Friction Reducers and the Challenge of High TDS Waters

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Abstract

Hydraulic fracturing around the globe is experiencing a rapidly transforming landscape. Advances such as horizontal drilling have granted access to previously unreachable oil and gas deposits. On the other hand, water stresses and environmental pressures are beginning to place restrictions on water use – especially fresh water use – for stimulation and production. Low-quality water sources like produced water and flowback water offer a path forward, but traditional friction reducers face compromised performance in such environments. Next-generation friction reducers have been developed, however, that provide up to 60% friction reduction across a wide range of TDS levels.

This unique class of friction reducers delivers high performance under what were previously restrictive conditions, such as water samples containing up to 230,000 ppm total dissolved solids, and tolerates extreme warm and cold temperatures. This allows stimulation companies to take advantage of a broader range of water sources and environmental conditions, expanding treatment options.

Friction reduction measurements were performed using a laboratory-scale friction loop designed to simulate the turbulent flow conditions encountered during hydraulic fracturing. Flow rates up to 121 liters per minute were achieved in 12.7-mm diameter tubing, resulting in Reynolds numbers as high as 150,000. The polymer systems developed provided friction reduction in as high as 60% at temperatures ranging from 4 to 38 °C. Maximum friction reduction was reached in 90 seconds or less in all cases. By comparison, conventional friction reducers took nearly twice as long in high-TDS water and gave significantly lower levels of friction reduction.

Introduction

Hydraulic fracturing has been a key tool for stimulating oil wells since its inception in 1947. Originally diesel was used to provide the hydrostatic pressure necessary to create and propagate fractures in hydrocarbon-bearing formations. Over the next several decades, diesel was replaced with aqueous solutions of natural or synthetic polymers. The latest revolution has been in slick water fracturing of shale plays where fracturing has evolved from a stimulation to a production tool, allowing oil and gas to be recovered from high porosity but low permeability strata like the Permian Irati Formation. A single shale frac job can require up to 150,000 m^3 of water spread across 40 stages.

In order to generate sufficient pressure, slick water frac fluids must be pumped at flow rates of 20 to 25 m^3/min through a bore 11.5-cm in diameter, resulting in highly turbulent flow. At these conditions, the Reynolds number is on the order of 500,000 to 5,000,000, and increasing the flow rate in this regime requires an exponential increase of energy. However, high molecular weight polymers have the ability to moderate this turbulence (Toms, 1949). While the exact mechanism is still unclear, polymeric friction reducers allow operators to reach higher flow rates without adding additional pumping capacity (McCormick 1991).

A friction reducer must excel in several areas. According to Bird and Hassager (1977), polymers that possess a linear structure, high molecular weight, high flexibility, and are composed of low molecular weight monomers will perform well as friction reducers. Additionally, the polymer should dissolve rapidly, and tolerate dissolved ions in the frac water. It also should avoid interacting with any other chemical additives present in the fluid or damaging the formation.

Synthetic polymers, particularly those based on acrylamide, are popular as friction reducers because they can achieve molecular weights as high as 30 million Daltons or more, and are predominantly linear. These polyacrylamides can be obtained in several different forms, each with its own advantages and disadvantages. Dry polyacrylamides (DPAMs) are the easiest to ship and are stable in virtually all environments, but have relatively lower molecular weights, require specialized equipment to prepare solutions, and can take up to an hour to completely dissolve. Solution polyacrylamides (SPAMs) have high molecular weights and dissolve rapidly, but consist mainly of water. Inverse emulsion polyacrylamides (EPAMs) possess the highest molecular weights and dissolve within minutes, and contain lower active solids than DPAMs but higher active solids than SPAMs.

EPAMs are the most common product form for friction reducers, because the faster dissolution and higher friction reduction performance outweigh the lower active solids content. These emulsions consist of a continuous oil phase, an internal water phase containing monomers and other additives, emulsion-stabilizing surfactants, and breaker surfactants (also known as inverters). The active polymer solids can be as high as 40% by weight. The performance of a friction reducer and its dissolution time can be manipulated by modifying the polymeric structure, or by changing any or all of the other components in the emulsion. With careful attention to components, a modular platform can be constructed that allows emulsion formulations to be tailored towards specific end uses.

