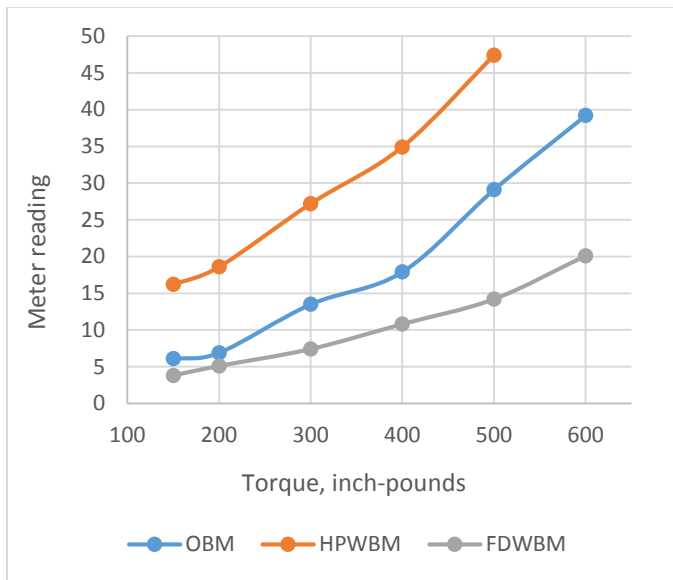


Fig. 2—Raw data recorded on lubricity testing.

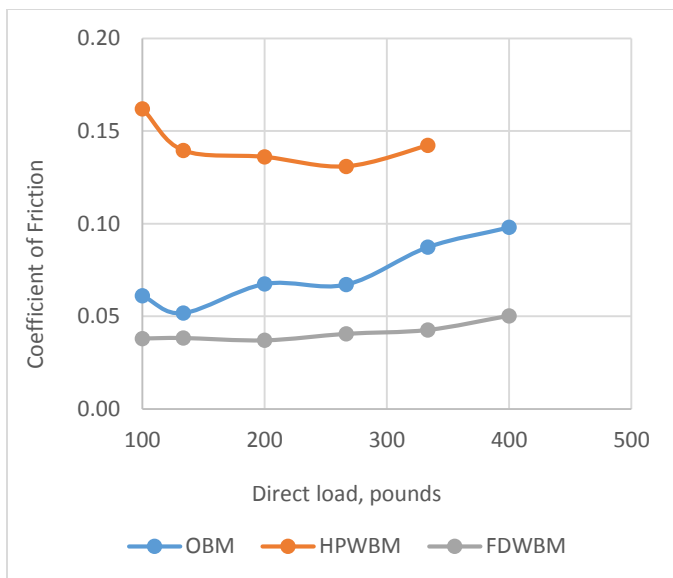


Fig. 3—Coefficient of Friction Comparison at various loads, FDWBM outperformed both OBM and HPWBM.

### Shale Inhibition Testing

An assessment of the hardness and dispersion of the shale following exposure to the FDWBM are shown in **Figs. 4 and 5** where comparison is made using shale play core substrate exposed to OBM and HPWBM under the same conditions.

The results of the X-Ray diffraction (XRD) data indicate that the shale play substrate has medium reactivity. The clay content in the sample of approximately 7% includes smectite, illite, and kaolinite.

**Table 2**—XRD mineralogical content (% wt.) for the shale play substrate.

| Mineral         | by wt. |
|-----------------|--------|
| Smectite*       | 10%    |
| Illite          | 14%    |
| Quartz          | 64%    |
| Feldspars       | 7%     |
| Kaolinite       | 3%     |
| Pyrite          | 2%     |
| CEC, meq/100 gr | 8      |

\*Includes illite/mixed layers

In this test the shale exposed to the FDWBM showed similar hardness and hot roll dispersion when compared with the other two fluids.

