

## Research Article

### Applications of Oilfield Produced Formation Water for Fracturing Fluid

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**Abstract:** Oilfield produced formation water containing complex mixture of Dissolved Solid Compounds (DSC), including sodium, boron, chloride, magnesium, potassium, calcium, barium, iron and other salts is used in this research with the objective to develop stable and degradable cross linked fracturing fluid useful in both oil and gas producing reservoirs. As a result of recent increasing interest in horizontal drilling and hydraulic fracturing operations, large volume of produced and/or flow back water containing complex mixture of organic and inorganic compounds is generated in the oilfield during the oil and gas recovery operations. Independently owned to larger oil and gas producing operators manage the generated oilfield produced water by one or more of the strategies, which include disposal, re-use and recycling of the produced water. However, large water consumption and strict environmental disposal issues associated with hydraulic fracturing treatment, combined with industry growth, are generating a crucial need for developing a good viscosity and reliably stable cross linked fracturing fluid systems, useful for transporting propping agents into the fracturing zones at moderate to high temperature range using the generated oilfield produced water. Presented in this study are the results of rheology and residue analysis of fracturing fluid systems prepared with oilfield produced formation water from a broad spectrum of geologic basins. The rheology studies were conducted to measure viscosity under a nitrogen pressure of >400 Psi and temperature window of 210-260°F. The guar residue analysis test was performed with series of gel breakers at 185°F. The fluid systems presented provide proof of concept of the ability to crosslink and degrade cross linked fluids to below 100 cP at shear rate of 100/sec under the considered treating down hole conditions. Data presented provide guidance for the potential use of generated oilfield produced water as source water and/or blend water for water-shortage oil and gas producing operators and reducing the negative environmental impact.

**Keywords:** Degradation, fracturing fluid, produced water, wastewater management, well drilling and completion, well stimulation

## INTRODUCTION

The increased interest of discovery oil and gas from the shale and other unconventional resources has provided enormous new sources of natural gas and hydrocarbon liquids. But as the resources are discovered in areas where the public is not familiar with oil and gas drilling and completion operations, environmental concerns associated to drilling and completion processes increases. One of the public's environmental concerns is the practices involving hydraulic fracturing treatment. Hydraulic fracturing, one of the completion phases presently used for recovering oil and gas from the hydrocarbon bearing zones comprises the pumping of sand loaded liquid material, also known as fracturing fluid at extremely high pressure in order to propagate fractures in the wellbore containing natural gas and/or hydrocarbon liquids. The fracturing fluid must exhibit good viscosity and stability at moderate to high temperature range.

Despite the significant applications of petroleum to mankind, during the oil and gas recovery operations in the oilfield, large volume of produced and/or flowback water containing complex mixture of organic and inorganic compounds is generated (Azetsu-Scott *et al.*, 2007). Varied concentration of compounds found in oilfield produced water are due to formation geology, lifetime of the well and type of hydrocarbon produced. Produced water has been identified as the largest water stream generated during the oil production process and the volume of produced water can be larger than the hydrocarbons produced (Fakhru'l-Razi *et al.*, 2009). In United States, estimates of 18 billion barrel (bbl) of produced water, 149 million bbl of drilling waste and 21 million bbl of associated waste generated through exploration and production operations are discharged into the environment or managed at well site (Puder and Veil, 2007). Typical cost associated with waste disposal varies from \$0.30 to \$10.00 per barrel for injection or cavern disposal and \$15 to \$22 per barrel for