Over most of hydraulic fracturing's history, fresh water was used for fracturing in order to achieve maximum performance. Dissolved ions in sufficient concentration can reduce the solubility of both ionic and nonionic polymers. If the polymers precipitate from solution, they can damage a hydrocarbon-bearing formation by plugging pores in the rock. Cationic polymers resist polyvalent ions, but may interfere with anionic additives like scale inhibitors and biocides. Anionic polymers are especially sensitive to polyvalent ions such as calcium and iron, which can electrostatically crosslink functional groups like carboxylates. Furthermore, dissolved ions can reduce the effectiveness of the inverting surfactants, reducing the amount and rate of polymer released from the emulsion state (Aften, 2010).

Operators can no longer assume that fresh water sources will be available for production and stimulation operations, nor can they count on easy disposal of flowback and produced water (Gupta and Hildek, 2009; Daniel-Arthur et al, 2010). One solution is to utilize the available brackish surface water, flowback water, or produced water to replace fresh water in frac fluids (Paktinat, 2011). Conventional friction reducers cannot deliver a strong performance in these high brines, however; they hydrate slowly and only provide a fraction of their fresh water performance. But a new friction reducer has been developed that hydrates in high brines in less than 60 seconds, and achieves up to 60% friction reduction.

Experimental

Polymer Synthesis

Inverse emulsion polymers were synthesized by previously established protocols using the free radical mechanism. Typical components of the system includes a continuous oil phase, water internal phase consisting of monomer, initiator(s) and other additives, primary surfactant for stabilizing the emulsion and breaker surfactants responsible for inversion.

Friction Reduction Measurements

Friction reduction performance was evaluated on a laboratory-scale friction loop designed to simulate well fracturing flow conditions (based on Aften and Watson, 2009). Although it is not possible to achieve this kind of flow in the lab, the friction loop simulates the field conditions at a Reynolds number of 120,000 to 150,000, following design and operation principles that are widely accepted by the industry. The core of the recirculating loop consists of a 20 L reservoir, a pump, and a magnetic flow meter and a differential pressure transmitter to create and monitor necessary conditions. All pipes and other components are constructed using 316L or 304L stainless steel. Different synthetic brines were prepared to simulate the water quality of seawater, brackish surface water, flowback water, or produced water, and the compositions of these brines are compared in Figure 1. If temperatures above or below ambient conditions were required, hot water or ice water was used to prepare the brines.