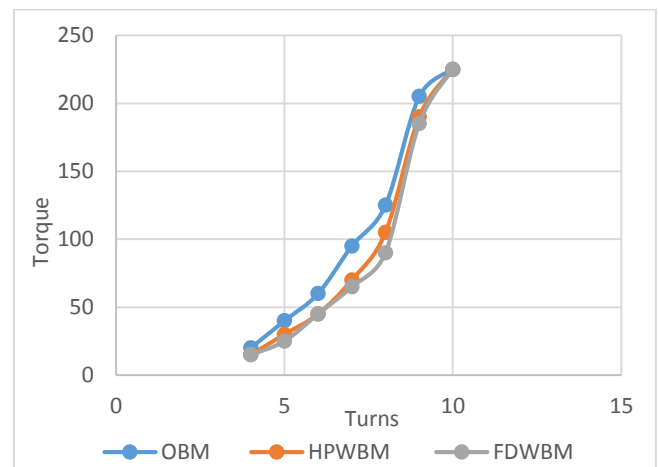


Fig. 4—Bulk hardness comparison using shale play substrate exposed to the reference and developed fluid.

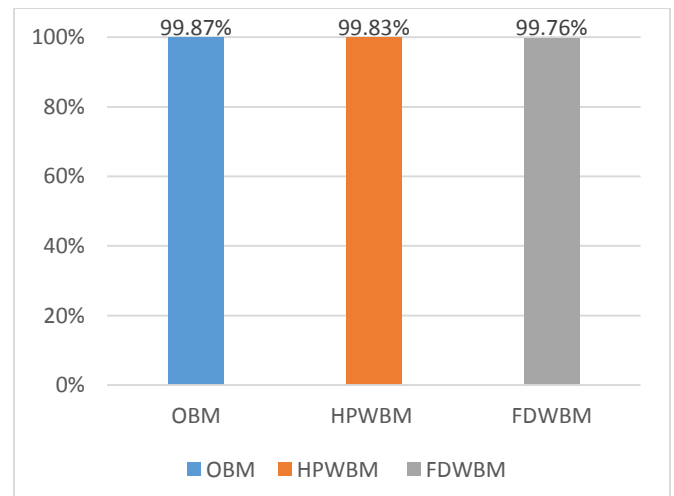


Fig. 5—Hot roll dispersion testing results using shale play core material exposed to the referenced fluids and newly developed FDWBM.

No cuttings / shale accretion was observed with any of the fluids in the comparative testing performed.

## Field Trials

The FDWBM was field trialed for the build section and the extended laterals for two operators in the Permian basin.

| Hole Size<br>Casing Size | Casing Program | Formations      | Depth MD | Depth TVD        | Mud System                                                                                                                          | Mud Weight (ppg) | Sum Days |
|--------------------------|----------------|-----------------|----------|------------------|-------------------------------------------------------------------------------------------------------------------------------------|------------------|----------|
| 17½"                     |                |                 |          |                  | Fresh Water/Native Clay                                                                                                             | 8.4              | 0        |
| 13½"                     |                | Santa Rosa      |          | 654'             |                                                                                                                                     |                  |          |
| 12½"                     |                | ICP             | 1,500'   | 1,500'           |                                                                                                                                     | 8.6              | 3        |
| 12½"                     |                |                 |          |                  | <b>Saturated Brine</b><br>Drill out with pre-saturated brine, pump high-viscosity sweeps to aid in hole-cleaning.                   | 10.0             | 4        |
|                          |                | T/ San Andres   | 5,000'   | 4,455'<br>5,000' | <b>Dispersed WBM</b><br>Displace well to prehydrated gel system.                                                                    | 10.0<br>8.8      |          |
|                          |                | T/ Clearfork    |          | 6,506'           | Begin pumping LCM Pills form LCM Plan                                                                                               |                  |          |
|                          |                | T/ U. Spraberry |          | 7,400'           | Reduce API FL <15cc/30min at TD.                                                                                                    |                  |          |
|                          |                | T/ L. Jo Mills  |          | 8,254'           |                                                                                                                                     |                  |          |
| 9½"                      |                | ICP             | 8,550'   | 8,550'           | Run 9 5/8" casing                                                                                                                   | 9.0              | 10       |
| 8½"                      |                | KOP             | 8,640'   | 8,640'           | <b>HydraGlyde</b><br>Begin building angle @ 12°/100'                                                                                | 9.0              | 11       |
|                          |                | Wilcamp B2      |          | 9,343'           | Land curve and hold ~34.11° inclination                                                                                             |                  |          |
|                          |                | Land Curve      | 9,906'   | 9,397'           | Maintain 9.0 ppg throughout lateral unless hole conditions dictate otherwise. Monitor for and report any signs of hole instability. |                  |          |
| 5½"                      |                | TD              | 16,002'  | 9,252'           |                                                                                                                                     | 9.0              | 25       |

Fig. 6—Typical casing design for Permian basin laterals.