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Table 1: Water analysis

Compounds (Conc. in mg/L)	Fraser-borden federal production water from bakken region	David Cook production water from bakken region	Synthetic production water	Wildhay plant production water from edson region	Ambridg, PA tap water
<b>Anions</b>					
P Alkalinity (mg/L as CaCO <sub>3</sub> )	0.00000	0.00000	0.000	0.000	0.00
M Alkalinity (mg/L as CaCO <sub>3</sub> )	210.000	250.000	180.0	140	55.0
Chloride (mg/L as Cl <sup>-</sup> )	190.000	192,500	162,400	4,900	17.0
Sulfate (mg/L as SO <sub>4</sub> <sup>2-</sup> )	138.000	106.000	428.000	ND	24.0
<b>Cations</b>					
Arsenic (mg/L as As <sup>5+</sup> )	ND	ND	ND	ND	ND
Sodium (mg/L as Na <sup>1+</sup> )	93,530.0	96,060.0	91,250	2,564	16.0
Potassium (mg/L as K <sup>1+</sup> )	7,840.00	7,151.00	4,659	97.00	1.40
Calcium (mg/L as Ca <sup>2+</sup> )	21,150.0	21,860.0	16,550	280.0	20.0
Magnesium (mg/L as Mg <sup>2+</sup> )	1,218.00	1,374.00	967.00	34.00	6.40
Barium (mg/L as Ba <sup>2+</sup> )	36.0000	36.0000	1.8000	202.0	ND
Strontium (mg/L as Sr <sup>2+</sup> )	1,906.00	1,896.00	726.00	112.0	0.10
Iron, Ferrous (mg/L as Fe <sup>2+</sup> )	154.000	182.000	6.4000	16.00	ND
Iron, Total (mg/L as Fe)	154.000	208.000	14.000	20.00	ND
Boron (mg/L as B <sup>3+</sup> )	400.000	429.000	69.000	4.000	ND
TDS	316709	321996	279177	8390	145.0
<b>Miscellaneous</b>					
pH	5.94000	6.23.000	6.11000	6.40	7.530
Conductivity (µmhos/cm)	368,600	337,200	254,000	13,68	262.0
Calc. Osmotic Strength (mOsm/Kg)	9,643.0	9,933.00	8,368.00	266.0	3.000
Calc. Total Hardness (mg/L as CaCO <sub>3</sub> )	57,869	60,283	45,338.0	841.0	77.00
Total Suspended Solids (mg/L)	364.00	139.000	6,590.00	265.0	0.000
Specific Gravity	1.2050	1.196.0	1.216.00	1,007	1.004
Δ ATP (rlu)-microbiological content	30.000	33.00.0	----	67.00	13.00
Microbiological Content	Moderate	Moderate	----	Moderate	Low
Langelier Saturation Index (LSI)	1.0300	1.4100.0	1.03000	-0.410	-0.65
Langelier Potential	Scaling	Scaling	Scaling	Corrosive	Corrosive



Fig. 1: Samples of oilfield produced formation water

solidification and landfill disposal (Puder and Veil, 2007). Offshore produced water treatment and disposal costs were reported to be more than \$400 million per year (Khatib and Paul, 2002). Independently owned to larger oil and gas producing operators manage the generated oilfield produced water by one or more of the strategies, which include disposal, re-use and recycling of the produced water (Daniel *et al.*, 2005). Without proper treatment, produced water is environmentally harmful. It can be costly to clean produced water following the stringent local, state, or federal regulations. The ability to prepare fracturing fluids with high brine and boron containing produced water can be a successful wastewater management approach, which only not reduces the operating cost and negative environmental impact, but reduces large volume consumption of fresh water that is becoming more costly and difficult to obtain due to natural drought

condition and stringent government regulation on water availability from surface and subsurface aquifers (Gleick, 1994). Hence, due to large water consumption, strict environmental disposal issues associated with hydraulic fracturing treatment, combined with industry growth, it is crucial to develop fluids using produced water to reduce operating costs and consequently, providing the potential use of oilfield produced water as source water and/or blend water for water-shortage oil and gas producing operators and reducing the negative environmental impact.

Numerous efforts have been made to treat flow back and produced formation waters and reuse them to develop fluids for slick-water and low temperature cross linked fracturing treatments (Blauch, 2010; Li *et al.*, 2009 and Satya *et al.*, 2012). These waters contain limited amount of dissolved solid compounds, including less than 165,000 ppm chloride and 340 ppm boron (Satya *et al.*, 2012). However, several formations have produced water with higher chloride and boron, typically greater than 190,000 ppm of chloride and 400 ppm of boron, as shown in Table 1. The Samples of oilfield produced formation water is shown in Fig. 1.

Presented in this study are the results of rheology and residue analysis for sufficiently high viscosity, stable and degradable crosslinked-guar fracturing fluid, useful in transporting propping agents into the fracturing zones at moderate to high temperature range. The crosslinked-guar fluids are prepared with high brine and boron contained oilfield produced formation water generally found in a broad spectrum of geologic basins. The rheology tests were conducted to measure viscosity under a nitrogen pressure of >400 Psi and

temperature window of 210-260°F. The guar residue analysis was performed with series of gel breakers at 185°F. The fluid is shown to have adequate rheology useful to transport and penetrate the propping agent into the fractured zones of the hydrocarbon reservoirs. In addition, it is established that the cross linked-guar fluid can be degraded to low viscosity fluid and flow back from the formation to enhance recovery from hydrocarbon reserves. Consequently, providing potential uses of formation produced water as source water and or blend water for water-shortage oil and gas producing operators. Applications of high brine and boron contained produced formation water for fracturing fluids can be a successful wastewater management approach and valuable solution for reducing completion cost and negative environmental impact.

## EXPERIMENTAL MATERIALS AND METHODS

The experimental approach used in this study focused on fluid development with actual produced formation water from a variety of important operating wells from Bakken region of USA (David-Cook and Fraser-Borden Federal production wells) and Edson region of Canada (Wildhay Plant production well). In addition, synthetic produced formation water, generally found in a broad spectrum of geologic basins (Fakhrul-Razi *et al.*, 2009) was used to develop the fracturing fluid. In these experiments, rheology at various down hole treating temperature conditions, representative shear history, cross linker, boron inhibitor and breaker optimization were performed to assess fluid performance requirements of sufficiently high viscosity, stable and degradable crosslinked fluid.

