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Enhancing Rheology in Invert Emulsion Fluids: Application of the Concept of Synergism in Chemicals

Dhanashree Kulkarni, Sandeep Kulkarni, Sharath Savari and Shadaab Maghrabi, Halliburton; Vikrant Wagle, formerly Halliburton

Abstract

An organic rheology modifier package (ORMP) containing an organic rheology modifier (ORM) and a novel ORM enhancer, demonstrate synergism in imparting improved rheology to organophilic clay-free invert emulsion fluids (IEF). The synergism provided enhanced rheology and HTHP fluid loss control as compared to the individual performance of ORM and ORM enhancer. Since the ORM enhancer is relatively inexpensive, the synergism allows for lower concentrations of the ORM used in the IEF thereby positively affecting the economics of formulating optimized clay-free IEF.

The IEFs with the ORMP exhibit enhanced low shear rheology for a range of mud weights (9.0 – 12.0 ppg) with similar plastic viscosity (PV) values when compared to IEFs formulated without the ORMP. When tested at up to 350°F and 15,000 psi, the IEFs formulated with ORMP show consistent yield point (YP) and low shear yield point (LSYP) with no significant change in PV. Static aging studies of these fluids at 250°F showed minimal oil separation with a sag factor less than 0.53 for 24 – 48 hours. The IEFs also showed good tolerance to contaminants which were easily treated with conventional thinners.

IEFs formulated with ORMP demonstrate strong yet fragile gel characteristic. This rapid gel-to-flow transition helps to minimize equivalent circulating density (ECD) inflections during tripping, running and breaking circulation to reduce induced mud losses. The ORM passes the North Sea and OSPAR environmental regulations and thus can be used in areas where environmental conditions are stringent. The ORM enhancer is biodegradable and is not bio-accumulating. The paper demonstrates the environmental and rheological performance of ORMP in organoclay-free fluids.

Introduction

To achieve a successful drilling operation, it is imperative for a drilling fluid to have an “optimum” rheology. The optimum rheology of a drilling fluid is typically characterized by a low plastic viscosity (PV), good yield point (YP) and low shear yield point (LSYP). The plastic viscosity is expected to be as low as possible whereas a low shear viscosity in the range of 7-15 lb/100ft^2 is desirable.[1,2,3] In some fields, the rule of thumb is an LSYP range from 1 to 1.5 times the hole diameter. A good YP can fall anywhere between 15 – 25 lb/100ft^2.[4,5] However, the needed LSYP and YP depend on the field requirements and are determined from hole cleaning and ECD simulations performed on hydraulic modeling software. This modeling performs complex calculations with the use of different rheological models, including Bingham Plastic and Herschel Buckley.

Maintaining appropriate rheology is very important since a low rheology can result in inadequate hole cleaning and reduced suspension of barite. These in turn lead to increased low gravity solids in the fluid, hole pack off, high fluid loss and increased ECD. The increased ECD can lead to high induced losses.[6,7]

In addition to the technical performance of an IEF the additives used in the IEF are expected to have a favorable environmental profile. In environmentally sensitive areas the additives / drilling fluid must pass the stringent regulations of OSPAR, North Sea or the Gulf of Mexico.

Organophilic clay-free IEFs introduced in the last decade have become extremely popular. These IEFs are formulated without organophilic-clays and organophilic lignite that form a part of the conventional IEF. The IEFs formulated here provides enhanced rheology in the presence of an organic rheology modifier package (ORMP). The requirements of rheology and fluid loss control of these IEFs are provided by polymeric viscosifiers and fluid loss control agents. The clay-free IEFs have demonstrated in the field to have to help achieve higher rates of penetration (ROP), tolerance to contaminants, HPHT stability and lower induced losses as compared to their conventional counterparts.

Recently clay-free IEFs were formulated with a novel organic rheology modifier (ORM) that imparted improved rheology to the IEF. However at low mud weights, higher concentrations of this ORM were needed, which negatively impacts the overall cost of the IEF. Therefore a new and inexpensive ORM enhancer was developed to interact synergistically with the ORM to significantly enhance the rheology and help control the fluid loss of the organophilic clay-free IEF. The ORM enhancer ensured a lower concentration of the ORM can be used to maintain the required rheology and fluid loss. The ORM and ORM enhancer together form a package (ORMP). This paper presents the ORMP performance in different mud weights, static aging conditions, tolerance to contaminants and HPHT conditions, as well as detailed gel testing of the ORMP based clay-free IEF on a Brookfield viscometer is presented. The environmental profile of the ORMP is also presented.

Methods and Materials

The organophilic clay-free IEFs were formulated with commercially-available primary and secondary invert emulsifiers, polymeric filtration control agent, lime, an inorganic viscosifier, $CaCl_2$, barite and paraffinic base oil. The organic rheology modifier (ORM) and the ORM enhancer are novel products developed in the laboratory for IEF applications.

