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Novel polymer chemistry increases shale stability

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Abstract

While water-based drilling fluids intrinsically offer environmental advantages over invert emulsion fluids, the performance deficiencies of conventional aqueous systems historically restricted their application in the more technically demanding applications. This shortcoming is particularly evident when encountering complicated and highly reactive shale formations, where ensuing low rates of penetration and the risk of serious hole problems could jeopardize the economics of a drilling program.

This paper describes the development and application of a uniquely engineered polymer that has demonstrated enhanced shale inhibition properties, thus allowing water-based drilling fluids to be used in applications previously reserved for invert emulsion fluids. The additive has been applied successfully in all water-based fluid systems to inhibit swelling and dispersive shales, while also providing the environmental advantages of a conventional aqueous system.

The authors will describe the development and unique properties of the additive and its successful application throughout many areas of the world. The case studies presented will document how the new polymer has made water-based drilling fluids more cost-effective in both vertical and extended reach wells drilled offshore and on land.

Introduction

The drilling industry is always driving towards improving the performance of the drilling process in an economical and environmentally attractive way. One such route is by using the best drilling fluid products available. Newly developed ingredients, included as components in existing fluid types, can often give step increases in performance of both water based (WBM) and Oil based (OBM) drilling fluids.

Since 1947 Carboxy methyl cellulose (CMC) has been used in various WBM as a viscosifier or as a fluid loss reducer. Initially CMC was used to stabilize WBM loaded with clay particles, the molecular weight of the CMC molecule determining the amount of viscosity contribution given. Later the interaction of the CMC molecule with clays was further investigated, and the anionic character of the molecules was altered to impart some level of shale inhibition – this resulted in the polyanionic cellulose (or PAC) polymers used widely in many WBM today.

In this case, CMC technology was again revisited, and modifications to the original Carboxy Methyl Cellulose molecule were made which resulted in an interesting application for water based drilling fluids. This research resulted in a highly versatile product that combines efficient shale inhibition properties with viscosity and filtration control in a wide variety of WBM formulations.

In this paper the results obtained from extensive research demonstrate that it is still possible to make modifications to CMC chemistry, yielding improved performance effects, even though the basic molecule was synthesized in 1930.

Polymer development

Oil based (OBM) and synthetic oil based (POBM) muds have been a subject of heavy discussion over the last few years, in particular regarding the negative effects of discharging such fluids to the environment. The superior drilling performance of such non-aqueous fluids has been well documented, showing ideal shale inhibition and chemical wellbore stability, coupled with high ROP, good levels of lubricity, and lower risk of stuck pipe. The application of water based fluids has generally been carried out when concerns are associated with the use of invert emulsion fluids such as poor logistics, high risk of lost circulation, and environmental compliance concerns and economics. The target for a fluid formulation based on a new product was to enhance the shale inhibition performance of water-based mud to approach the same levels as with OBM or POBM.

On reviewing the existing CMC chemistry, it was believed that the inhibition of cellulosic materials could be boosted. Shale inhibition can be approached in a number of ways; principally the design of a properly inhibitive fluid should take in to account prevention of both shale hydration and shale swelling. The design of previous inhibitive WBM's have taken various approaches to solving these complex inhibition issues. With the developed polymer, the principle of the design was to create a polymer which would form a kind of film over the clay surface to regulate the fluid transfer processes which can take place when clays come in contact with water and exchangeable ions. The protection given to the shale by the polymer will be augmented when combined with other ingredients such as potassium ions and other more conventional inhibitors such as glycols.

