

Novel Invert Emulsion Gravel-Pack Carrier Fluid for Open Hole Gravel packs

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Abstract

A novel oil-based invert emulsion gravel-pack carrier fluid (IEGPCF) was developed for open hole gravel-pack applications through Alternate Path Technology. Presently only water-based fluids (WBF) are available for such jobs. Gravel-packing with a WBF in an oil-based environment is time consuming, expensive, and presents its own technical challenges. Inefficient displacement of oil-based mud with water-based spacers can be extremely problematic when water sensitive shales are present. The availability of this new oil-based IEGPCF reduces these risks and simplifies logistics. This uniquely engineered oil-based IEGPCF utilizes a novel emulsifier and a polymeric viscosifier to deliver optimized rheological profile and low friction pressure, which is required for shunt-tube gravel-packing applications. After the wells are drilled with synthetic or oil-based reservoir drill-in fluids, gravel-packing with shunt-tubes can be carried out straight away using this novel fluid. This allows the wells to remain in a non-reactive oil-based environment from drilling through completion with a simplified displacement that eliminates fluid compatibility and shale stability issues during gravel-packing operations. This novel fluid uses minimal components to form a very stable invert emulsion with all commonly used brines in oil field, such as Sodium Bromide (NaBr), Calcium Chloride (CaCl_2), Calcium Chloride/Calcium Bromide ($\text{CaCl}_2/\text{CaBr}_2$), CaBr_2 , and Zinc Bromide (ZnBr_2). It is compatible with most mineral oils. By adjusting the oil to brine ratio and the type of brine as internal phase, the density of this solid-free fluid can be formulated from 7.5 to 13.0 lb/gal (ppg). Furthermore, this fluid has excellent gravel suspension capability and minimum gravel-pack damage with low initiation pressure.

Introduction

Gravel-packing is the preferred method for open-hole completions with sanding tendencies, such as horizontal or highly deviated wells in unconsolidated formations. Selection of appropriate gravel-packing operation and gravel-pack carrier fluids is crucial for a successful gravel-pack, especially for the reactive reservoir shales drilled with oil-based reservoir drill-in fluid (OBRDF) (Wagner et al. 2004).

Conventionally, water-based fluids are used for gravel-packing reactive reservoirs drilled with OBRDF. Gravel-

packing with a water-based fluid in an oil-based environment is very challenging due to the incompatibility between water-based fluid and OBRDF. Efficient displacement that can effectively transit the oil-wet environment to water-wet is essential. Inefficient displacement can generate highly viscous emulsions that negatively impact gravel-pack efficiency and well productivity. In addition, the solvent in the transition pills can destabilize the filter cake, which increase the chances for exposure of reactive shales to brine. The undesired swelling, dispersion, and/or collapse of the shales due to its contacting with brine can result in an incomplete gravel-pack. To mitigate all these issues, oil-based gravel-pack carrier fluids have been developed in the laboratory (Price-Smith et al. 2000, Donaldson et al. 2001, and Panamarathupalayam et al. 2009) and successful field deployments have been reported (Aragao et al. 2007, Jones et al. 2009, and Strachan et al. 2016). The benefits of gravel-packing wellbores with oil-based gravel-pack fluids after drilling with OBRDF are:

- Mitigate risks of generating a highly viscous emulsion
- Prevent crossflow fluid compatibility issues
- Eliminate shale stability and dispersion issues
- Reduce overall rig time and fluid costs
- Simplify well site logistics

All the above reported oil-based gravel-pack fluids, however, are Newtonian fluids with low viscosity designed for Alpha/Beta gravel-packing. Those fluids are not suitable for Alternate Path Technology as they don't have the capability to suspend sands or gravels.

This paper presents the successful development of a novel IEGPCF designed for shunt-tube gravel-packing applications. In this work, fluid design and performance evaluation are described, which include fluid rheology profile at different temperatures and pressures, gravel suspension capability at temperature, and gravel-pack retained permeability. In addition, a yard mixing of 25 bbl IEGPCF was performed and friction pressure was measured by passing the fluid through a 120 ft long shunt-tube. The test showed that the fluid met all the requirements for the alternate path shunt-tube gravel-packing applications. Finally, fluid reuse and recycle were also evaluated.