The formulation and testing procedure of a typical fluid is presented below

1. Mix the fluids on a multimixer (Model #9B5) as per the formulation and mixing time given in **Table 1 & 1a**.
2. The fluids were hot-rolled at 250°F /300°F in a roller oven (Model 705ES) for 16 hours
3. Rheology was measured on the FANN® 35 viscometer at 120°F, as per API RECOMMENDED PRACTICE 13B-2; 6.3.
4. The HPHT fluid loss was measured at 300°F/250°F, with 500 psi differential, as per API RECOMMENDED PRACTICE 13B-2; 7.2.

The rheology of the fluid was characterized in terms of PV, YP, and LSYP. The YP and PV are parameters from the Bingham Plastic rheology (BP) model. The YP is determined by extrapolating the BP model to a shear rate of zero; it represents the stress required to move the fluid. The YP is expressed in the units of $lb/100ft^2$. The YP indicates the cuttings carrying capacity of the IEF through the annulus or in simple terms the IEF's hole cleaning ability. A YP of 10-25 is considered good for drilling.

The PV represents the viscosity of a fluid when extrapolated to infinite shear rate, expressed in units of centipoise (cP). The PV indicates the type and concentration of the solids in the IEF, and a low PV is preferred. Both PV and YP are calculated using 300 revolutions per minute (rpm) and 600-rpm shear rate readings on a standard oilfield viscometer as given in **Equations 1** and 2 below.

The yield stress or Tau0 is a parameter from the Herschel Buckley (HB) rheology model which is the equivalent of the YP in the BP model. The Tau0 is determined by fitting the HB model to the shear stress vs shear rate curve, which is the dial readings plotted against the corresponding rpm determined on the standard oil field viscometer. The Tau0 is expressed in similar units as the YP. The Tau0 indicates the susceptibility of the IEF to barite sag: a high Tau0 is expected to deliver a sag-resistant IEF. The Tau0 can be estimated reasonably by calculating the LSYP value from **Equation 3**.

PV = (600 rpm reading) – (300 rpm reading) (Equation 1)

YP = (300 rpm reading) – PV (Equation 2)

LSYP = [2×(3 rpm reading)] – (6 rpm reading) (Equation 3)

The gels formed in the IEF were characterized by the 10 sec / 10 min gel strength which represents the highest dial reading at 3 rpm on the viscometer, after keeping the IEF static for an interval of 10sec / 10 min. The gel strengths indicate suspension ability of the IEF for cut drill solids and barite particles when drilling stops.

The static aging was performed on the IEF to see the effect after prolonged exposure to high temperature on the rheology, fluid loss and suspension ability. The procedure for static aging is presented below as continued from Step 4

5. The 16 hour Hot rolled IEF is mixed on a multimixer (Model #9B5) for 5 minutes.
6. The IEF is then taken in stainless steel aging cells, pressurized as per API with nitrogen and placed in upright position in the static age oven at temperature 250°F.
7. The static aging is continued for 24 and 48 hours at 250°F.
8. After static aging the cells are cooled and opened in the upright position to determine the SAG performance.

In the SAG performance test the specific gravity of the top (SG_{top}) and bottom (SG_{bottom}) sections of the fluids in the aging cells was measured. The SAG test determines the sagging tendency of the fluid measured in terms of the Sag factor, for the static aged fluid was calculated using the formula below:

$$Sag\ Factor = \frac{SG_{bottom}}{SG_{bottom} + SG_{top}}$$

An IEF with a SAG factor of between 0.50 – 0.53 is considered a SAG resistant fluid.

9. After the static ageing the IEF is then mixed for 5 mins on a multimixer followed by rheology and HTHP fluid loss measurements as described in Steps 4 & 5 respectively.

Results and Discussions

The synergistic interaction between the ORM and the ORM enhancer now referred to as the ORMP was tested as per the plan outlined below:

1. Synergism in low medium mud weight IEF – 9.0 ppg IEF formulated at 60/40 OWR, 200K WPS and hot rolled at 250°F for 16 hours.
2. Synergism in medium mud weight IEF – 12.0 ppg IEF formulated at 70/30 OWR, 250K WPS and hot rolled at 250°F for 16 hours.
3. Performance of ORM in Static aging – 12.0 ppg IEF formulated at 70/30 OWR, 250K WPS and static aged for 24 and 48 hours at 250°F.
4. Tolerance testing of the ORMP with contaminants – 12.0 ppg IEF formulation at 70/30 OWR, 250K WPS and hot rolled at 250°F.
5. HTHP rheology testing on Fann75 for 12.0 ppg IEF

6. Testing of gels on Brookfield for the 12.0 ppg IEF.

1. Synergism in Low Mud Weight IEF

Synergism involves interaction between two entities to give better performance than each entity's individual performance. The formulations for 9.0 ppg IEF are presented in Table 1; the rheological and fluid loss properties of these IEFs are presented in Table 2. Initially Fluid 1 containing 3.0 ppb ORM only and Fluid 1a containing the 2.0 ppb ORM enhancer only were formulated 9.0 ppg mud weight.

