AADE-10-DF-HO-07

Gravel Packing with OBM Carrier Fluids in Remote Locations – Accepting the Challenges, Overcoming the Odds

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This paper was prepared for presentation at the 2010 AADE Fluids Conference and Exhibition held at the Hilton Houston North, Houston, Texas, April 6-7, 2010. This conference was sponsored by the Houston Chapter of 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 individuals listed as authors of this work.

Abstract

Conventionally gravel packing unconsolidated reservoirs is the preferred method of sand control in many reservoirs. Until recently, the alpha-beta (α-β) gravel pack carrier fluids preference has been clear brine fluids. Despite a long history of success, brine carrier fluids are limited to relatively shale-free reservoirs that do not overly hydrate and destabilize the open hole. Unfortunately, shale-free reservoirs are becoming more and more uncommon.

A solids-free invert emulsion carrier gravel pack fluid (IEGPCR) option is available that overcomes the issue of wellbore destabilization while incorporating most properties of traditional brine carrier fluids. It is well-known that oil-based (OBM) systems are wellbore-stabilizing fluids; less well-known is that these systems can be engineered to carry gravel with near-Newtonian behavior like their brine counterparts.

The use of rapid deployment liquid mud plants (RDLMP) has expanded the applicability of these systems to remote locations where infrastructure costs might otherwise render a project unfeasible. These self-contained, skid-mounted, modular plants can be quickly mobilized to remote locations in a matter of weeks and are equipped with diesel-generated power, a mixing hopper, storage capacity and transfer capabilities.

This paper outlines the design criteria and properties of a new wellbore-stabilizing OBM gravel pack (GP) carrier fluid, the design, capabilities and logistics of deploying the RDLMP to remote locations and case histories demonstrating how each of these challenging aspects can overcome obstacles to achieve a successful, economical gravel pack operation.

Introduction

The methods available to operators to drill and complete unconsolidated reservoirs are numerous. Many openhole completion applications that require sand control typically install completion screens. For extended well life, many operators choose to gravel pack the completion screen annulus[1].

For nearly three decades gravel packing has been used to control sand production in unconsolidated wells. The gravel pack fluids used during this time span have been brine-base carrier fluids. These fluids are used as the primary component for what is known by the industry as a conventional gravel pack. There is little controversy that these carrier fluids are ideal for this purpose. However, it is becoming more and more frequent that the reservoirs drilled today require more than a clear brine-based carrier fluid. In fact, the selection of brine as a carrier fluid could be a serious mistake due to the presence of brine-sensitive formations[2]. Despite brine systems having a reputation for providing inhibition to water-sensitive zones, many reservoirs require more surety that the wellbore will remain stable for long periods of time between the brine displacement through the gravel pack operation and completion phases. In addition, many wellbores completed with gravel packs are highly deviated, horizontal and/or extended reach and may require a more lubricious carrier fluid. To avoid these wellbore issues, operators have been searching for alternative carrier fluids to maintain optimum wellbore conditions.

The industry has known for several decades that drilling difficult wells with invert emulsion drilling fluid has been made easier because these fluids offer many advantages over aqueous-based systems. Invert emulsion drilling fluids are stable fluids and easy to maintain. They are inherently inhibitive and lubricious in sand and shale formations. The bulk of these advantages are primarily due to their external oil phase and the internal brine phase.

The use of brine-based carrier fluids to gravel pack wellbores after drilling with an invert system has been successful in a handful of applications. This approach was never popularized because operators considered the risk too high. Their primary concern was the belief that despite the shale-stabilizing effect of the invert drilling, these intervals would eventually be destabilized in the presence of the brine carrier fluid and jeopardize the project.

The obvious solution to these drawbacks and the thrust of this paper was the development of an invert emulsion gravel pack carrier fluid. This new technology was designed to incorporate the benefits of invert emulsion drilling fluids and the critical properties of a brine carrier fluid[3]. In the example application presented in this paper, numerous challenges were overcome to design and maintain a quality invert carrier fluid to include the historical performance of brine-based carrier fluids. In addition, logistical challenges to use this system in remote locations will be discussed.