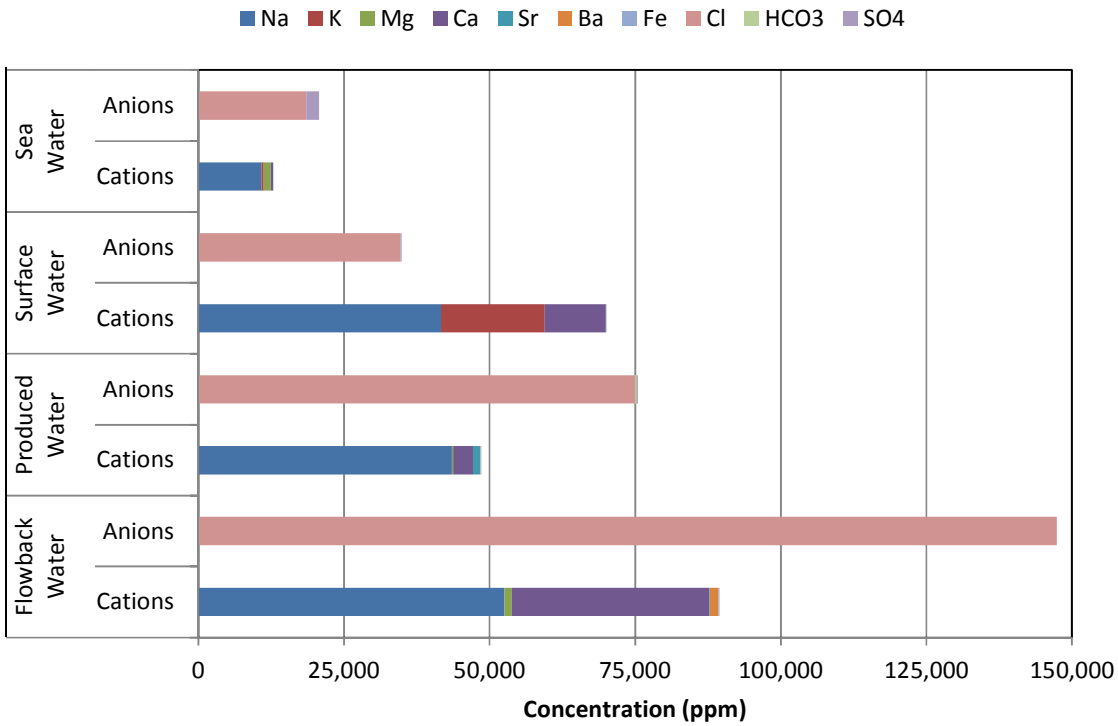

Figure 1. Compositions of the sea water (TDS 33,541 ppm), surface water (TDS 104,975 ppm), produced water (TDS 124,037 ppm), and flowback water (TDS 236,840 ppm) used.

To evaluate the friction reduction performance of a polymer, the loop reservoir was filled with the required brine. This brine was then recirculated through the friction loop at a flow rate of either 91 L/min (Re 120,000) or 112 L/min (Re 150,000) across a 1.5 m section of 1.27 cm diameter pipe. A baseline pressure drop was measured, and then the polymer was added at a concentration of 1 part per thousand by volume, where it inverted and dissolved. The degree of friction reduction (%FR_t) was

calculated from the initial pressure drop of the frac water ($\Delta P_{solvent}$) and the pressure drop at after the friction reducer was added ($\Delta P_{solution}$) using Equation 1. The amount of time to achieve maximum friction reduction also was recorded.

$$\%FR = \frac{\Delta P_{solvent} - \Delta P_{solution}}{\Delta P_{solvent}} \times 100 \quad (1)$$

Results and Discussion

The performance of conventional friction reducers A and B with brine tolerant polymers C and D were compared in waters with different amounts of dissolved solids. Experiments in fresh water, sea water, and flowback water were conducted at flow rates of 91 L/min, while the produced water tests were run at 112 L/min. Figure 2 compares the percentage of friction reduction measured, while Figure 3 shows the amount of time needed to fully invert the polymers in each fluid.