In the development of the new polymer a combination of two basic chemical components and sodium carboxy methyl cellulose leads to the product developed exhibiting a dual drilling fluid function. The CMC component provides fluid loss control, and the additional chemistry incorporated in the molecule allows a loose bonding to shale of the CMC polymer providing a level of shale inhibition. Environmental acceptability was a key criteria considered from the beginning of the development and all components used in the reaction to obtain the new polymer are listed in the PARCOM-list A as safe to use chemicals and have been widely used for many years in the oil industry. The complex polymeric structure (see figure 1) is able to coat both cuttings and the borehole wall to ensure optimum fluid inhibition performance and wellbore stability. Selection of the correct molecular weight of CMC to be used for the final polymer was critical in the development such that the final product provided adequate filtration control and shale inhibition, without giving excessive viscosity which could compromise overall drilling fluid design

Once formulated, extensive laboratory work was undertaken to produce a number of fluid formulations, and to evaluate the polymers performance – the results being fed back into producing a better performing end product.

Laboratory evaluation

Initial investigation into the performance of the new polymer centered round its performance as both a shale inhibitor and as a filtration control additive. Various base fluid formulations were utilized from deionised water through seawater and Potassium Chloride (KCl) to saturated Sodium Chloride. In each case the performance of the polymer was compared to a conventional CMC polymer, and to PAC polymer.

Shale inhibition testing was carried out using two different shale substrates (raw Wyoming bentonite, and native outcrop clay from Norway – Foss Eikeland clay). The XRD and CEC values for these substrates are shown in table 1.

The level of shale inhibition was determined using three test methods – hot roll/dispersion, Slake durability, and bulk hardness tests. These test methods are outlined in appendix 1. In this initial evaluation stage it was recognized that viscosity could contribute to the shale inhibition results obtained. Every effort was made to adjust fluids to the same viscosity – using a Yield point (YP) of c.20 lbs/100ft2 @ 50C as the control value, and adjusting viscosity's to this level with Xanthan Gum polymer. Each test polymer was added to the base brine solutions at a concentration of 3 ppb. Summaries of the initial evaluation results are shown in figures 2 – 6.

These initial results indicated the potential of the new polymer as an improved shale inhibitor as well as an effective filtration control additive. Further laboratory work was then undertaken to fine-tune fluid formulations to allow potential field applications of the polymer, and to determine the compatibility of the polymer with other water based drilling fluid additives – particularly those additives used for viscosity control, and for supplementary shale inhibition.

Potassium polymer fluids

Environmental, health and safety regulations in the North Sea area are restricting the use and discharge of partially hydrolyzed polyacrylamide (PHPA) polymers. These were traditionally used in conjunction with KCl as effective shale encapsulating polymers. The new polymer was tested as a potential environmentally acceptable replacement for the PHPA polymers in KCl based drilling fluid. Comparative results are shown in figure 7.

From these results it can be seen that the new polymer performs better than the PAC polymer containing blank, but does not provide the same level of shale inhibition given by the PHPA polymers. During this study, however, it was noted that the new polymer appeared to give a better performance when used in combination with xanthan gum polymer, the latter being used for viscosity control. This was further investigated by varying concentrations of xanthan gum and the new polymer in a KCl base – the results (see figure 8) confirming the initial findings – i.e. xanthan gum appears to have a synergistic shale inhibition effect in combination with the new polymer.

One of the initial potential applications of the new polymer was to be for a land well in central Europe. In this situation, drilling "waste" (excess drilling fluid and fluid contaminated cuttings) can become a critical issue in well economics, as "waste" which contains chloride levels in excess of 2000 mg/l is highly expensive to dispose of, with only very few disposal site suitable for handling such material. Alternative, chloride-free, sources of potassium were tested along with the new polymer to allow for reduced disposal costs. The results of these tests are shown in figures 9 - 10. From this evaluation, potassium Carbonate (K_2CO_3) was chosen as the best alternative both from a performance and cost standpoint.

Glycol and Silicate fluids

KCl/Glycol and KCl/Silicate fluids are commonly used in many areas to control highly water sensitive shales, and to provide alternatives to OBM and POBM for drilling such formations and demanding extended reach wells through formations which have proven troublesome with less inhibitive WBM. Commonly these fluids use PAC polymer or a PAC/Starch polymer combination to control fluid loss and give improved fluid inhibition properties. The new polymer was introduced into these fluids, and compared against the currently used polymers to investigate any potential improvements in inhibition performance, and any potential fluid compatibility issues. The results of these tests are shown in figures 11 – 13).