Fluid 1 demonstrated a YP of 12, LSYP of 6 and –a 10-min gel strength of 20 which are fair values for an IEF. But Fluid 1a demonstrated a YP of 1, LSYP of 2 and 10-min gel strength of 5 which were lower values. The fluid loss results on both Fluid 1 and 1a were similar and low.

As a next step Fluid 2 was formulated at 3 ppb ORM and 2 ppb ORM enhancer. Fluid 2 demonstrated synergism between the ORM and ORM, as can be seen from the increased rheology of Fluid 2. Quantitatively Fluid 2 demonstrated an increase in PV, YP, LSYP, 10-sec and 10-min gel strengths by 33%, 175%, 167%, 90% and 25% respectively as compared to Fluid 1. The HPHT fluid loss of Fluid 2 was also lower and similar to both Fluid 1 and 1a.

2. Synergism in Medium Mud Weight IEF

To evaluate the performance of ORMP at higher temperatures, 12.0 ppg organoclay-free IEFs were formulated with and without ORMP and hot rolled at 300°F for 16hrs. The rheological and filtration properties of the fluids are mentioned in **Table 3**. Fluid 3 was formulated with 2.0 ppb ORM (referred to as "base" 12.0 ppg fluid) but without ORM enhancer.

Fluid 3a was formulated with ORM enhancer without ORM.

Fluid 4 was formulated with ORMP comprising 2.0 ppb ORM and 1.5 ppb ORM enhancer.

Fluids 3 and 3a formulated with no ORMP as expected showed low rheological properties with YP of 7 and 1 respectively.

The synergistic effect of ORM enhancer on the ORM contained in Fluid 4 led to a 67%, 129% and 300% increase in PV, YP and LSYP respectively as compared to the base 12.0 ppg fluid (Fluid 3). The 10 sec and 10 min gel strength increased from 3 and 4 to 13 and 25 respectively. The synergistic effect of the ORMP also led to a decrease in HTHP fluid loss 6ml (Fluid 3) to 2ml (Fluid 4).

Due to synergistic effects, the ORMP worked effectively in both the 9.0 ppg and 12.0 ppg IEFs without causing any adverse effects on their rheological and filtration properties.

3. Performance of ORM in Static Aging

Static aging studies were performed in order to evaluate the sag performance of the IEFs containing the ORMP. It is well known that barite sag can cause mud weight fluctuations, well control problems, downhole mud losses, etc. The ageing test used in the study determines how the bottom-hole conditions affect mud properties under static conditions. A good fluid is considered to be the one that has minimal oil separation after static ageing and possesses a sag factor less than 0.53. The experimental part of this study is described in brief in methods and materials.

A 12.0 ppg IEF was formulated with the ORMP comprising of 1.0 ppb ORM and 2.5 ppb ORM enhancer and was hot rolled at 250°F for 16hrs (Fluid 5, Table 1a).

Fluid 5 was then static aged at 250°F for 24hrs and then subsequently for 48hrs. The fluid properties were then measured as given in Table 4. The PV, YP and LSYP of the 24hr-static aged fluid increased by 18%, 53% and 125% respectively as compared to Fluid 5. Similarly, the increase in PV, YP and LSYP of the 48-hr static aged fluid was 12%, 44% and 138% as compared to Fluid 5.

Though the rheology increased after static ageing we can see that the rheology for both 24 and 48 hours static aged fluids were similar, and the HTHP fluid loss was well under control at 2.0 ml. A closer look at the gels for 24 and 48 hour static aged fluids suggests only a 33% increment for the 10 min gel strength. The oil separation obtained after static ageing was minimal (approximately 4.0 ml) and the sag factor obtained by recording the top and bottom densities of the fluid was less than 0.53. Thus, it could be concluded that no barite sag was observed in the formulated fluids and the fluid were stable after the static ageing process.

4. Tolerance testing of the ORMP with contaminants

Tolerance to contamination is the primary requisite of any good drilling fluid. The contaminants used for the testing included the following:

- 40.0 ppb of artificial drilled solids
- 10% v/v seawater increment
- 2.0 ppg weight up with barite and
- 5.0 ppb lime.

The contamination study was divided into following two parts:

Part A: Effect of contaminants

1. Hot roll ORMP based 12.0 ppg IEF (Fluid 6, Table 1a) at 250°F for 16 hrs.
2. Measure the HPHT fluid loss and the rheology.
3. Mix the IEF with the contaminants for 5 min.
4. Hot roll the IEF at 250°F for 4 hrs.
5. Measure the HPHT fluid loss and the rheology of contaminated IEF

Part B: Effect of treatment on the contaminated IEF to restore its rheology and filtration values within ~20% of its original values (uncontaminated state)

1. Mix the contaminated IEF with the required treatment for 5 min.
2. Hot roll the treated IEF at 250°F for 4 hrs.
3. Measure the HPHT fluid loss and the rheology

The effect of contaminants on the 12.0 ppg LGS-free IEFs are given in **Figure 1**.