The fluid viscosity was measured with Grace M5600 viscometer equipped with R1-B5 rotor-bob couvette geometry for several hours to show continuous loss of viscosity with time at stimulated down hole temperature range of 210-260°F and constant shear rate of 100/sec. The fluids were formulated using either linear guar or derivatized guar polymers as gelling agent. In addition to other fluid additives, either borate or zirconate cross linker was used as cross linker.

**Fluid formulation:** For the borate-fluid system, the gelling polymer was added to the water sample after adding the biocide for hydration. The gel was circulated at low speed for 15-min to allow complete hydration of the gel. Other fluid additives were added and circulated for few minutes to allow their complete dispersion, after which, sodium hydroxide was added to raise the pH up to above 11.

Due to instant surface crosslink noticed with the zirconate-fluid system, the fluid additives were first added to the water sample and sodium hydroxide was used to raise the pH up to about 7, after which, gelling polymer was added and circulated at low speed for 15-



Fig. 2: Fluid sample lip test on crosslinked-guar

min to allow complete hydration of the gel. Viscosity of the hydrated gel was measured with Fann-35 model viscometer at 300 rpm (511/sec).

Varied concentrations of crosslinker were added to the hydrated linear gel to give good crosslinked gel. The fluids were designed with/without gel breaker. Lip test was performed in sample cup until the gel shown strong crosslink by the gel hanging at least one inch over the mouth of the cup and return easily (Fig. 2). Ambridge; PA tap water was used to blend representative produced water.

**Breaker effects:** Breaker testing was performed using the Grace M 5600 unit and the same method described above for baseline data. When the breaker was used, the breaker was added first before cross linker. If breaker is added after cross linker, the breaker could not dissolve properly since the molecular chains in the guar polymer have been cross linked to each other.

**Blending produced formation water:** The most basic solution for obtaining usable fluid for fracturing is to use neat produced formation water. This option was considered prior to broader blending options. Applying such approach requires extensive laboratory testing and evaluation. During the experiment, the gelling polymer could not hydrate in neat water samples from Bakken region. Whereas, the gelling polymer hydrated in neat water sample from Edson region. But, the hydrated gel could not cross linked when gel crosslinker was added. +When the quantity of produced formation water samples from Bakken and Edson regions were reduced to 50% and 90% respectively, hydrated linear gel and crosslinked fluid were noticed.

Thus, 50% of Bakken region water sample, 50-90% of Edson region water sample and 50-100% of synthetic produced water sample were used in this study. The differences in water blend ratio noticed between produced formation water and synthetic produced water could possibly be attributed to high level of complex mixture of organic and inorganic constituents present in typical water samples (Table 1).

**Residue analysis:** Jars of guar or crosslinked guar were prepared with series of breakers. The jars were

immersed in a water bath for 24-h at 185°F. The contents were centrifuged at 1500 rpm for 10 min and filtered through a weighed paper. The filter paper and residue were incubated in the oven for 20-h at 110°C (230°F) and reweighed to calculate the amount of residue recovered. This value is expressed as a percentage of the original weight of guar polymer in the solution. The filter and residue were then incubated for additional 7-h and reweighed to ensure the moisture had been completely removed. The fluid tested contained 7.5 gpt of linear guar at pH of 6.5. With the exception of enzyme breaker tested at 100 ppm and 500 ppm, other breakers were used at 1 ppt and 5 ppt.

### RESULTS AND DISCUSSION

**Rheology at downhole temperatures:** It is crucial that the fracturing fluid formulated with oilfield produced formation water only not maintains a sufficiently high viscosity, but the fluid remains stable during the fracturing treatment and degradable for effective well clean-up after fracturing treatment. Thus, the rheological properties of fracturing fluid tested are evaluated at various downhole treating temperatures. For fracturing treatment, a stability of at least 1-h at treating temperature is generally required, before the fluid degrades to low viscosity fluid of 100 cP at 100/sec for efficient well cleanup. A viscosity performance of cross linked-guar designed with typical oilfield produced formation water at temperature range of 210 -260°F are presented in Fig. 3 to 15.

**Neat produced formation water:** Rheology plot of crosslinked-guar formulated with 100% of produced formation water at 210°F is presented in Fig. 3. The Figure revealed that the hydrated gel polymer could not be crosslinked with both borate and zirconate crosslinkers when neat (100%) typical produced formation water sample was used.