Laboratory Design and Confirmation

To carry gravel with an invert emulsion system, the fluid's most important property is that it be near-Newtonian. A near-Newtonian fluid is needed to carry gravel via an alpha wave. Brine fluids are naturally Newtonian but this is not the case for invert emulsion fluids. The first design criterion for a new-generation invert emulsion carrier fluid is to formulate it in such a way that it has low shear-rate viscosity or near Newtonian behavior. This behavior of the carrier fluid can be confirmed in several ways. In the laboratory, acceptable Newtonian behavior (low viscosity) is confirmed by using a MCR-301 and a RFS-III rheometer. These stress/strain-controlled instruments are capable of measuring viscosity at shear rates less than 0.01 sec^{-1}, shear rates that closely mimic shear rate of settling gravel pack particles in a carrier fluid.

In addition to requiring near-Newtonian character, IEGPF fluids must be solids-free before being infused with gravel during placement. Most gravel is inherently water-wet; therefore, an oil-wetting surfactant package is introduced into the carrier fluid along with the gravel to quickly reverse the wettability of the gravel from water-wet to oil-wet. Thus, the near-Newtonian viscosity coupled with the reversed gravel wettability works to ensure the rapid settling of the gravel in the screen annulus. A high rate of settling facilitates the formation of a tight pack from heal-to-toe (alpha-wave) and then from toe-to-heal (beta-wave).

To achieve the desired density without solids, these fluids are formulated by mixing various densities of brine with the base oil. To make a solids-free carrier fluid greater than 9.0 lbm/gal, 14.2 lbm/gal $CaBr_2$ brine is blended with 7.0 lbm/gal low viscosity mineral oil. A specially selected blend of surfactants (emulsifiers and wetting agents) is selected to emulsify the brine to achieve the near-Newtonian behavior. The carrier fluid design should have a low hear-rate viscosity (LSRV) that does not vary significantly from its high shear-rate viscosity (HSRV) measurements. **Figure 1** shows the viscosity in sec^{-1} at various temperatures. There should be minimal deviations in the viscosity readings. Increased viscosity at low shear rates will slow the rate of settling and discourage alpha wave propagation to the wellbore toe. LSRV instruments are not field worthy so Fann 35 viscometers are used to monitor properties and aid in the maintenance of a good formulation. Correlation testing in the lab confirmed that this would be an acceptable practice provided the field formulation is evaluated in the laboratory in advance. Rheological properties are typically measured at a range of temperatures to ensure the carrier fluid is capable of good downhole performance. Results from one such field application can be seen in **Table 1**. In this example, the 120°F and 160°F measurements ranged from 5 to 11 cP at the low and high shear rates, confirming a satisfactory design.

Well Design and Project Objectives

An operator in the Gulf of Thailand suspected water/brine-sensitive shale in the reservoir, prompting the selection of an inhibitive, 9.6 lbm/gal mineral oil-based drill-in fluid (DIF) to drill the reservoir, maintain wellbore stability and deposit a non-damaging filter cake. Another critical objective was to work within the space limitations on the rig when switching from the standard drilling fluid to the oil-based DIF. In addition, the DIF was formulated to ensure a thin filter cake was deposited on the reservoir face. Thin filter cakes are needed in order to avoid costly swabbing procedures often required to bring a well on line. To ensure fluid continuity, compatibility and wellbore stability, an IEGPCF system was selected to enable an α-β gravel pack. Having a carrier fluid composed of the same external phase as the DIF would ensure that the filter cake would not lose its integrity or increase the flow-initiation pressure after gravel placement.

The wells in this project were batch drilled and a liner set into the top of each reservoir before later returning to batch drill the reservoir intervals. Surface casing was run on each well to the kick-off point and later 7-in. production casing was run to the top of the pay zone and cemented. Each reservoir was drilled with a bi-centered bit to 7 1/8-in.