To date, the new FDWBM was utilized on twenty-two wells in the Permian basin with laterals sections ranging from 6,000 ft. to 12,000 ft. The shales drilled have a moderate reactivity, but they are dispersive and under mechanical stresses which can result in large hole washouts. Additionally, some formations are micro-fractured and can be very easily destabilized by fluid or filtrate, which leads to wellbore collapse.

## Oil & Gas Operator 1

The Wolfcamp Formation in the Midland basin of West Texas contains interbedded shale and limestone that can cause high torque, thus limiting the ROP. The curve build section through the Spraberry formation also presented a challenge because it required higher shale inhibition compared with the lateral. The operator needed to minimize drilling torque in a 15,260-ft measured depth (MD) well while drilling the curve and a 5,485-ft lateral throughout the 8½-in production interval. In previous wells, an inhibitive HPWBM provided the required shale inhibition, but torque limits impaired the rig's overall ability to drill as fast as was possible using an OBM.

The FDWBM system included approximately 1.5 lb/bbl of encapsulating additive to minimize clay dispersion and enhance wellbore integrity, 1–2% v/v of shale inhibitor to provide wellbore stability, and 2–3% v/v of the ROP-enhancing primary lubricant to deliver required lubricity and mimic an OBM.

The new FDWBM system met the expectations by contributing to the successful drilling of the 8½-in lateral section with less torque readings on the two first field trial wells in comparison to offset wells previously drilled with an inhibitive HPWBM in the area.

Table 3—Torque readings on field trials vs. offset wells at similar other drilling parameters.

| Well Name      | Max Torque (kft.lb) | Avg. ROP (ft/hr) | Mud System | Max drilling MW [ppg] |
|----------------|---------------------|------------------|------------|-----------------------|
| Offset #1      | 26.0                | 76               | HPWBM      | 9.3                   |
| Offset #2      | 26.5                | 88               | HPWBM      | 10.0                  |
| Field Trial #1 | 18.5                | 81               | FDWBM      | 9.5                   |
| Field Trial #2 | 21.5                | 95               | FDWBM      | 9.5                   |

The ROP enhancing additive tested in the lab, to lower the CoF to the values similar to an OBM, is a very effective lubricant (up to 3% v/v) for reducing the surface torque in the field.

The 8½-in production interval was drilled in approximately five days, making it one of the operator's fastest-drilled wells in the area. Drilling torque was up to 5,000 ft.lbf less than seen in offset wells. Subsequent trips out of the hole with the drilling assembly were executed as planned, and neither tight spot issues nor mud losses to formation observed. The entire section was drilled to TD with one bit and exhibited a smooth wellbore that was successfully cased and cemented.

## Oil & Gas Operator 2

The first three field trials with the second operator were deployed using the same rig on the same pad location. The operator used an OBM in previous wells drilled in the Midland basin's laterals, but the resulting haul off and cuttings disposal requirements increased the overall well cost. The operator sought a solution to match or exceed the ROP achieved using the OBM without the ancillary cost.

Using the FDWBM system, the operator drilled the production interval in 4.38 days, 1.5 times faster than the average time spent drilling wells with offset OBM. The average ROP in the lateral sections (excluding the build section) drilled with the FDWBM was 138.8 ft/h, a 60% increase compared with the average of seven offset wells drilled with OBM.