**Bakken produced formation water:** Figure 4 shows range of crosslinking activity of zirconate in 30-lb per 1000-gallon linear guar solution for both David-Cook and Fraser-Borden Federal produced water. With David cook produced water, the fluid maintained a fluid stability when tested over 2-h, while for the Fraser-Borden Federal produced water, the fluid was stable when tested for over 70-min.

Figure 5 shows the crosslinking activity of zirconate-crosslinked fluid with guar and derivatized guar polymer at 240°F and shear rate of 100/sec. As shown in Fig. 5, the linear guar polymer crosslinked with zirconate becomes more stable as the concentration of zirconate crosslinker increases, while the derivatized guar (CMHPG) polymer crosslinked with zirconate shown the contrary. This contrast is not understood, however, it could be attributed to differences in chemistry of the gelling polymers.

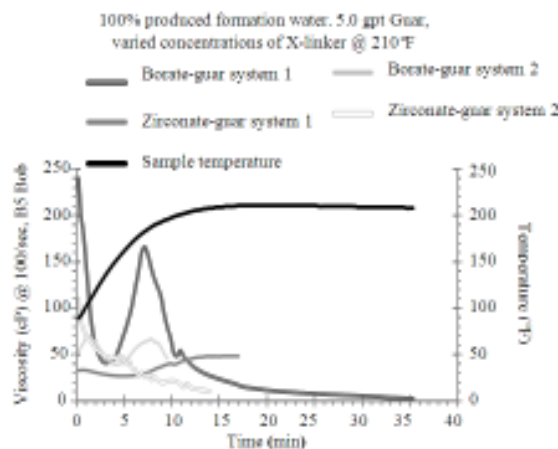


Fig. 3: Rheology study of crosslinked guar at 210°F and 100/sec 100% of produced formation water

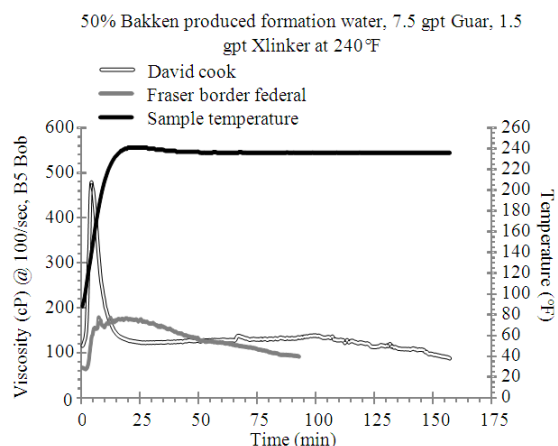


Fig. 4: Rheology study of crosslinked guar with zirconate crosslinker at 240°F and 100/sec. 50% of produced formation water from Bakken region

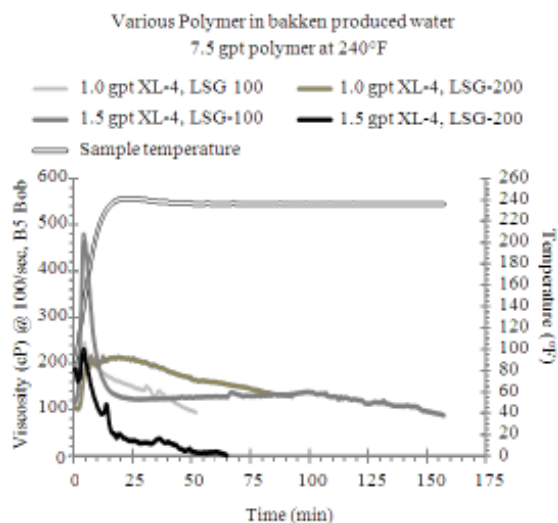


Fig. 5: Rheology study of various guar polymers on zirconate-crosslinked guar at 240°F and 100/sec. 50% of oilfield produced formation water from Bakken region

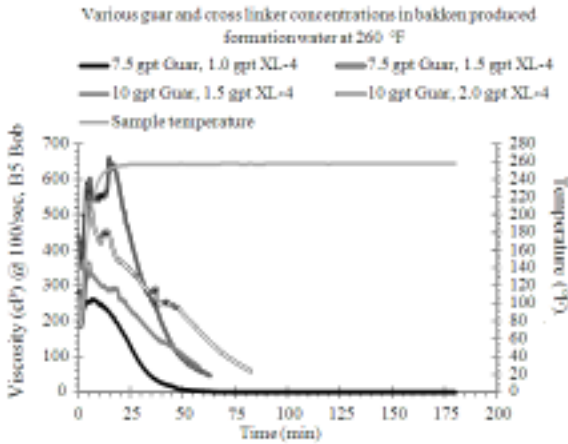


Fig. 6: Rheology study of various guar and crosslinker concentrations on zirconate-crosslinked guar at 260°F and 100/sec. 50% of oilfield produced water from Bakken region