The completion phase consisted of an open hole gravel pack tool system with a gravel pack packer, a gravel pack extension tool and a crossover tool for gravel placement. An example of this gravel pack assembly is shown in **Figure 2**.

Remote Location Operations

From the RDLMP to the Rig

There are numerous oil fields in remote locations where the local infrastructure cannot accommodate all of the drilling and completion fluid activities. Most rigs are designed to accommodate any type of drilling fluid system but when an IEGPCF is required, an onshore mixing facility is needed to avoid downtime on the rig.

On this project, the IEGPCF not only required onshore mixing but also required a blending facility with high-energy mixing pumps and liquid storage capacity. RDLMPs are cost-efficient, self-contained units that can be mobilized and installed in a matter of weeks on a small land space. Because these facilities are mobile, they are ideal for short-term projects and offer the operator a relatively inexpensive, flexible option to take on difficult projects in remote locations.

For this project, the RDLMP comprised five 40-ft modular storage tanks (**Figure 3**), a 20-ft pump module with generator, two pumps, a mixing hopper, and the associated lines and valves necessary to complete the unit. Two tanks were used for the mixing of the IEGPCF system (**Figures 3 and 4)**. These tanks had been cleaned to a brine standard before mixing the carrier fluid. The IEGPCF was mixed according to the formulation provided by the fluid laboratory, and products were mixed in the specified order. The quantities of each product used to build 430 bbl of the fluid per tank and the typical fluid properties are given in **Tables 2** and **3.**

The carrier fluid was transported to the rig via work boats with storage tanks that had been inspected for cleanliness and stored in a brine tank on the rig. The fluid was transferred as needed into the rig pits prior to the start of the first displacement. The pit used as the holding tank for the IEGPCF system was cleaned and inspected prior to the fluid transfer. In addition, the valves in the transfer lines used to transfer fluid into the mud pits were closed and lock-out tag-out procedures were followed to ensure no fluid was transferred without specific instructions.

DIF to Carrier Fluid Displacement

Before the gravel pack operation could begin, the mineral oil-based DIF was displaced to the IEGPCF. This process involved the use of 10 bbl of base oil followed by the carrier fluid. The pumping occurred in two stages. First the open hole (OH) was displaced into the 7-in. liner. After the workstring was pulled up above the casing shoe, the DIF was displaced from the liner to surface with the carrier fluid. To ensure the OH was condition for the gravel pack and all drilling fluid solids efficiently removed, the carrier fluid was circulated in turbulent flow at a rate of 5 bbl/min.

Approximately 10 bbl of the carrier fluid interface was blended into the OBM pit prior to stopping the pumps and used to clean the surface system (flow line, ditches and other surface lines). All lines used in conjunction with the carrier fluid were flushed with base oil. The carrier fluid was then circulated until the wellbore was declared clean. At this time, the workstring was pulled out of the hole.

Gravel Pack Operation

After running in the hole with the completion screens and setting the GP packer, the IEGPCF was circulated to determine the pressures required to gravel pack. The GP operation began by infusing 20/40 gravel into the circulating carrier fluid. After screen-out was achieved, excess gravel was reversed out and the drill pipe was pulled out of the OH until the bottom of the pipe was at a depth of 400 m. The casing was then displaced to seawater. **Table 4** provides the job summary information for each of the gravel pack operations for five wells.

Samples were collected at the end of each displacement and at the end of the gravel pack operation for each well. The samples were sent to the laboratory for analysis. Before and after samples were evaluated to determine variances in low shear-rate viscosity (LSRV). In addition, contamination levels were evaluated as the plan was to recycle and reuse the carrier fluids on multiple jobs.

Project Results

The data for five GP wells showed a close match to the pressures and durations shown in the pumping results. The summarized GP efficiency of each well is given below.