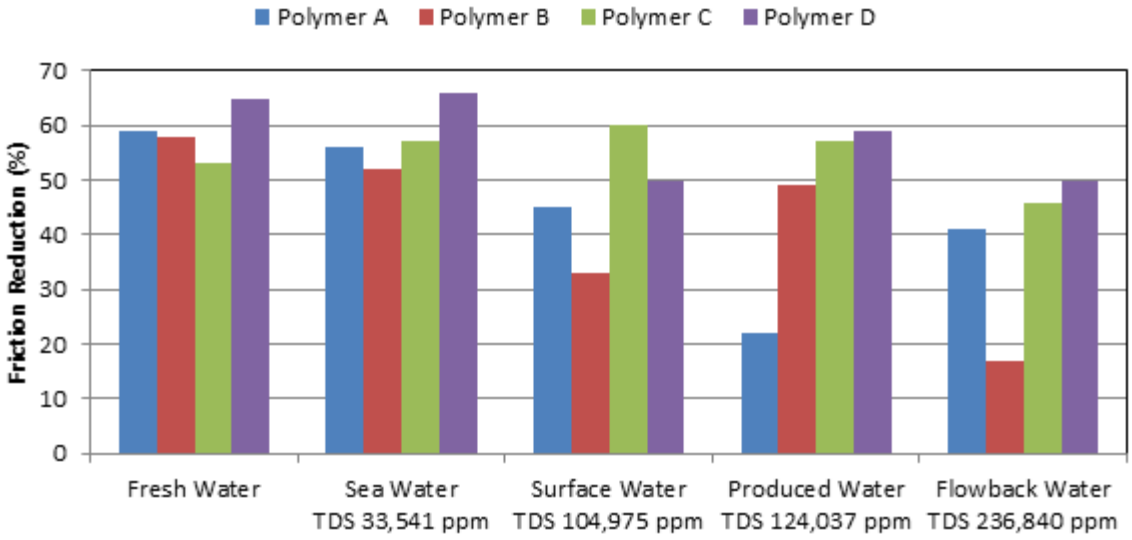

Figure 2. Friction reduction for 1 ppt of Polymers A, B, C, and D in different brines.

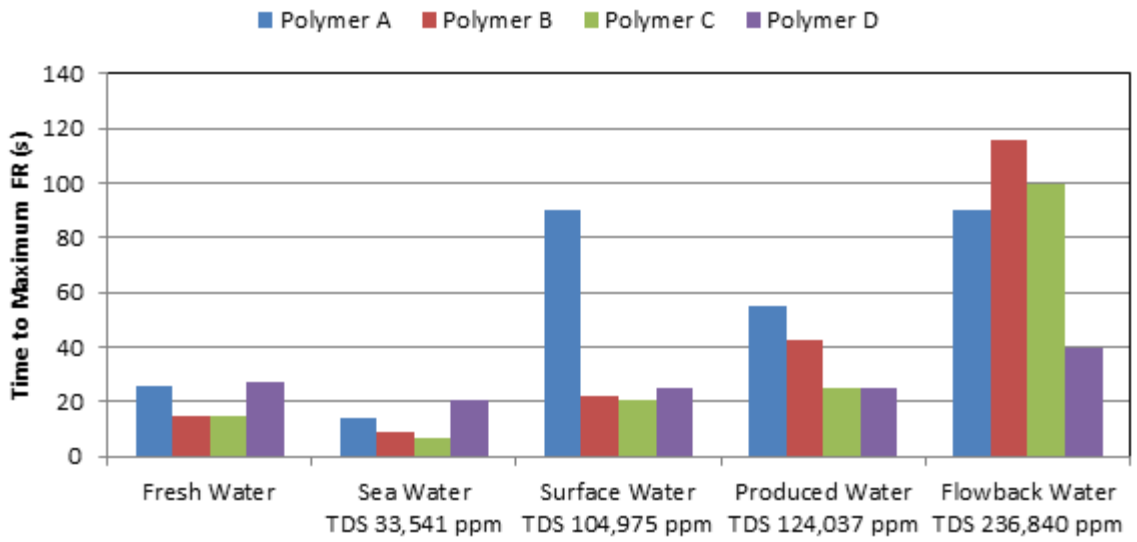

Figure 3. Time for 1 ppt of Polymers A, B, C, and D to reach maximum friction reduction in different brines.

All polymers perform similarly in fresh water, and while the sea water has a TDS of over 30,000 ppm, most of its dissolved solids are monovalent ions that have little impact on the emulsions. As the concentration of dissolved solids continues to increase, however, Polymers A and B begin to lag behind in performance as the divalent ions in the water prevent the inverting surfactant from rupturing the polymer-containing micelles. The divalent salts also prevent the polymers from reaching a fully-extended conformation in the frac fluid, which reduces the maximum level of friction reduction achievable. Polymers C and D have been tailored specifically for high brines, and while they are still affected by the high TDS, they deliver higher friction reduction and hydrate more rapidly than Polymers A and B.

Temperature can also be an issue for friction reducers, particularly in high brines. Temperature increases the viscosity and decreases the solubility of polymers, which can slow inversion times and decrease friction reduction. Because of the high pumping rates used in hydraulic fracturing, treatment fluids will not have the opportunity to significantly warm before they reach the target stratum. Figures 4 and 5 show the effects of temperature on Polymers B, C, and D in brackish surface water.