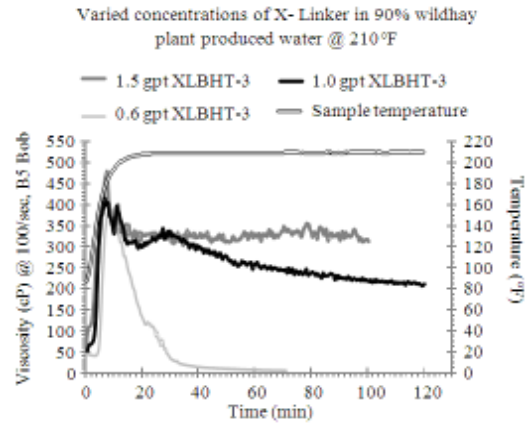


Fig. 9: Rheology study of borate-crosslinked guar at 210°F and 100/sec. 90% of wild hay plant produced frac water

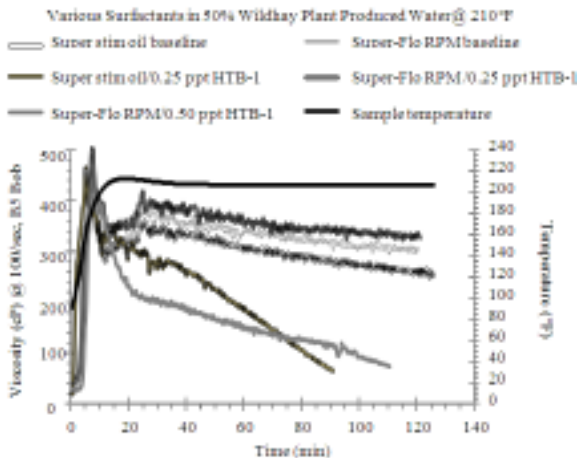


Fig. 7: Rheology study of borate-crosslinked guar at 210°F and 100/sec. 50% of wild hay plant produced frac water. Fluid designed with different surfactants

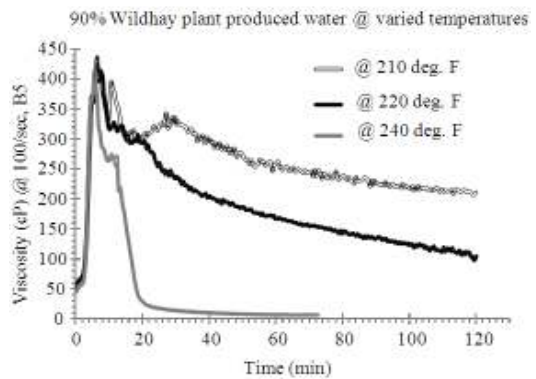


Fig. 10: Rheology study of borate-crosslinked guar at varied temperatures. 90% of wild hay plant produced frac water

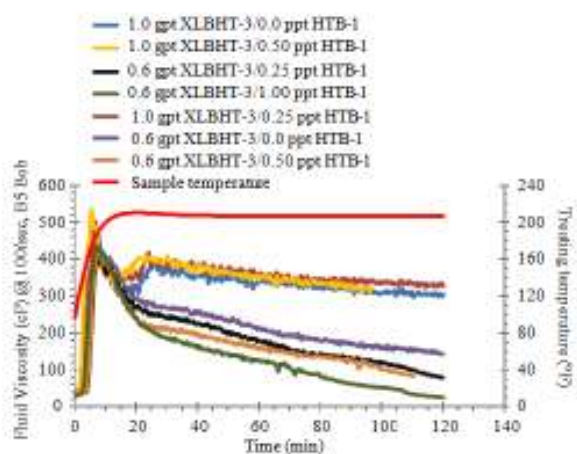


Fig. 8: Rheology study of borate-crosslinked guar at 210°F and 100/sec. 50% of wild hay plant produced frac water. Fluid designed with super-flo rpm

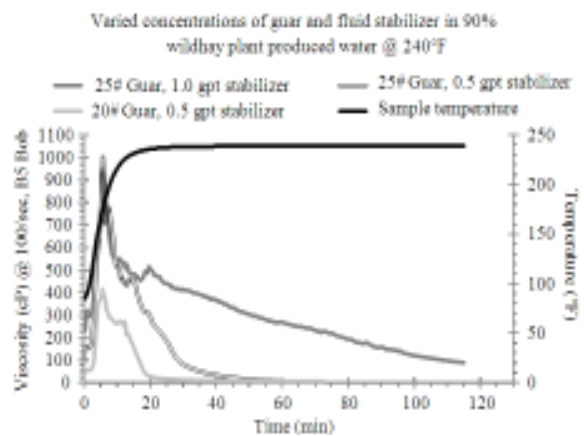


Fig. 11: Effect of guar polymer and fluid stabilizer concentrations at 240°F and 100/sec. 90% of wild hay plant produced frac water