- Well 1: 151%
- Well 2: 110%
- Well 3: 107%
- Well 4: 127%
- Well 5: 167%

The high-efficiency values of all five wells indicate that despite washouts, the downhole packing was complete. This is to be expected from low viscosity packing fluids and in an indication of excellent proppant transport. **Figure 5** is a summary of the gravel pack efficiencies, showing calculated gravel volumes versus actual volumes. Note the each well had >100% gravel pack efficiency suggesting that the new IEGPCF supported the alpha-beta pack application as expected. Additional supporting performance evidence can be found in **Figure 6,** which shows the LSRV values of the batches mixed at the RDLMP. The LSRV graphs of each carrier fluid prior to the five gravel pack jobs are shown in **Figures 7, 8, 9, 10 and 11.**

Production Results

Published results confirm that the five-well project was a technical success. The field was put into production in August 2008 and a month later was producing 17,000 BOPD. Each well was brought on line without the need of stimulation and some of the ESPs have had as many as 70 starts. There is no evidence of sand production or any other technical problems which suggests that the gravel packs using the IEGPCF adequately supported the project objective and contributed to tightly packed, very productive wells.

Conclusions

1. The five wells gravel packed in the Gulf of Thailand were successful applications using a solids-free, near Newtonian, invert emulsion carrier fluid.
2. Each well packed resulted in an alpha-beta pack with 100% gravel pack efficiency or greater.
3. The wellbores of all five wells remained stable despite the presence of water-sensitive clays in the grave pack interval.
4. The carrier fluid was conditioned and reused after each well without deterioration of the LSRV.
5. In remote locations or fields where infrastructure is lacking, a rapid deployment liquid mud plant can be mobilized quickly to support difficult and logistically challenged projects.

Acknowledgments

The authors would like to thank Baker Hughes for allowing the publication of this paper and in particular Alex McKellar and Steve Willis who were instrumental in the fluid design and field supervision for this project.

Nomenclature

IEGPCF = *invert emulsion gravel pack carrier fluid*
OHGP = *open-hole gravel pack*
$CaBr_2$ = *calcium bromide*
Bbl = *barrel*
lbm/bbl = *pounds per barrel*
lbm/gal = *pounds per gallon*
ft = *feet*
°F = *temperature in Fahrenheit*
ESP = *electric submersible pump*

BOPD = barrels of oil per day

References

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2. Ali, S., Griffith, G., Jones, T., and Hinojosa, R., Smejkal, K. 1999. A Synthetic Reservoir Drill-in Fluid for Gravel Pack Application in a Pressured Shale / Depleted Sand Environment: A Case Study. Paper XXXXX presented at the AADE Annual Technical Forum, April, 1999.
3. Aragao, A., Calderon, A., Lomba, R., Moreira, J., Martins, A., Sa, A., Quintero, L. 2007. Field Implementation of Gravel Packing Horizontal Wells Using a Solids-Free Synthetic Fluid with Alpha/Beta Wave Technology. Paper SPE 110440 presented in Anaheim, CA, 11-14 November.

Tables

Table 1: Fann 35 Properties

Fann 35 Properties	120°F	140°F	160°F
Plastic viscosity, cP	6.5	5.5	4.5
Yield point, lbm/ 100 ft^2	0	0	0
6-RPM reading	0	0	0
3-RPM reading	0	0	0
10-sec/min gel readings	0/0	0/0	0/0

Table 2: Properties of Carrier Fluid

GP Carrier Fluid Composition - Properties	
Synthetic base oil, bbl	0.585
Emulsifier package, lbm/bbl	10
14.2 lb/gal $CaBr_2$ brine, bbl	0.384
Density, lbm/gal	9.6
Oil/brine ratio	62/38

Table 3: Properties of Carrier Fluid

Initial Properties at 120°F	
Plastic viscosity, cP	12
Yield point, lbm/ 100 ft^2	1
200-RPM reading	9
100-RPM reading	5
6-RPM/ 3-RPM reading	0/0
10-sec/ 10-min gel readings	0/0
Electrical stability, volts	400
Post-Aging Properties at 120°F	
Aging conditions: static	48 hrs at 200°F
Plastic viscosity, cp	7
Yield point, lbm/ 100 ft^2	1
200-RPM reading	5
100-RPM reading	3
6-RPM/ 3-RPM reading	0/0
10-sec/ 10-min gel readings	0/0
Electrical stability, volts	200