- The YP of the base fluid increased by 110%, 40% and 70% when contaminated with Rev-Dust, barite and 10% v/v sea water respectively.

- The LSYP increased by roughly 150%, 62% & 75% for Rev Dust, barite weight up and 10% sea water respectively.
- The PV increased by 50% with contamination for Rev Dust, barite weight up and 10% sea water respectively.
- In the presence of lime the YP and LSYP decreased by 80% of its value before contamination.

The increased rheological properties of the contaminated fluid with the 40 ppb Rev Dust, 2.0 ppg barite weight up and 10% v/v sea water were easily brought within the 20% of the value before contamination by treatment with conventional thinners as can be seen in **Figure 2**.

However since contamination with 5.0 ppb lime thinned the system the rheology of the fluid was restored within 20% of the base fluid rheology by the addition of 1.0 ppb ORM and 2.0 ppb ORM enhancer (Figure 2).

The contamination studies on the ORMP based 12,0 ppg IEF thus showed that any effect of the contamination on the rheological and filtration properties of the IEF can be easily restored by using conventional thinners or viscosifiers.

5. HTHP rheology testing on Fann75

In this section, the rheology of the 12.0 ppg IEF formulated with ORMP comprising of 2.0 ppb ORM and 2.5 ppb ORM enhancer (Fluid 7, Table 1a) was measured on a Fann 75 HPHT rheometer simulating downhole conditions.

The rheology of the 12.0 ppg IEF measured under HTHP conditions is shown in **Figure 3**. The pressures were varied from 3000-15,000 psi for a temperature range of 150°F to 350°F. For the 12.0 ppg IEF formulated with ORMP, the PV varied from 25 to 37 across the pressure and temperature range whereas the YP and LSYP varied from 31 to 38 and 18 to 23 respectively. It is known that at lower temperatures the fluid thickens up and at higher temperatures the fluid tends to thin down. However, it could be observed from **Figure 3** that the ORMP provided a consistent rheology profile in Fluid 7 in spite of the high temperatures and pressures.

The HPHT rheology data show that these IEFs exhibit sufficient rheology to perform the functions of hole cleaning and suspension under high pressure and high temperature in addition to resistance to barite sag. Usually a decrease in the rheology of the IEF is observed under HPHT conditions when compared to rheology at 120°F but this was not the case here.

6. Testing of gels on Brookfield for the 12 ppg IEF

A “fragile” gel is easily disrupted or thinned, and liquefies or becomes less gel-like and more liquid-like under stress. These fragile gels are easily disrupted with a pressure wave or a compression wave during drilling, helping to prevent induced fractures that initiate fluid loss to the formation especially due to surge and swab pressures. These fragile gels require lower surface pressures to break gels thereby minimizing the need to modify fluid rheology before running casing.

Brookfield measurements to determine fragile gels were performed for the 12.0 ppg IEF. Automatic steps in this experiment on the Brookfield viscometer are as follows:

1. The fluid is first stirred at 100 rpm to break any gel structure formed
2. The gel peaks (actually the highest shear stress registered in units of $lb/100ft^2$) are measured at a shear rate of ½ rpm (viscosity is recorded once per second) after 10-second, 10-minute, and 30-min static intervals.
3. Following the gel peaks, the shear stress is measured at the same shear rate for a stipulated time interval before stirring again at 100 rpm to break up the gel.

The 12.0 ppg IEF was formulated in the presence of ORMP comprising of 2.0 ppb ORM and 2.5 ppb ORM enhancer (Fluid 7, Table 1a). The 12.0 ppg fluid was hot rolled at 250F for 16hrs. The viscosity versus time profiles for the fluid is shown in **Figure 4**.

It can be observed for the 30 min gel test (the region in the plot around 70 mins) that at 71-1/2 minute the test begins and the gel peak starts its ascension. But at 72-1/4 minute, the ascension registers an abrupt descent to zero reading. This is a limitation of instrument which could not register a reading greater than 37 units ($lb/100ft^2$) and therefore descends to zero units. In the next 30 seconds in the 72 minute a reading of 37 units is registered when the gel peak is on its descent, implying that from 72-1/4 minute to 72-3/4 minute the gel peak ascends reaches its highest value and then starts its descent. The gel peak soon falls from 37 to 30 units at 73-1/2 minute and continues its descent for the next 3 minutes till it reaches 29 units.

So from the start of the 30 minutes gel test, to the ascent of gel peak greater than 37 units, followed by its descent to 30 units, it took approximately 2 minutes to break the gel structure. If the time from the gel peak to its rapid fall to 30 units is considered, then this takes approximately 30-45 sec. The force applied to break this gel was very small, at 0.5 rpm with a vane spindle.