Figure 6 shows the effect of varied concentrations of guar polymer and crosslinker on stable activity of zirconate-crosslinked fluid at 260°F and shear rate of 100/sec. As shown in Fig. 6, the guar polymer

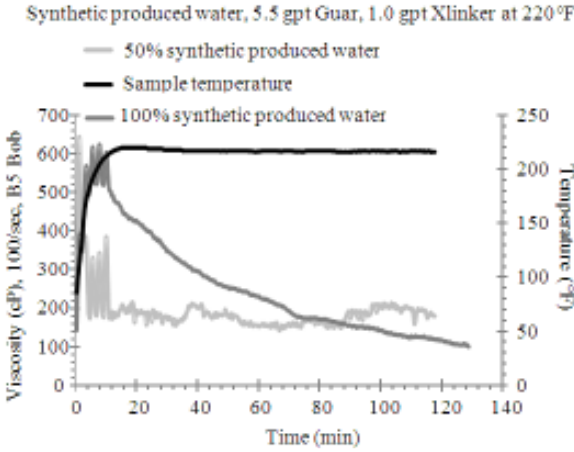


Fig. 12: Rheology study of crosslinked gel with zircon at cross linkers at 220°F and 100 sec<sup>-1</sup> varied water ratio of synthetic produced water

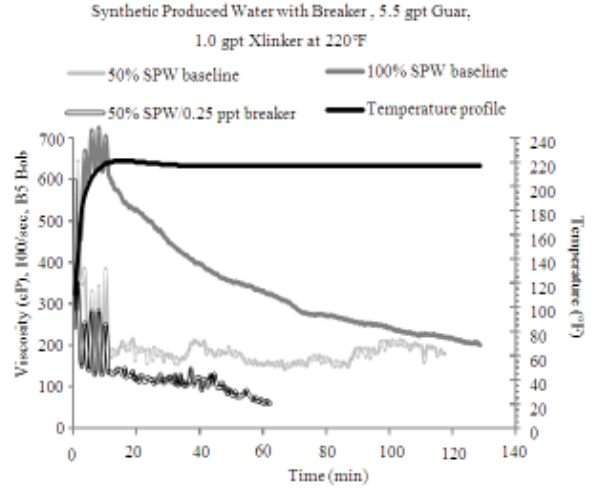


Fig. 15: Rheology study of oxidative breaker on zircon at-crosslinked guar at 220°F and 100/sec c. Varied water ratio of synthetic produced water

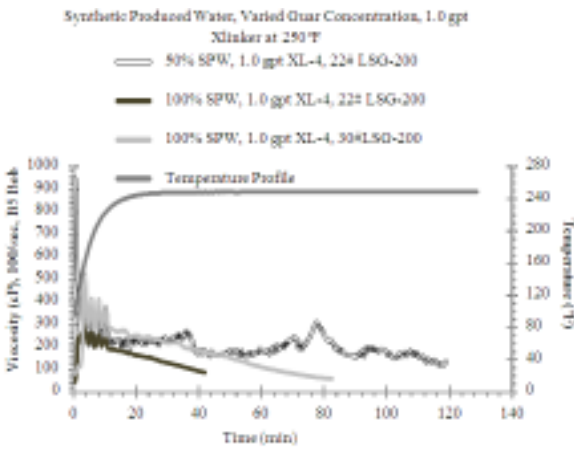


Fig. 13: Rheology study of crosslinked gel with zircon at cross linkers at 250°F and 100 sec<sup>-1</sup>. Varied water ratio of synthetic produced water

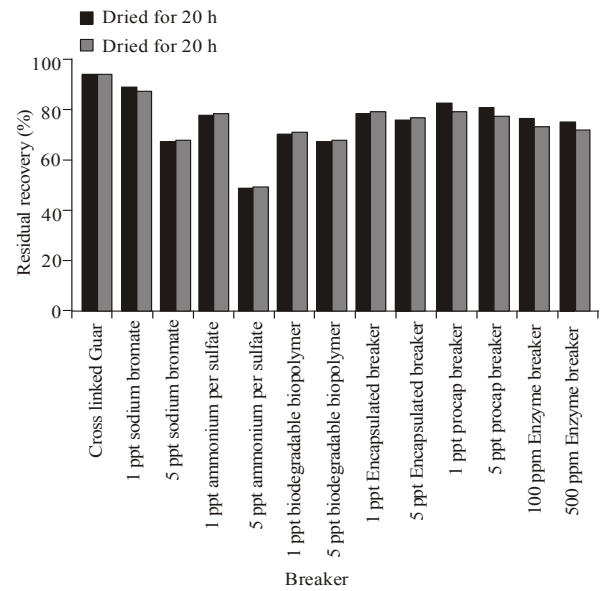


Fig. 16: Residue analysis for comparison of various breakers at 185°F. All breakers reduced the residue, but biodegradable biopolymer breaker shows lower amounts of residue