Fluid Design

The basic composition of an IE includes base oil, water/brine, and an effective emulsifier. However, the simple three component IE fluid does not provide the gravel suspension capability required for shunt-tube gravel-packing. An effective oil phase viscosifier that can generate micro-network structure is needed to achieve the desired gravel suspension. The challenge to develop such a fluid for gravel-packing through shunt-tube is to find the right balance between fluid rheology (gravel suspension) and friction pressure, that is, the fluid needs to be viscous enough to suspend the gravels and meanwhile the pumping pressure does not fracture the formation.

To achieve the desired gravel suspension capability, introduction of sufficient micro-network structures into the continuous oil phase of the emulsion is essential. The reflection of the presence of micro-network structure is low shear rate viscosity of the fluid. Based on our laboratory experience, for this particularly designed fluid, a viscosity of minimum 1000 cp at 5 s^{-1} at BHST and pressure is essential to achieve the required gravel suspension. A novel oil dispersible polymer was identified to be able to form the micro-structure that provides the desired gravel suspension. The application temperature of the final IEGPCF is up to 210°F .

In addition to the primary emulsifier which stabilizes the IE fluid, a secondary emulsifier/viscosity modifier was also used to boost the low-shear rate viscosity (LSRV) and reduce the high-shear rate viscosity. Addition of this additive reduces the concentration of polymer and thus minimize the friction pressure while maintaining its gravel suspension capability.

The external continuous oil phase can be any mineral oil or synthetic oil with low aromatic content.

The internal brine phase was utilized to provide desired fluid density. The requirement on density is met by selecting the right brine and by adjusting oil to brine ratio (OBR). The Oil-brine volume ratio should be within 40/60 – 60/40. If OBR is too high, it is difficult to reach the desired fluid density. On the other hand, if OBR is too low, the emulsion can become too viscous (high rheology due to the high amount of internal phase droplets), yet with no improvement on gravel suspension capability. Various brines such as NaBr, CaCl_2 , $\text{CaCl}_2/\text{CaBr}_2$, CaBr_2 , and ZnBr_2 have been tested and qualified as internal phase to form stable IE. The maximum density of IEGPCF can be as high as 13.0 ppg. All the data presented in this paper is for a 10.8 ppg IEGPCF using CaBr_2 as internal phase with OBR set at 45/55.

Performance Evaluations

Performance evaluations on rheology profiles, gravel suspension, and gravel-pack retained permeability have been conducted.

Fluid Rheology

Fluid rheology profile for a typical IEGPCF was measured at different temperatures and pressures with a Grace M7500 rheometer using a cup and bob geometry. The pressure and

temperature effect on fluid rheology are shown in Figures 2 and 3, respectively. As observed, to achieve the desired low shear rate viscosity, the high shear rate viscosity of this IEGPCF is much higher than that of conventional single-phase water-based systems such as VES or Xanthan viscosified fluids.

It is obvious to see that pressure and temperature have counter effects on the fluid rheology. This implies that increase in downhole pressure can overcome the thinning effect due to the increase in temperature as illustrated in Figure 4.