The Brookfield test clearly demonstrates the presence of strong gels provided by the ORMP. At the same time the rapid fall of the gel shear stress values demonstrates that there is a rapid transition from the gel to the liquid state. This clearly demonstrates the presence of strong yet fragile gels in the IEF formulated with the ORMP. This implies lesser resistance of the fluid to convert from the gel state to the liquid flow-able state.

Therefore in the field it translates into lower pump pressures required to initiate flow and low or minimized ECD inflections during tripping, running casings and breaking circulations. All these factors contribute to lower induced losses.

6. Environmental performance of ORMP

The ORM was subjected to biodegradability and eco-toxicity studies. The biodegradability and eco-toxicity data of

ORM is given in **Table 5**. ORM was subjected to marine biodegradation assessment by BODIS method where its biodegradation was recorded every week, up to 35 and 45 days respectively. The eco-toxicity studies of ORM were performed in the presence of marine juvenile fish *Cyprinodon variegatus*, marine copepod *Acartia Tonsa* and marine algae *Skeletonema costatum* in seawater. The test methods for *Cyprinodon variegatus* fish are consistent with OECD 203 guideline for marine testing of offshore chemicals. The test methods for copepods *Acartia Tonsa* are consistent with ISO 14669:1999(E) guideline for marine testing of offshore chemicals while the test methods for algae *Skeletonema costatum* were consistent with ISO 10253:2006, OECD guideline as adapted for marine testing of offshore chemicals.

North Sea regulations require an offshore chemical to show a LC50 value of >10mg/L and a biodegradability of >60% to be classified as Yellow – suitable to use in North Sea. ORM additive is North Sea compliant since they not only show an LC50 value greater than 10mg/L for each of the toxicity tests but also show biodegradability in excess of 60%.

Biodegradability and Eco-toxicity tests of ORM enhancer to test its "North Sea" compliance are in progress. However, literature data shows that the ORM enhancer too is readily biodegradable (OECD TG 301B method: 91 % after 28 days) and also has a low potential for bioaccumulation in aquatic organisms (Log Pow = 0.09).

Conclusions

1. Synergism between ORM and ORM enhancer, the constituents of ORMP, resulted in enhanced rheology in 9.0 ppg and 12.0 ppg IEFs formulated at 250°F and 300°F respectively.
2. 12.0 ppg IEFs formulated with ORMP were sag resistant and showed no top oil separation for extended hours of static aging at temperatures of 250°F.
3. 12.0 ppg IEFs comprising ORMP were tolerant to the effect of contaminants. Any deviations from the desired range were easily treated with conventional additives.
4. HPHT rheology studies of 12.0 ppg IEFs show consistent YP and LSYP across a temperature and pressure range
5. 12.0 ppg IEF with ORMP demonstrated strong yet fragile gel character when tested on a Brookfield viscometer.
6. ORMP is environmentally friendly with both the ORM and ORM enhancer being readily biodegradable.

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Nomenclature

BHA = *Bottomhole assembly*
YP = *Yield point*
LSYP = *Low shear yield point*
PV = *Plastic viscosity*
IEF = *Invert emulsion fluids*
ppg = *Pounds per gallon*
ppb = *Pounds per barrel*
LGS = *Low gravity solids*
ECD = *Equivalent circulating density*
OWR = *Oil water ratio*
WPS = *Water phase salinity*
ORM = *Organic rheology modifier*
ORMP = *Organic rheology modifier package*
NOEC = *No observed effect concentration*
LC_{50} = *Lethal dose required to kill 50% of the organisms*

References

1. Bern, P.A., et al. 1996. The Influence of Drilling Variables on Barite Sag. Paper SPE 36670 presented at the SPE Annual Technical Conference, Denver, October 6-9.
2. Maghrabi, S. et Al. 2010. Rheology Modifier for Low Density Invert Emulsion Drilling Fluid. IORS, Mumbai, India, September 9-10.
3. Maghrabi, S. et Al. 2011. Low Plastic Viscosity Invert Emulsion Fluid System for HPHT Wells. Paper AADE-11-NTCE-15 presented at the AADE National Technical Conference and Exhibition, Houston, April 12-14.
4. Okrajni, S.S. and Azar, J.J. 1986. The Effects of Mud Rheology on Annular Hole Cleaning in Directional Wells. *SPEDE* (August) 297-308.
5. Becker, T.E., Azar, J.J. and Okrajni, S.S. 1991. Correlations of Mud Rheological Properties with Current Transport Performance in Directional Drilling. *SPEDE* (Mar) 16-24.
6. Rommetveit, R. and Bjorkevoll, K.S. 1997. Temperature and Pressure Effects on Drilling Fluid Rheology and ECD in Very Deep Wells. Paper SPE/IADC 39282-MS presented at the SPE/IADC Middle East Drilling Technology Conference, Bahrain, November 23-25.
7. Oort, E. et al. 2004. New Flat-Rheology Synthetic-Based Mud for Improved Deepwater Drilling. Paper SPE 90987 presented at the SPE Annual Technical Conference and Exhibition, Houston, Texas, 26-29 September.