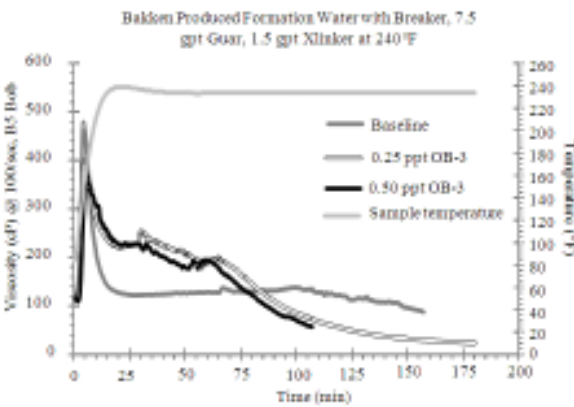


Fig. 14: Rheology study of oxidative breaker on zirconate-crosslinked guar at 240°F and 100 sec<sup>-1</sup>. 50% of bakken produced formation water

crosslinked with zirconate becomes more stable as the concentrations of the guar and zirconate crosslinker

**Edson produced formation water:** Presented in Fig. 7 to 10 are rheology plots for borate-crosslinked guar

formulated, with different surfactants, varied concentrations of biopolymer breaker (HTB-1) and varied water ratios (50-90%) of Wildhay Plant produced frac water from Edson region at varied temperatures.

As shown in Fig. 7, the fluids designed with Super-Stim Oil and Super-Flo RPM maintained fluid stability when tested over 2-h. The effect of the biopolymer breaker (HTB-1) was noticed on the fluid. The fluid formulated with 0.25 ppt HTB-1 and Super-Stim Oil was stable and degraded to below 100 cP fluid viscosity at about 85-min.

Similarly, as presented in Fig. 8, the fluid formulated with Super-Flo RPM, 1.0 gpt of gel crosslinker and various concentrations of HTB-1 maintained fluid stability when tested for 2-h. However, when the gel cross linker was reduced by 40% from 1.0 to 0.60 gpt, the fluid stability was retained for 2-h test period and degraded to below 100 cP fluid viscosity when HTB-1 was added as cross linked-gel breaker. The fluid formulated with 0.60 gpt crosslinker and 0.25 ppt HTB-1 was stable and degraded to below 100 cP fluid viscosity at about 110-min. Increasing the concentration of HTB-1 reduces the fluid stability time. The crosslinked fluid degraded to below 100 cP fluid viscosity at about 100-min and 75-min, respectively when 0.50 ppt and 1.0 ppt HTB-1 were added.

Rheology plot of borate-crosslinked gel with 90% Wildhay Plant produced formation water at 210°F is presented in Fig. 9. The fluid formulated with 1.0 gpt and 1.5 gpt borate-crosslinker, 0.50 gpt fluid stabilizer and 20 pound per 1000 gal guar polymer demonstrated a fluid stability when tested over 2-h, while the fluid formulated 0.6 gpt borate-crosslinker was stable and degraded to below 100 cP fluid viscosity at about 24-min. A difference in fluid stability was noted when 0.6 gpt borate-crosslinker was used for both 50 and 90% produced water ratio (Fig. 8 and 9). This difference could be attributed to level of complex mixture of organic and inorganic compounds present in blended water samples.

Presented in Fig. 10 is a rheology plot for borate-crosslinked gel with 90% Wildhay Plant produced frac water at varied downhole temperatures from 210 to 240°F. The crosslinked fluid contains guar polymer, X-linker and fluid stabilizer. Figure 10 revealed the effect of temperature on crosslinked fracturing fluids. The fluid tested at 240°F maintained fluid stability for about 17-min before degraded to fluid viscosity below 100 cP, while the fluids subjected to 210 and 220°F maintained fluid stability when tested for 2-h period.

Figure 11 shows the effect of varied concentrations of guar polymer and fluid stabilizer at 240°F. Increasing the concentrations of guar polymer and fluid stabilizer increases the stability period of crosslinked fluid. When the concentration of the fluid stabilizer was maintained and increasing the guar polymer

concentration by 25%, the fluid stability period was increased from 17-min to about 30-min before degraded to fluid viscosity below 100 cP. However, when the fluid stabilizer was increased from by 50%, fluid stability was maintained for over 100-min test period before degraded to fluid viscosity below 100 cP. The trend noticed in Fig. 11 indicates that more concentration of guar polymer will be needed for fracturing treatment at higher temperature.