From these results it can be seen that the new polymer enhances the shale inhibition of the KCl/Glycol fluids, particularly in more dispersive (Foss Eikeland) shale types. Little difference was seen with the Silicate fluids, which exhibit very high levels of shale inhibition initially. No direct incompatibilities were observed, however filtration levels were higher with the new polymer when compared to equivalent concentrations of PAC polymer.

PHPA fluids

As discussed earlier, PHPA polymer has been included in a number of fluid formulations to provide shale encapsulation. The new polymer was tested in conjunction with PHPA in a number of fluid formulations to determine whether the shale inhibition properties of these fluids could be enhanced. Freshwater, seawater, and saturated saltwater PHPA fluids were evaluated, substituting the conventionally used PAC polymer with the new polymer. The results of these tests are summarized in figures 14-15.

As previously seen with polymer/KCl fluids, the new polymer shows significant improvements in inhibition with both shale types and in all types of fluid.

Field Applications

Based on the extensive development and laboratory evaluation work carried out, a number of field applications of the new polymer have been conducted spanning a variety of areas globally. These field applications have seen use of the polymer for drilling a wide variety of formation types, and use in a wide variety of water based drilling fluid types. Outlined below are summaries of some of the areas of the polymer application, and the results achieved with the use of this polymer.

Central Europe

For its initial field trial, the new polymer was applied in a K_2CO_3 polymer mud. The purpose of this fluid formulation was to generate cuttings and fluid waste with low chloride content, whilst maintaining good shale and wellbore inhibition, coupled with low dilution rates to minimize disposal volumes. Drilling was conducted in a directional well through a dispersible shale type with low content of swelling clays, the formations being tectonically stressed. The test well was drilled successfully, showing a reduction in bbl/ft dilution of 15% compared to offset KCl/PAC fluids. In addition to the drilling performance, the fluid was designed for a trial with cuttings recycling. Contaminated cuttings from the well were taken to a brick making factory, a ceramics factory, and a cement kiln, to determine the potential for using the contaminated cuttings as a feed material in these industries. This re-use project showed good compatibility of the fluid contaminated cuttings, giving future options for a “no waste” concept of drilling in this area.

North Sea

In a number of North Sea wells, the new polymer was applied in KCl/Glycol fluids for drilling highly water sensitive shale sections in extended reach wells, in both 17 ½” and 12 ¼” hole sections. Improved cuttings condition was observed when compared to offset wells drilled with conventional KCl/glycol fluids, particularly through areas of more dispersive shales (see Picture 1). Fluid dilution rates were reduced by 10 – 18% compared to offset wells, and fluid cost/ft was reduced by an average of 17%. Previously observed problems with slower ROP through the dispersive shales were not observed when using the new polymer formulated fluid.

The Gulf of Mexico

In the Gulf of Mexico a seawater/PHPA fluid had been used on previous wells, the new polymer being added in place of PAC polymer in the same fluid formulation to improve wellbore stability and shale inhibition. Cuttings condition was reported as being improved, and dilution rates were reduced by 12% from offset wells.

Irish Sea drilling

In the Irish Sea the 17 ½” hole section was drilled with a KCl/Xanthan/PAC/New polymer system. The section was drilled trouble-free through highly water sensitive shales, the new polymer contributing to a reduction of 20% in fluid cost/ft when compared to an offset well drilled with a similar KCl/PAC fluid.

Rocky Mountains drilling
In the Rocky Mountain area, tectonically stressed and highly dispersive clays have created problems with drilling fluid design for many years. This coupled with ever increasing environmental demands to reduce harmful discharges. The new polymer was used in freshwater/PHPA fluids, replacing PAC polymer used on previous wells. Some improvement in cuttings condition was observed, and fluid dilution rates were reduced by 5 – 10%.