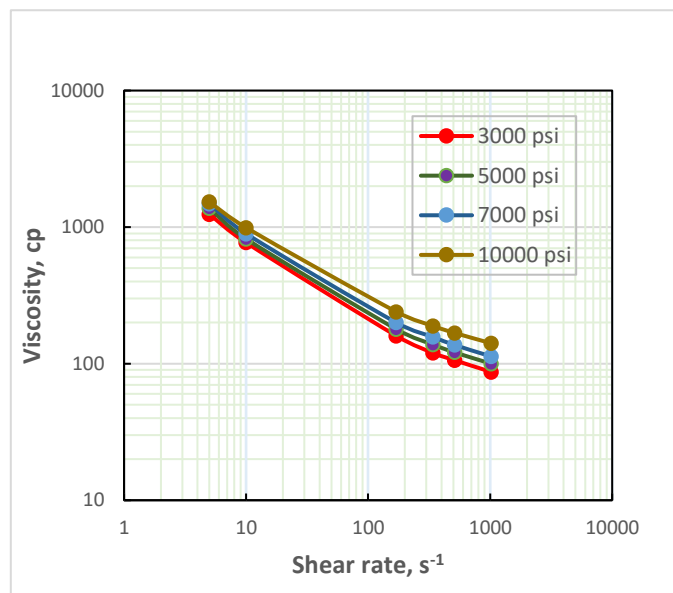


Figure 2. Pressure effect on fluid rheology at 200°F

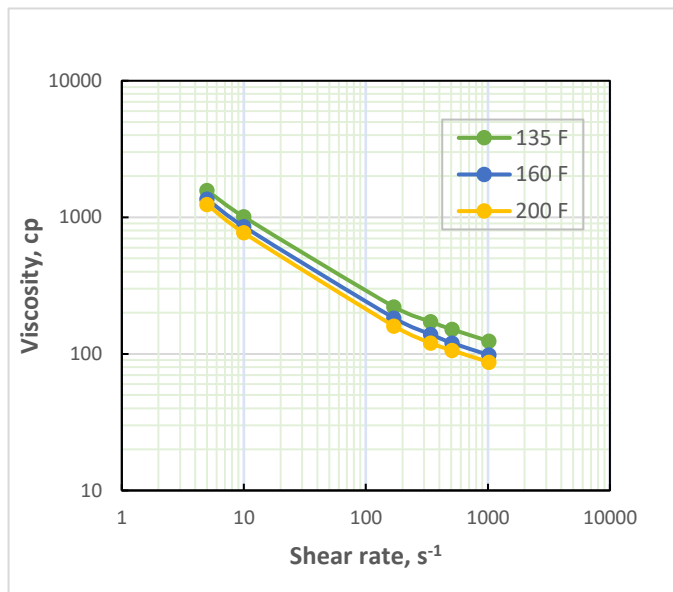


Figure 3. Temperature effect on fluid rheology at 3000 psi

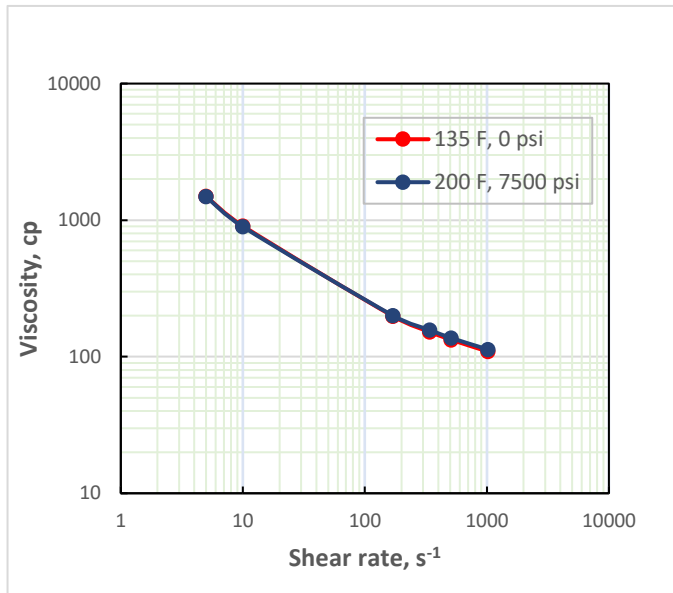


Figure 4. Counter effects of pressure and temperature on fluid rheology

Static Gravel Suspension

One of the key performance requirements for IEGPCF for Alternate Path Technology is that the percentage of gravel settling (%GS) should be less than 20% settling in 30 minutes at the bottom hole static temperature. The equation below is used for the calculation of %GS.

$$\%GS = \frac{V_{MCF}}{(V_T - V_G)} * 100$$

Where V_{MCF} is the measured volume of clear fluid on top of the slurry

V_T is the measured total volume of slurry

V_G is the bulk volume of gravel and calculated by

$$V_G = \frac{1.6667 \times V_T \times C}{C + (SG_G \times 8.34)}$$

Where C is the concentration of the gravel in ppa (pounds per gallon added)

SG_G is the specific gravity of gravel

Table 1 shows the static gravel settling test results for a typical IEGPCF after 30 minutes at 135 °F. The tests were conducted with 40/70 and 30/50 mesh Econoprop gravels at 6 ppa concentration. As shown in the table, the fluid can successfully suspend both size of the gravels with the %GS being only 4.1 in both cases.