Figures

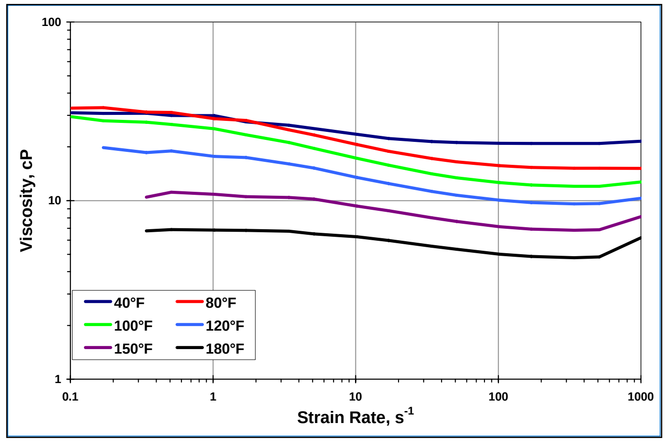

Figure 1: LSRV of a lab prepared IEGPCF

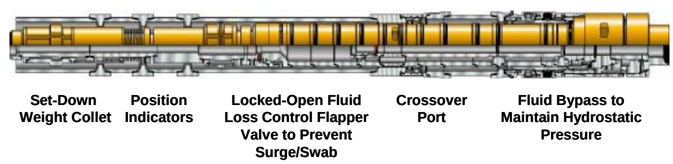

Figure 2: Example of gravel pack tool

Figure 3: RDLMP (1)

Figure 4: RDLMP (2)