Latin America wells
In a number of areas the new polymer has been applied in PHPA, KCl/Glycol, and LMW amine inhibitive fluids. In all cases improvements in shale stability, and reduction in dilution rates have been observed. Drilling fluid cost/ft reductions of up to 19% have been recorded when compared to offset wells drilled with similar fluid systems without the new polymer.

Discussion
Based on the basic structure of the CMC/PAC molecule functional groups were added resulting in a new molecule, described in various patent applications. The newly manufactured polymeric product has “arms” functioning as contact points to react and link with the anionic groups of other polymers and clay structures, thus providing enhanced shale inhibition and synergy with other polymer types.

The new polymer has been thoroughly evaluated both in laboratory and field, showing measurable benefits in shale inhibition. Initial testing of the first version of the polymer indicated unacceptably high viscosities and poor filtration control. The current version of the polymer (that applied in the field and used for the laboratory work) was manufactured at a reduced molecular weight, overcoming these initial issues. The viscosity contribution can be seen as similar to a Low viscosity PAC polymer.

The developed cellulose based polymer provides a cost-effective addition to currently used WBM formulations, without compromising environmental discharge restrictions. Although the filtration control is not as tight as equivalent concentrations of PAC polymer, this does not appear to have any negative effects on shale inhibition nor drilling performance. In some cases, where tighter fluid loss control has been required, the new polymer has been used in conjunction with low or extra low viscosity PAC polymers and starches to minimize filtration and reduce filter cake thickness.

Conclusions
A new polymer, derived from environmentally friendly CMC chemistry has been shown to be effective in improving the shale inhibition of existing water based drilling fluids without adding to the overall drilling fluids cost. The additional shale protection supplied by the new polymer has resulted in reduced drilling fluid dilution rates, reduced drilling fluid costs, reduced drilling fluids related problems, and reduced environmental discharges.

The new polymer has shown its versatility in application, being used for both supplementary shale inhibition and fluid loss control in a number of different drilling fluid formulations and in a number of different global drilling areas.

Appendix – Shale inhibition test methods

Hot roll/dispersion Test
The hot roll/dispersion test is designed to give an assessment of the inhibition of shale cuttings exposed to a drilling fluid. The test involves placing a measured quantity of sized shale cuttings in to 350 ml of fluid in a roller oven cell, the rolling the fluid/cuttings for 16 hours at 150F. Following the aging period the cuttings are screened from the fluid and gently washed with brine water, prior to being dried and reweighed. The amount of cuttings recovered is used as a measure of the inhibitiveness of the fluid.

Bulk Hardness Test
The bulk hardness tester is a device designed to give an assessment of the hardness of shale cuttings exposed to a drilling fluid. The hardness of the shale cuttings relates to inhibitive properties of the fluid being evaluated. In this test, shale cuttings are hot rolled in the test fluids for 16 hours at150°F. After hot rolling, the shale cuttings are recovered on a screen, washed with brine and then placed into the bulk hardness tester. Using a torque wrench the cuttings are extruded through a plate with holes. Depending upon the hydration of the cuttings, the torque may reach a plateau region or may continue to rise during the extrusion. The harder the cuttings, the higher the torque reading and the more inhibitive the mud system.

Slake Durability Test
The Slake durability test is similar to the hot rolling dispersion test but it provides a harsher, more abrasive environment. The evaluation consists of placing a known quantity of sized shale cuttings into a round cage immersed in a test fluid container. Then the cage with cuttings is rotated for a period of 4 hours. During rolling, the exposed cuttings can break up and disperse, and will pass through the cage screen. The cuttings remaining in the cage after the test period are washed, dried and weighed. The percent recovery of shale cuttings is calculated.

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Picture 1 – Picture of shale cuttings drilled with new polymer fluid and K2CO3, showing bit marks on overall large, well inhibited cuttings.