Table 1. Gravel settling test results for a typical IEGPCF

Gravel size	30/50 gravel	40/70 gravel
%GS	4.1	4.1
Picture after 30 minutes At 135 °F		

Gravel-pack Retained Permeability

Gravel-pack retained permeability is another key requirement that clients expect to be evaluated. The retained permeability after extended shut in at test temperature was measured using an in-house built setup as shown in Figure 5. Assembled gravel-pack is sealed in the hassler cell and connected to an accumulator. A piston inside the accumulator separates it into two parts. Top part is for the testing fluid or baseline and is connected to the gravel-pack. The bottom part is connected to an ISCO pump A containing DI water, which provides hydraulic force to push testing fluids in the top part through the gravel-pack. ISCO pump B is connected to hassler cell and provides confining pressure for the gravel-pack by pumping water to the hassler cell.

Table 2 shows the test result for a typical fluid under the following test conditions:

- 40/70 Carbolite gravels
- 9 inches in length gravel-pack
- 1000 psi confining pressure
- 7 days shut-in at 140 °F

Retained permeability (%) is calculated with the equation below:

$$\text{Retained permeability (\%)} = \frac{\text{Final permeability}}{\text{Initial permeability}} * 100$$

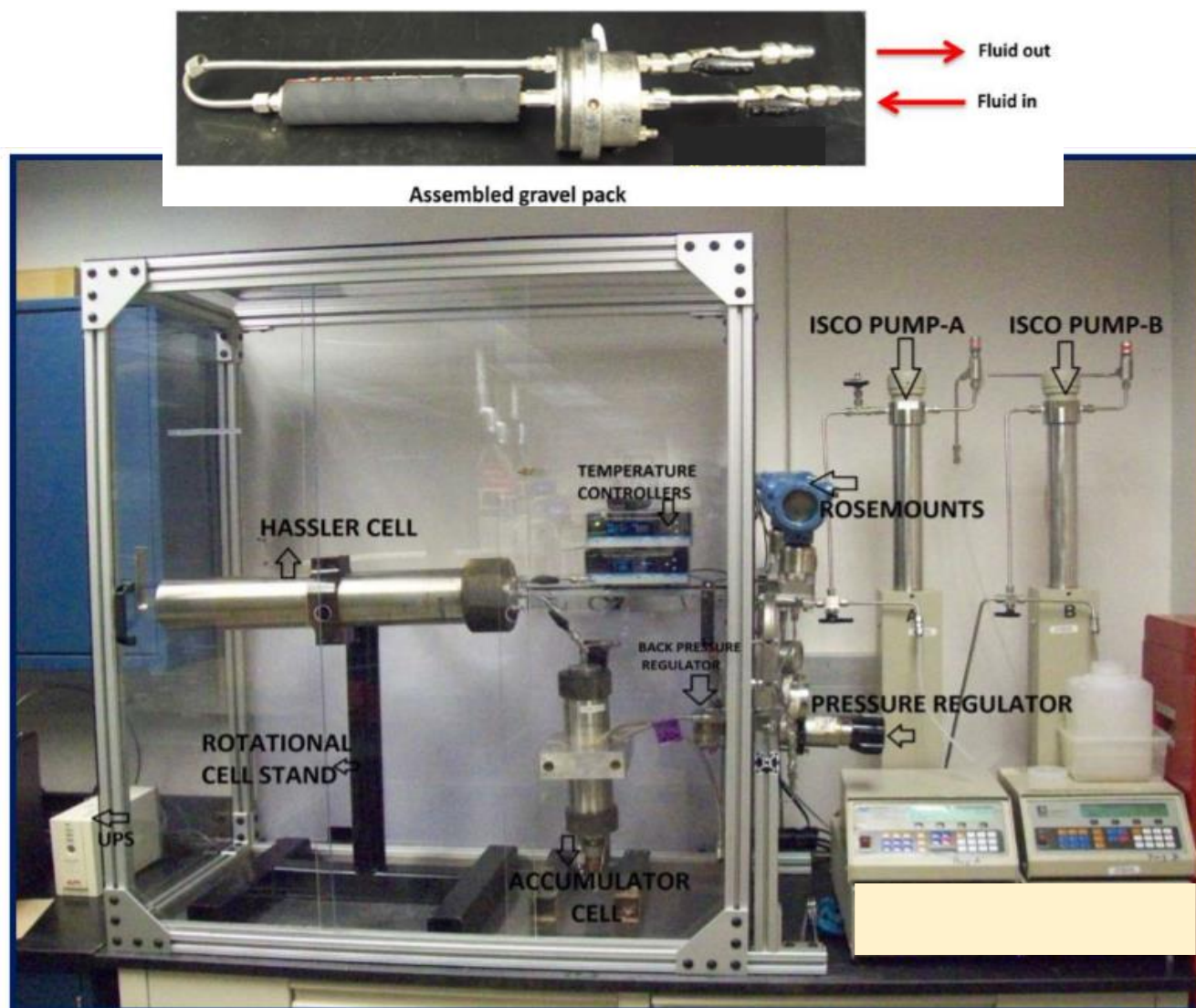


Figure 5. Image shows the setup for gravel-pack retained permeability test

Initial permeability was measured with base oil at 140 °F by injecting the base oil through fresh gravel-pack, then 2 pore volumes of IEGPCF was injected through the gravel-pack and the system was left static shut in at 140°F for 7 days. The final permeability was measured with the base oil after 7 days shut in and post-flush the gravel-pack with the same base oil.

Retained permeability (%) equal or greater than 60% is usually considered acceptable. An 80% retained permeability is considered good. As seen in the Table2, the retained permeability for the tested fluid is approaching 80%.

Table 2. Retained permeability results for a typical fluid

Flow rate (ml/min)	Permeability (mD)		Retained Perm (%)
	Initial	Final	
35	30997	22343	72
25	28375	22858	81
15	32446	25065	77
10	31779	23866	75
5	28841	21728	75
Average	30488	23172	76

Yard Test with Batch Mixing