**Synthetic produced water:** The rheology study of zirconate-crosslinked fluid using neat (100%) and 50% synthetic oilfield produced water at 220 and 250°F are shown in Fig. 12 and 13, respectively. The Figures clearly indicate that the fluid stability can be adjusted by varying the guar polymer and crosslinker loadings at respective downhole treating temperature to achieve desired stability.

As seen from the Figure 12 and 13, application of neat (100%) and 50% synthetic oilfield produced water to formulate fracturing fluid is viable. The zirconate-crosslinked fluids were stable for over 2-h of test at 220°F for 50 and 100% synthetic produced water (Fig. 12). At 250°F and application of 100% synthetic produced water to formulate the zirconate-crosslinked fluid, the fluid degraded at about 40-min of test (Fig. 13). However, a noticeable stable zirconate-crosslinked fluid was observed when the 50% of synthetic produced water was used. Increasing the gelling polymer from 22-lb per 1000-gallon to 30-lb per 1000-gallon when 100% synthetic produced water was used at 250°F, the degradability of zirconate-crosslinked fluid is delayed from 40 to 60-min during the testing period. The noticed trend indicates lower activity of the polymer gel consistent with larger levels of complex mixture of organic and inorganic compounds present in oilfield produced formation water.

**Effects of gel breaker:** The Figures below show the breaking activities of various concentrations of oxidative breaker on zirconate-crosslinked guar fluid for 7.5 gpt polymer in 50% produced water from the Bakken formation at 240°F (Fig. 14) and 5.5 gpt polymer in 50% synthetic produced water at 220°F (Fig. 15). Increasing the concentration of the oxidative breaker clearly results in significant reduction of viscosity. The trend noticed in Fig. 14 and 15 is consistent with the observation noted in Fig. 7 and 8. The rheology results were run for several minutes to show the continual reduction of viscosity with time. Clearly, for crosslinked fluids, more gel breaker is needed for the fluid containing higher concentration of guar.

**Residue analysis:** Figure 16 compares the effect of breaker on zirconate-crosslinked guar residue at 185°F.

After the 20-h incubation at 230°F, treated crosslinked fluid with 5 ppt ammonium persulfate has significantly lower amounts of residue than the corresponding solutions with other oxidative breakers (sodium bromate, encapsulated and procap breaker), biodegradable biopolymer (HTB-1) breaker and enzyme breaker. Though, the results from the residue analysis suggest that breaking profiles of oxidative breakers are not identical to biodegradable biopolymer and enzyme breakers, but a sufficient break can be achieved with the biodegradable biopolymer. The breaking activities of breakers considered in this study could possibly be attributed to the selective nature of the  $\beta$ -1,4-glycosidic bond of guar catalyzed by the active site of breaker molecules. The oxidative breaker has been reported to attach more randomly at the  $\beta$ -1, 4 linkage and  $\alpha$ -1, 6 linkage, which result in a higher level of insoluble fragments that are captured as residue (Zhang *et al.*, 2012). The data shows that the additional 7-h of incubation time was unnecessary. If the jars were exposed to higher temperature above 185°F, it is assumed that the residue would decrease further for all breakers tested in this study. For ammonium per sulfate and sodium bromate, the breaking activities are sensitive to breaker concentration, while, the breaking activities of biodegradable biopolymer, encapsulated, procap breaker and enzyme breakers are less noticeable with increased breaker concentration.

### CONCLUSION

Crosslinked-guar polymer with boron mitigation additive has been used to develop fracturing fluid, from oilfield produced formation water containing high level of Total Dissolved Solids (TDS) amount up to 320,000 ppm without reducing its performance. The fluid is shown to have adequate rheology useful, not only to transport and retain propping agent into the fractured zones of the hydrocarbon reservoir, but both borate and zirconate crosslinked-guar fluid can be degraded to low viscosity fluid and flow back from the formation to enhance productivity of hydrocarbons. The data clearly indicate that the fluid stability can be adjusted by varying loading concentrations of guar polymer, cross linker and gel breaker at respective treating downhole conditions to achieve desired stability. Using neat (100%) oilfield produced formation water with low boron contents is also viable for formulating fracturing fluid.

Although, designing the fracturing fluid with either Super Stim Oil or Super-Flo RPM surfactant showed adequate stability and degradability for the fluid. However, the rheology results revealed that lower concentration of gel crosslinker can be used to design the fracturing fluid when Super-Flo RPM is desired as

surfactant. Data is also provided from the residue analysis that breaking activities of different breakers are not identical, but a sufficient breaking fluid can be achieved with respective breaker considered in this study.

The ability to provide fracturing fluids with high brine and boron contained produced formation water can be a successful wastewater management approach and valuable solution for reducing completion cost and negative environmental impact. Potential use of produced formation water as source water and/or blend water for water-shortage oil and gas producing operators provide a gain competitive edge to the oil and gas pressure pumping Services Company.

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