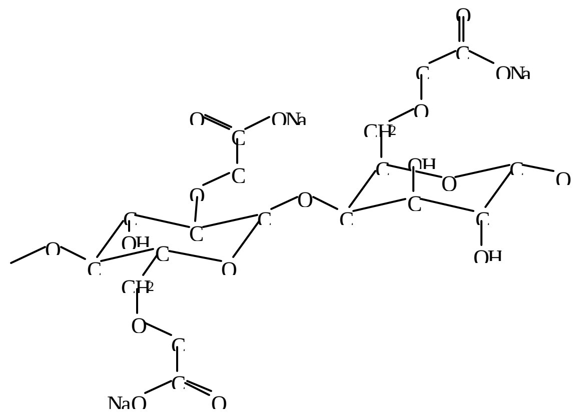

Figure 1 – Basic CMC chemical structure

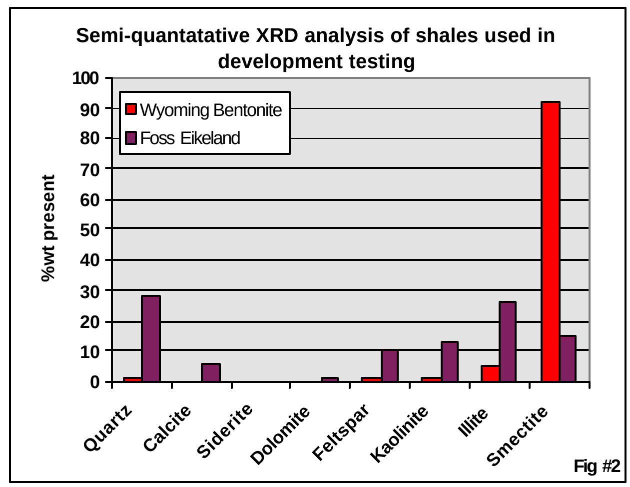

Figure 2 – XRD analysis of test clays

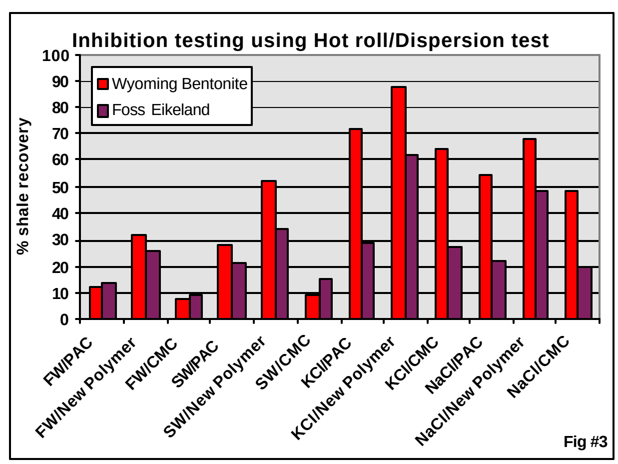

Figure 3 – Initial Shale inhibition test comparison.

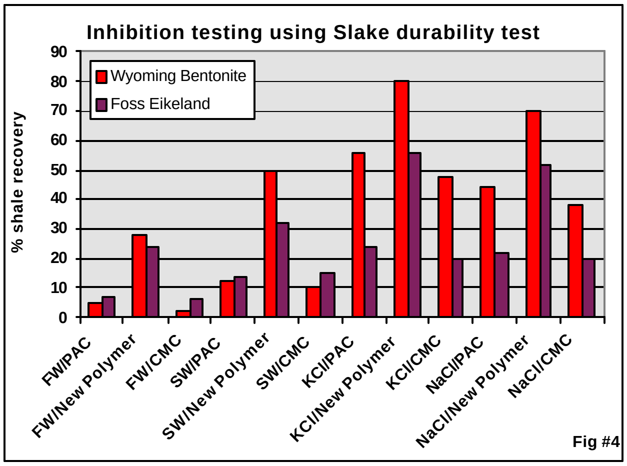

Figure 4 – Initial Shale inhibition test comparison.