Table 1: Mixing order, concentration and mixing time of products

	Mixing time (min)	Fluid 1	Fluid 1a	Fluid 2	Fluid 3	Fluid 3a	Fluid 4
Mud weight, ppg	**--**	**9**	**9**	**9**	**12**	**12**	12
OWR	**--**	**60:40**	**60:40**	**60:40**	**70:30**	**70:30**	70:30
Base oil, ppb	--	As required	As required	As required	As required	As required	As required
Primary emulsifier, ppb	2	8	8	8	10	10	10
Secondary emulsifier, ppb	2	--	--	--	3	3	3
Lime, ppb	2	1.5	1.5	1.5	2	2	2
Filtration control agent, ppb	5	1.5	1.5	1.5	4	4	4
ORM enhancer, ppb	5	**0**	**2**	**2**	**0**	**1.5**	**1.5**
Water phase salinity (WPS) in ppm of $CaCl_2$	5	200,000	200,000	200,000	250,000	250,000	250,000
Inorganic viscosifier, ppb	5	5	5	5	5	5	5
Drilled solids, ppb	5	20	20	20	20	20	20
Baroid, ppb	10	As required	As required	As required	As required	As required	As required
ORM, ppb	2	**3**	**0**	**3**	**2**	**0**	**2**
Hot rolling temperature		250°F	250°F	250°F	300°F	300°F	300°F

Table 1a: Mixing order, concentration and mixing time of products

	Mixing time (min)	Fluid 5	Fluid 6	Fluid 7
Mud weight, ppg	**--**	**12**	**12**	**12**
OWR	**--**	**70:30**	**70:30**	**70:30**
Base oil, ppb	--	As required	As required	As required
Primary emulsifier, ppb	2	11	11	11
Secondary emulsifier, ppb	2	--	--	--
Lime, ppb	2	1.3	1.3	1.3
Filtration control agent, ppb	5	2	2	2
ORM enhancer, ppb	5	**2.5**	**2**	**2.5**
Water phase salinity (WPS) in ppm of $CaCl_2$	5	250,000	250,000	250,000
Inorganic viscosifier, ppb	5	--	--	--
Drilled solids, ppb	5	20	20	20
Baroid, ppb	10	As required	As required	As required
ORM, ppb	2	**1**	**1**	**2**
Hot rolling temperature		250°F	250°F	250°F

Table 2: Performance of ORMP in 9ppg IEF @ 250°F

9ppg 60/40OWR	Fluid 1	Fluid 1a	Fluid 2
600 rpm	54	45	89
300 rpm	33	23	61
200 rpm	25	16	49
100 rpm	18	9	35
6 rpm	8	2	18
3 rpm	7	2	17
PV	**21**	**22**	**28**
YP	**12**	**1**	**33**
LSYP	**6**	**2**	**16**
Gel strength lbs/ft2 10sec/10min	10/20	2/5	19/25
HTHP, ml/30min	2	2	2

Table 3: Performance of ORMP in 12ppg IEF @ 300°F

12ppg 70/30 OWR	Fluid 3	Fluid 3a	Fluid 4
600 rpm	61	73	106
300 rpm	34	37	61
200 rpm	24	25	47
100 rpm	15	14	31
6 rpm	4	2	10
3 rpm	3	2	9
PV	27	36	45
YP	7	1	16
LSYP	2	2	8
Gel strength lbs/ft2 10sec/10min	3/4	2/4	13/25
HTHP, ml/30min (300F)	6	6	2

Table 4: Performance of ORMP in 12ppg IEF after static aging @ 250°F

12ppg 70/30 OWR	Fluid 5	Fluid 5 Static aged @ 250F 24hrs	Fluid 5 Static aged @ 250F 48hrs
600 rpm	100	129	122
300 rpm	66	89	84
200 rpm	53	73	67
100 rpm	37	53	49
6 rpm	12	22	21
3 rpm	10	20	20
PV	34	40	38
YP	32	49	46
LSYP	8	18	19
Gel strength lbs/ft2 10sec/10min	14/34	28/44	27/42
Oil separation,ml		4	4
Sag factor		0.52	0.52
HTHP, ml/30min	2.4	2	2

Table 5: Environmental performance of ORM

Tests		ORM
Biodegradation		66.5% (28days)
		82.1% (35 days)
Skeletonema	72-hr EC_{50}	23mg/l
	72-hr EC_{90}	29mg/l
	72-hr NOEC	15mg/l
Acartia Tonsa	24-hr LC_{50}	>10g/l
	48-hr LC_{90}	
	48-hr NOEC	
Cyprinodon variegatus	48-hr LC_{50}	>10g/l
	96-hr LC_{50}	
	96-hr NOEC	