A batch of 25 bbls of 10.8 ppg IEGPCF (45/55 oil-brine ratio) was mixed in a yard test. Large quantities of fluid like base oil and brine were added to the mixing tanks by draining the fluids to the mixing tank. Other additives were added in through the vortex hopper. After addition of all the additives and sufficient circulation time, the mixture was pumped passing

through a shearing unit. The high shear helped with the full yielding the polymer (viscosifier) and generating a highly uniform emulsion. Table 3 shows the details of mixing procedure.

Table 3. Example for mixing 25 bbls of 10.8 ppg IEGPCF

Order of Addition	Function	Mixing Time (min)	Comments
1. Mineral oil	Base oil	0	
2. Polymer	viscosity	30 -60	High shear/heat is required to fully yield the polymer into base oil.
3. Primary emulsifier	emulsification	10	Readily soluble in oil. Short time mixing/circulating is sufficient to homogenize it into the base fluid.
4. Secondary emulsifier	Rheology modification	10	Same as primary emulsifier
5. Brine	Density	30 -60	Add brine in controlled manner to the oil, apply strong mixing or circulating to help disperse brine into small droplets.

This mixing pilot test verified that the IEGPCF can be successfully batch mixed with sufficient shearing and it meets all the targeted requirements.

Yard Test for Friction Pressure Measurement

A full-scale yard test was performed in view of measuring friction pressure by pumping IEGPCF through a 120 ft long shunt tube. Two pressure transducers were mounted onto the shunt tube separated by a distance of 100 ft. The pressures at those two points were monitored and recorded throughout data acquisition. Fluid was pumped through the shunt tube and returned to a catching tank for QC check or to mixing tank for further circulation. During the circulation mode, the fluid was pumped at various pumping rates and stayed at each rate till the friction pressure stabilized. Firstly, the pumping rate ramps up from zero to approximate 4 bpm, then the pumping rate ramps down at the same pumping rate points back to zero. Curves of friction pressure versus pumping rate for ramping up and down overlap each other as shown in Figure 6. Also, rheology profile of the fluid are the same before and after the pumping. Those prove that the fluid is robust to high shear and the emulsion is very stable.