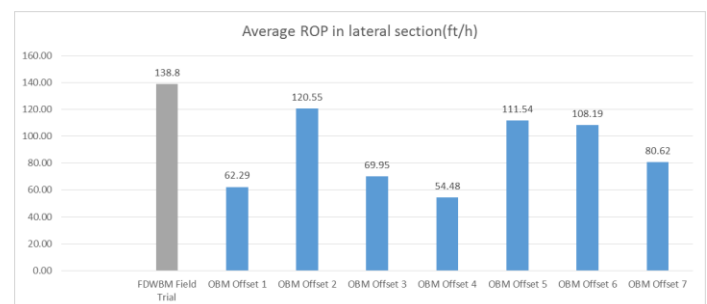


Fig. 7—Average ROP comparison with same rotary steerable system BHA.

## Conclusions

Gliding through the extended laterals of the shale plays was made easier through the use of the fit-for-purpose FDWBM with a focus on drillability, low torque & drag, good hole cleaning, and superior wellbore stability without being an economic liability.

The design, selection, and concentrations of each component were selected to optimize the performance of the overall system to meet the environmental acceptance criteria required for land drilling application. The laboratory results show that the system significantly reduces the CoF, and minimizes clay hydration, dispersion, and accretion of drill cuttings. The FDWBM was evaluated against the OBM and inhibitive high-performance water-base drilling fluid formulations.

The newly developed FDWBM provided the oil and gas operators several value drivers:

1. Performance (match the OBM performance, and improve the lubricity over the inhibitive HPWBM)
  - Reduced drilling days through increased ROP and good hole cleaning
  - Minimized tripping time due to a stable wellbore, reduced potential of sticking
2. Lower logistics cost over the OBM
  - Mitigate OBM transportation cost
  - Reduce cost of cuttings haul-off and disposal to landfill
3. Reduced cost of materials
  - Reduce use of materials due to less WBM less prone to whole mud losses
  - Less lost circulation contingency materials
4. Minimized HSE compliance cost associated to OBM
  - Eliminate cost of spill containment
  - Reduce health and safety liability to rig personnel

Initial field trials have proven that the FDWBM can be easily prepared and exhibits outstanding drilling performance. Using this fluid to drill extended laterals confirmed the laboratory predictions for lubricity, cuttings integrity, and wellbore stability. The overall performance and user friendliness are two attributes that bring this drilling fluid close to the goal of matching an OBM.

## Acknowledgments

The authors would like to thank the development team, technical services engineers, and fluids specialists assisting with the field trials. We also want to thank the oil operators for their confidence in field trials and the sustainable continuous work, and the management of M-I SWACO, a Schlumberger company, for their permission to publish this work.

## Nomenclature

|       |                                  |
|-------|----------------------------------|
| FDWBM | —Fast-drill water-base mud       |
| HPWBM | —High performance water-base mud |
| OBM   | —Oil-base mud                    |
| BHA   | —Bottomhole assembly             |
| LCM   | —Lost circulation material       |
| CoF   | —Coefficient of friction         |

## References

1. A.Patel, E.Stamatakis, S.Young and S. Cliffe, “Designing for the Future – A Review of the Design, Development and Testing of a Novel, Inhibitive Water-Based Drilling Fluid”, AADE-02-DFWM-HO-33, Houston, April 2-3, 2002
2. Gomez, S. and He, W. “Laboratory Method to Evaluate the Fracture Development in Hard Shale Formations Exposed to Drilling Fluids”, AADE-06-DF-HO-38. AADE Fluid Conference, Houston, April 11-12, 2006
3. OFI Testing Equipment, Inc., “Extreme Pressure and Lubricity Tester Instruction Manual, Ver. 2.0, Updated 7/07/2015
4. Recommended Practice for Field Testing Water-based Drilling Fluids - FOURTH EDITION; ISO 10414-1:2008 Adoption; ERTA 1: August 2014
5. Recommended Practice for Field Testing Oil-based Drilling Fluids - FIFTH EDITION; ERTA 1: AUGUST 2014
6. Stephens M., Gomez S. and Churan M., “Laboratory Methods to Assess Shale Reactivity With Drilling Fluids”, AADE2009-NTCE-11-04, AADE National Technical Conference and Exhibition, New Orleans, March 31-April 2, 2009