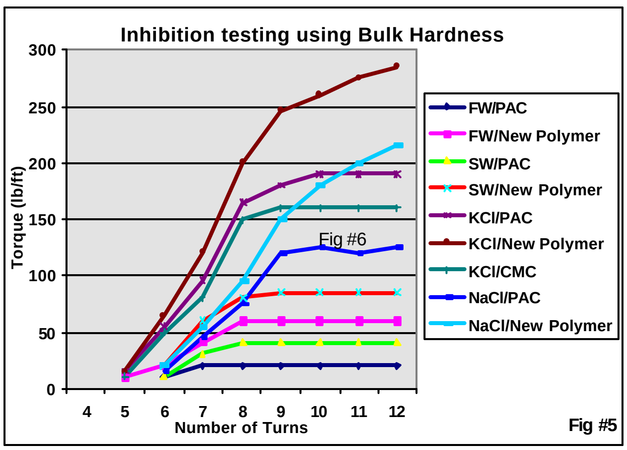

Figure 5 – Initial Shale inhibition test comparison.

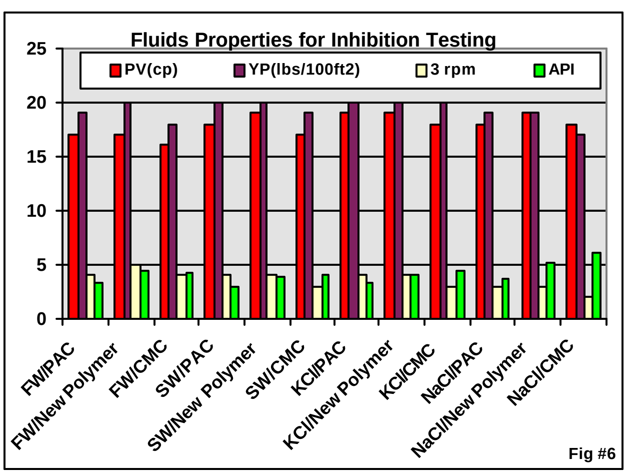

Figure 6 – Initial Fluid properties comparison.

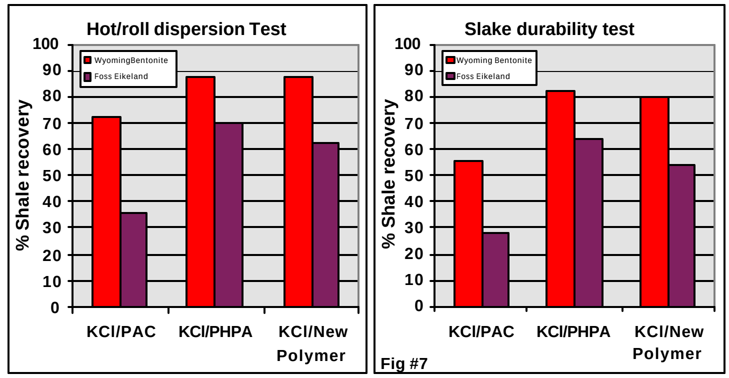

Figure 7 – Shale inhibition test comparison with KCl/PHPA and KCl/PAC fluids formulated at 1.20 sg.

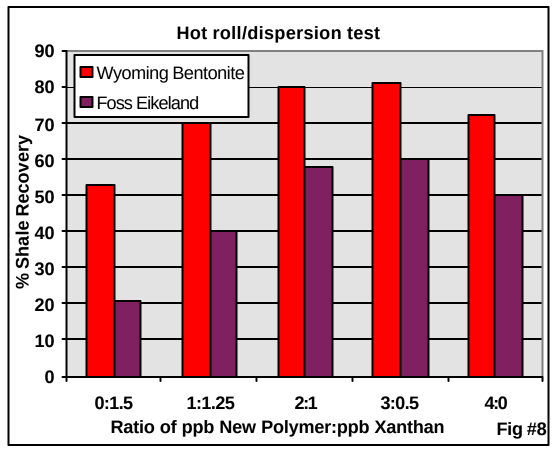

Figure 8 – Effect of Xanthan to new polymer ratio on shale inhibition in 35 ppb KCl fluid.