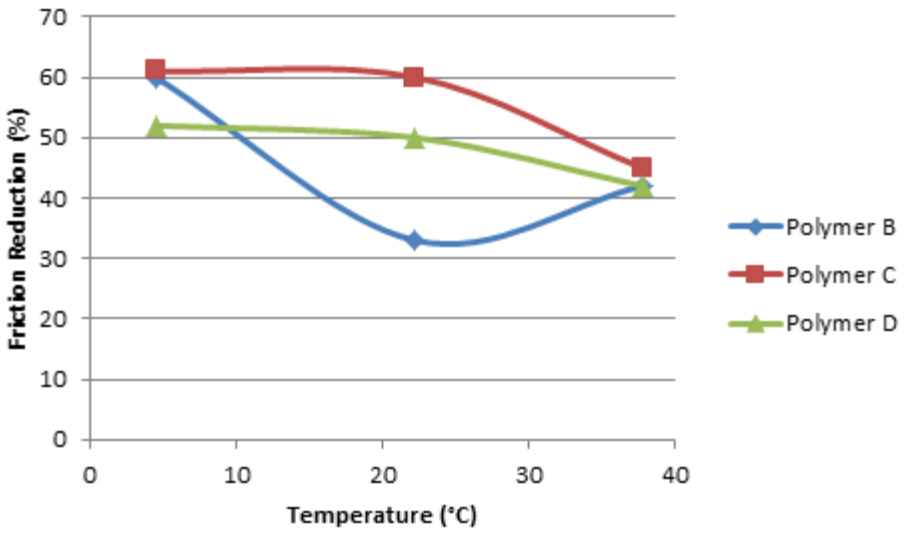

Figure 4. Friction reduction for 1 ppt of Polymers B, C, and D in surface water at different temperatures.

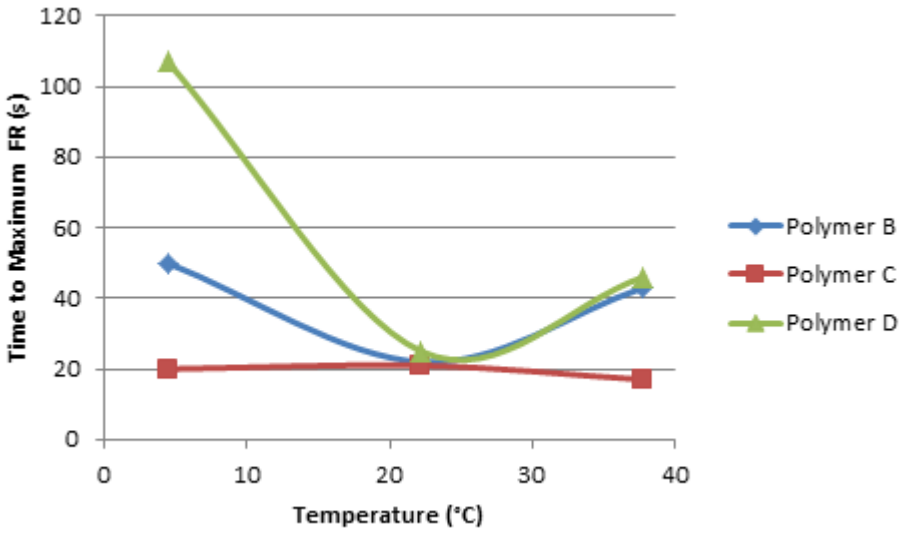

Figure 5. Time for 1 ppt of Polymers B, C, and D to reach maximum friction reduction in surface water at different temperatures.

Conclusions

Friction reducers are important tools for oil and gas production and stimulation. As fresh water sources become rarer and disposal of produced and formation water becomes more difficult, one solution is to use these readily-available high brines instead. Conventional anionic friction reducers suffer from diminished performance and longer hydration times in high TDS water, but newly-developed polymers tailored for high brines can deliver strong performance in waters containing up to 230,000 ppm TDS. These new polymers are also tolerant at high temperatures without compromising FR performance.

Acknowledgements

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