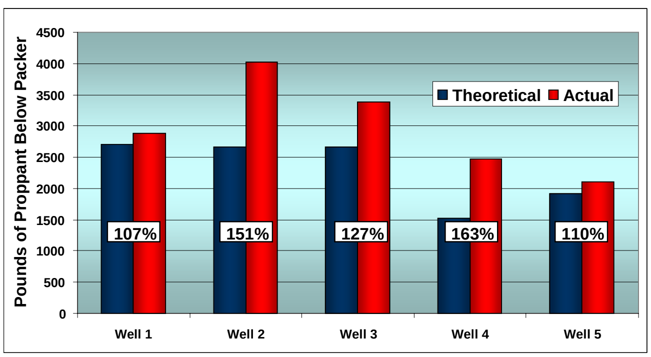

Figure 5: Gravel pack efficiencies of five wells

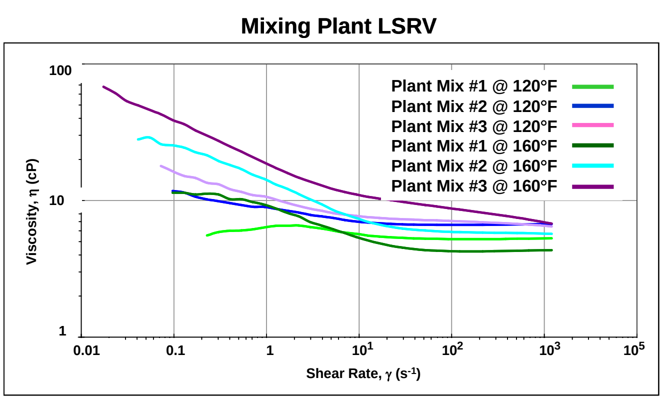

Figure 6: LSRV of plant batch mixes

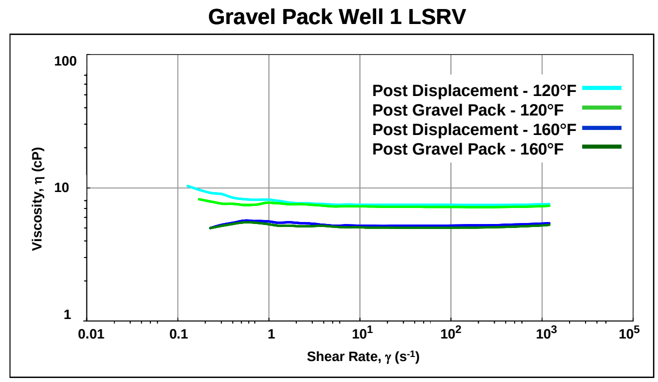

Figure 7: LSRV of gravel pack well 1

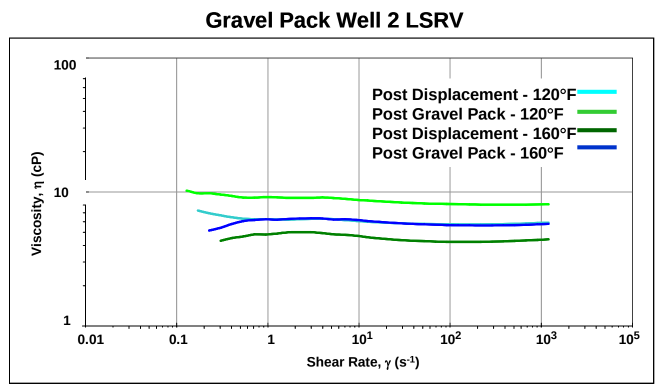

Figure 8: LSRV of gravel pack well 2

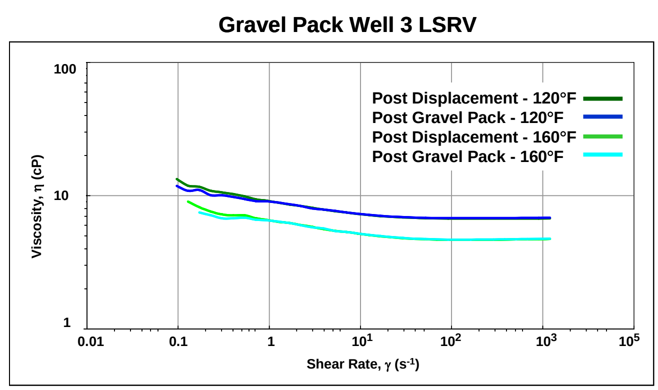

Figure 9: LSRV of gravel pack well 3

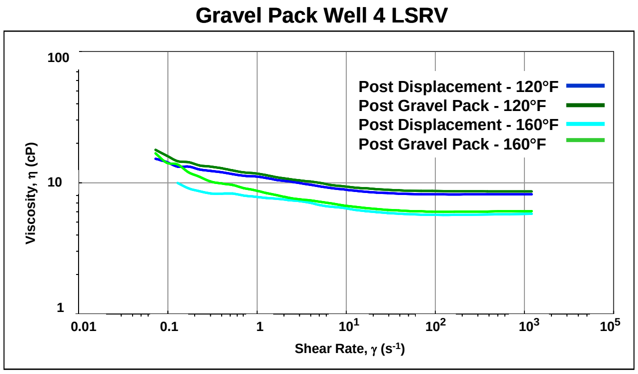

Figure 10: LSRV of gravel pack well 4

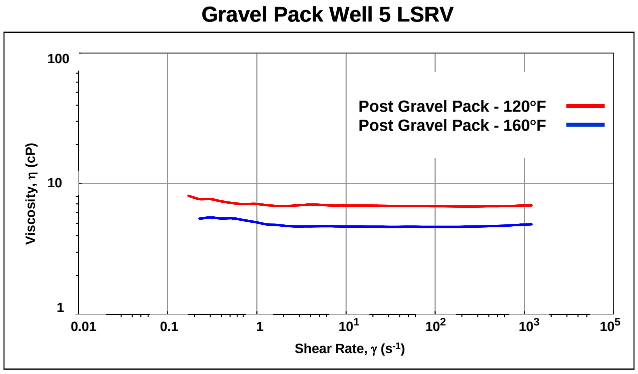

Figure 11: LSRV of gravel pack well 5