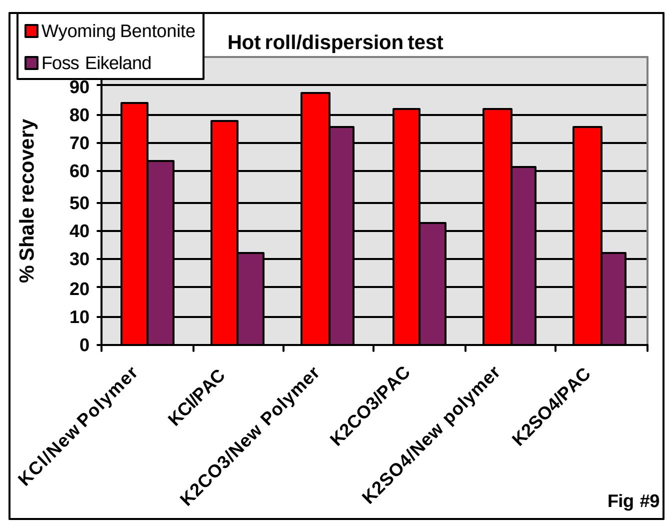

Figure 9 – Comparative shale inhibition of new polymer in various potassium base fluids (15 pb equivelant K+).

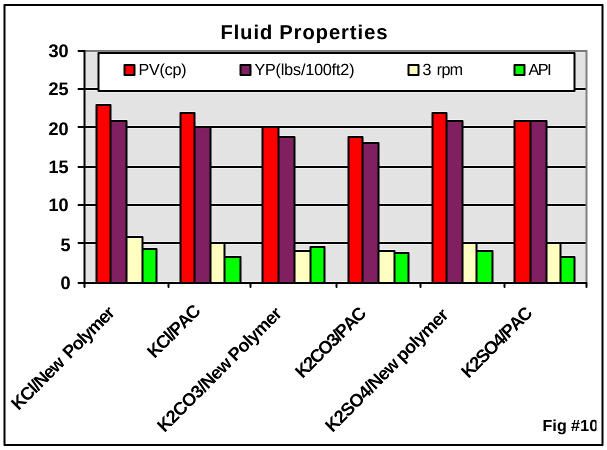

Figure 10 – Fluid properties comparison in various potassium base brines.

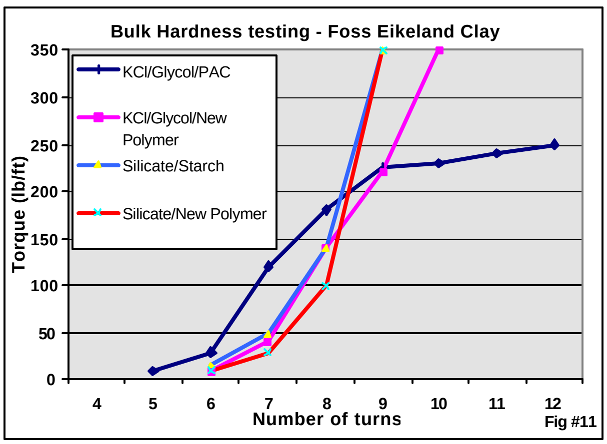

Figure 11 – Comparative shale inhibition using new polymer in 1.4 sg KCl/Glycol and Silicate fluids.