Figure 6 shows the yard test results of friction pressures for the batch mixed IEGPCF from the yard mixing. The friction pressures for a 10 ppg pure brine and a 9.5 ppg IE were also

plotted for comparison. IE is a simple invert emulsion with no viscosifier at OBR of 30/70, which is very viscous but poor in gravel suspension. As seen in the figure, the friction pressures at different pumping rates for the IEGPCF follow a near-straight line within the measured pumping rate range and are slightly higher than those of the pure brine. However, the simple IE exhibits much higher friction pressure even at low pumping rate.

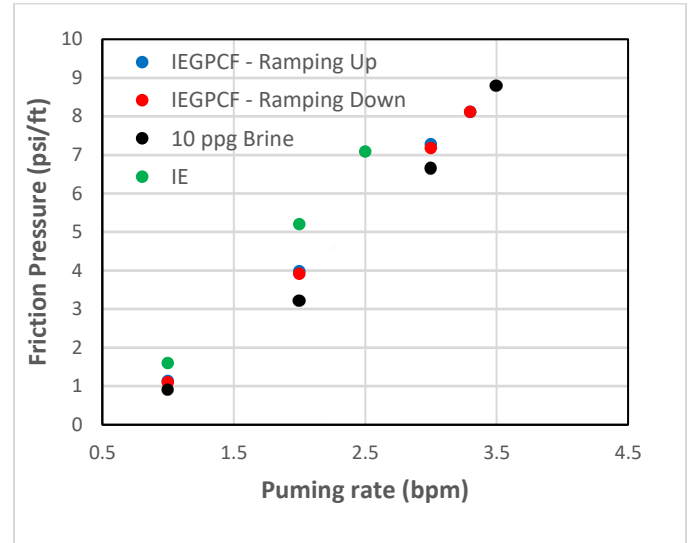


Figure 6. Friction pressures for different systems

Reuse and Recycle

There are two options for handling this IEGPCF after a gravel-pack operation: reuse as gravel-pack fluid or recycle fluid into oil-base drilling mud.

Reuse as Gravel-Pack Fluid

It has been verified that the IEGPCF is very stable and can be reused as gravel carrier fluid after removing the solids from the slurry. If viscosity of the fluid prevents the effective removal of solids including gravel, the fluid can be diluted by base oil to reduce its viscosity, for example by 10 -15% dilution. Once the viscosity decreases, the gravel settles down and the solids can be easily removed. Before reuse, the fluid needs to be reconditioned back to its original formulation and should pass all fluid quantification tests.

Recycling Fluid into Oil- Base Drilling Mud

Another way to reuse the fluid after gravel-pack is to recycle the fluid into the oil-base mud. It has been tested that the fluid was compatible with oil-base muds (OBM) and the impact on drilling mud properties is negligible if the blending ratio of IEGPCF to OBM was controlled at less than 1:5. Table 4 shows the rheology of a 16.0 ppg OBM and mixture of IEGPCF and OBM at different blending ratio. As can be seen, the change of rheology at ratio of 1:5 (IEGPCF:OBM) is insignificant.

Table 4. Rheology of an OBM and blend of it with IEGPCF

Fann 35 reading @ 150°F	Pure Mud	10.8 ppg IEGPCF: 16.0 ppg OBM		
		1:10	1:5	1:1
600 rpm	99	104	100	132
300 rpm	55	55	55	72.5
200 rpm	39	40	39	52.5
100 rpm	24	24	24	31
6 rpm	7	6.5	6	5
3 rpm	6	5.5	5	3.5
ES	851		653	151

Conclusions

- A novel invert emulsion gravel-pack carrier fluid was developed for open hole gravel-packing application with Alternate Path Technology.
- A novel polymer was identified as an oil viscosifier to provide gravel suspension.
- A secondary emulsifier was introduced to boost the low-end rheology.
- Majority of the commonly used field brines can be used as internal phase.
- IEGPCF poses minor damage to the gravel-pack, greater than 75% retained permeability was obtained.
- Large scale yard mixing verified that the IEGPCF can be batch mixed with sufficient shear.
- Friction pressure measured in yard test verified that the fluid can be safely implemented in the field.

Nomenclature

ppg = Pound Per Gallon

BHST = Bottomhole Static Temperature

bpm = Barrel Per Minute

bbl = Barrel

ft = Feet

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