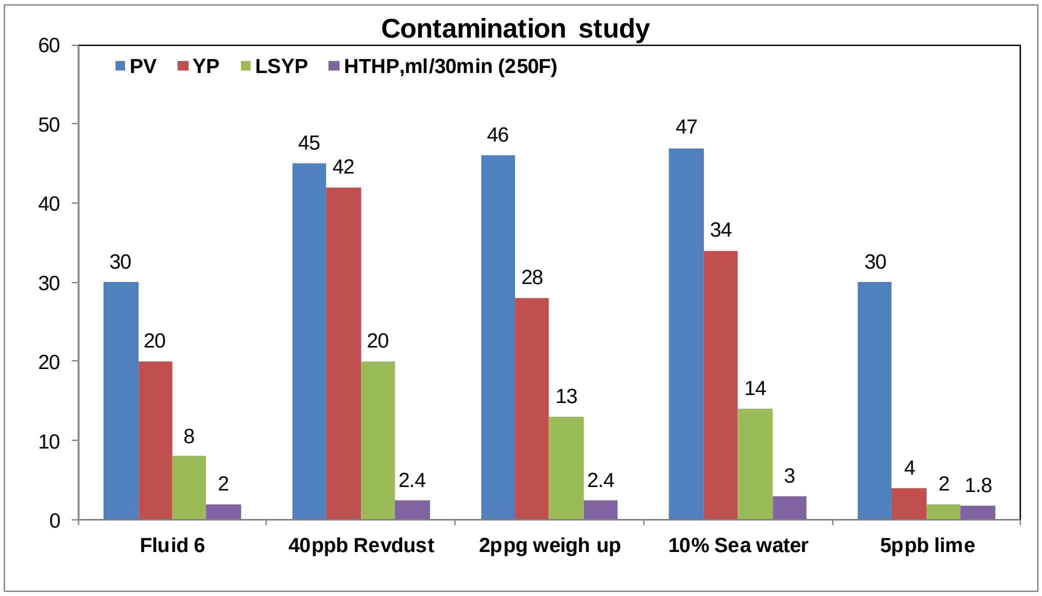

Figure 1: Contamination study of 12ppg IEF

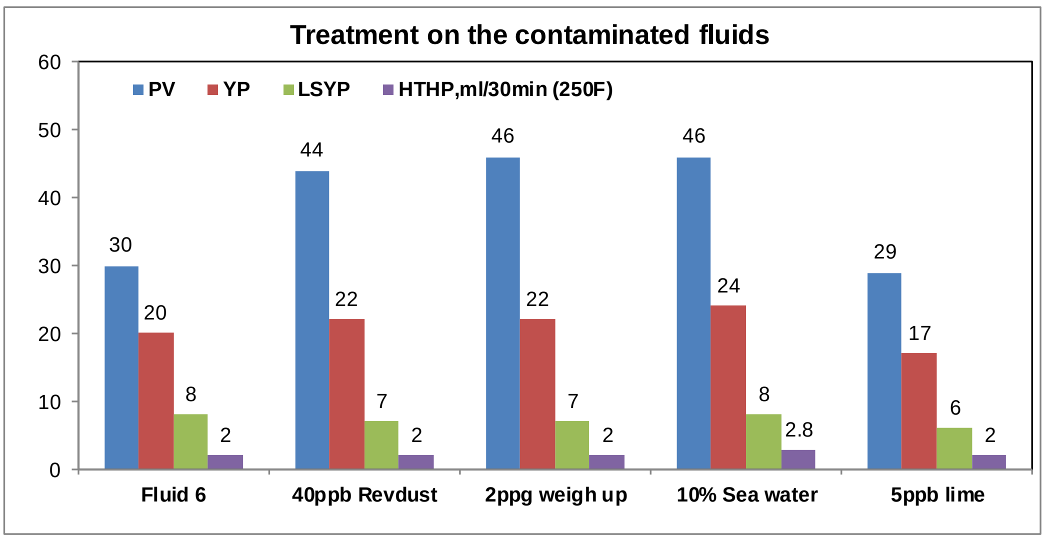

Figure 2: Treatment study of 12ppg IEF