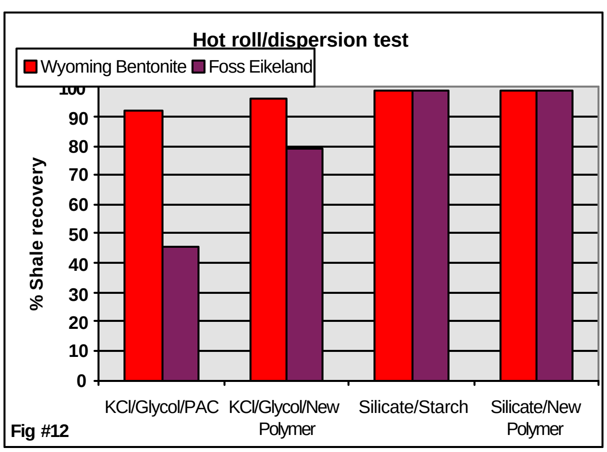

Figure 12 – Comparative shale inhibition using new polymer in 1.4 sg KCl/Glycol and Silicate fluids.

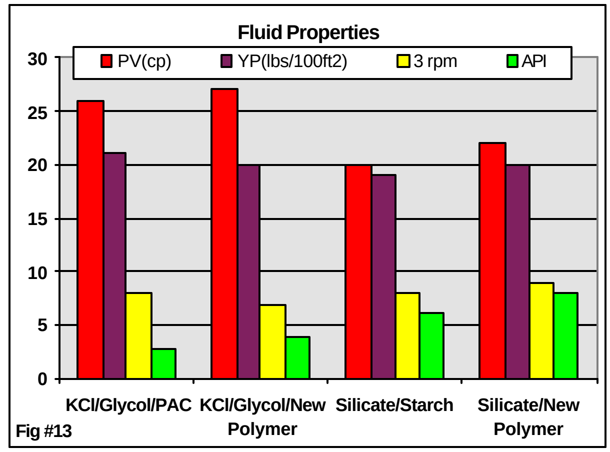

Figure 13 – Fluid properties comparison for 1.4 sg KCl/Glycol and silicate fluids.

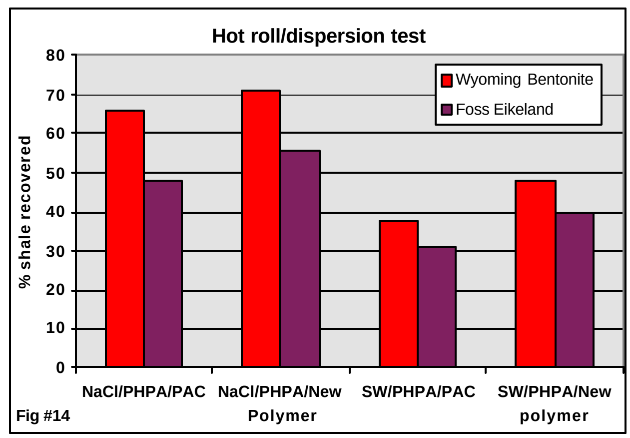

Figure 14 – Shale inhibition comparison in 1.25 sg PHPA fluids.

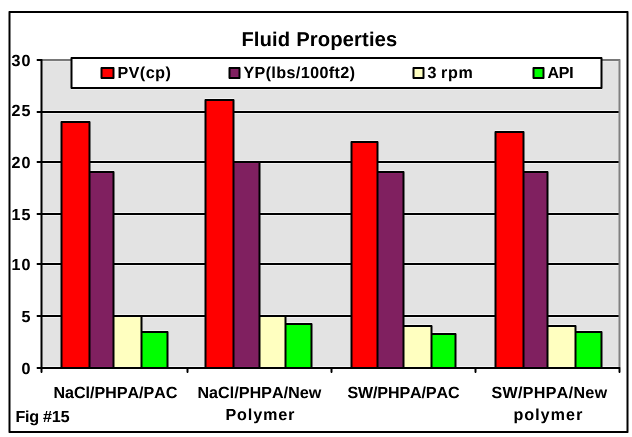

Figure 15 – Fluid properties comparison for 1.25 sg PHPA fluids.