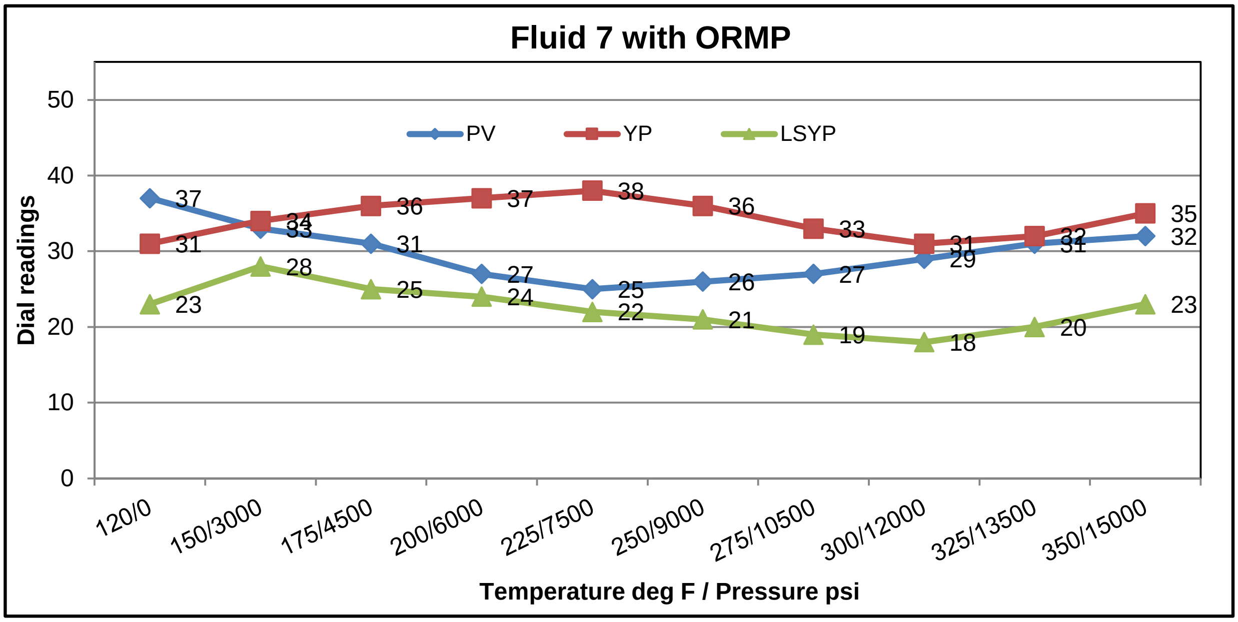

Figure 3: HTHP rheology of 12ppg IEF with ORMP

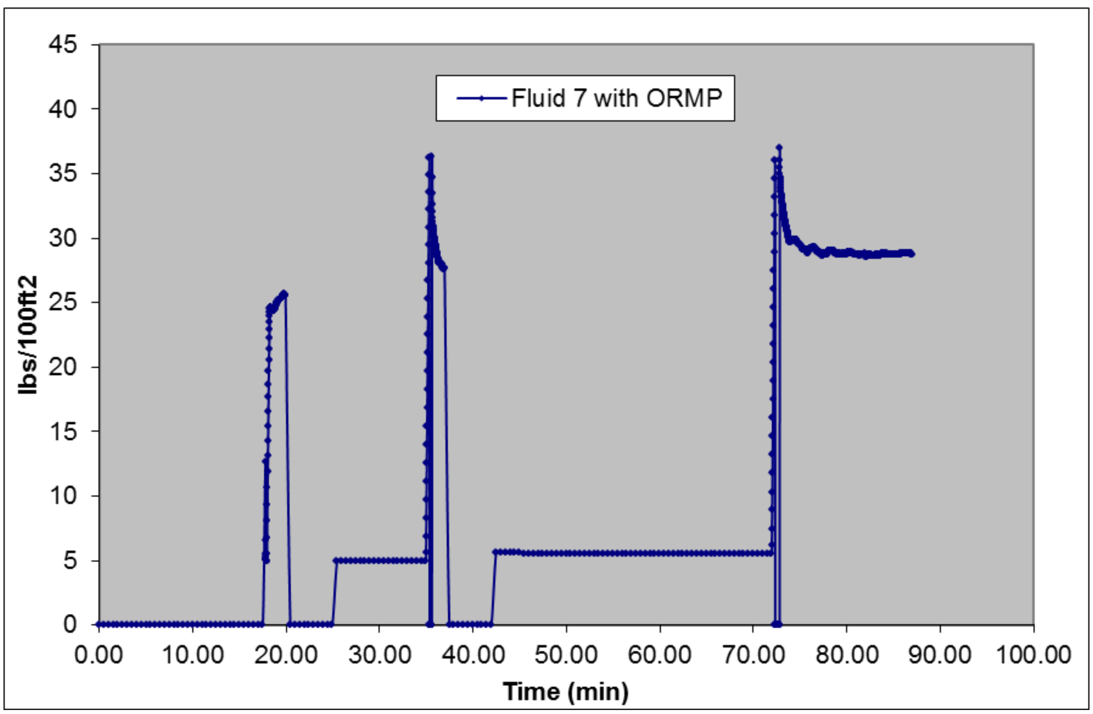

Figure 4: Fragile gel character of 12ppg IEF with ORMP