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Influence of inorganic ions in recycled produced water on gel-based hydraulic fracturing fluid viscosity

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ABSTRACT

In an effort to determine impacts of the increased use of treated produced water in new fracs, the rheology of two fracturing fluids was observed for varying water qualities. Specific ions of interest were spiked at varying concentrations into tap water that was used as a base for the fluids. Apparent viscosities were measured using a Chandler 5500 viscometer once fluids were formulated. Empirically, it was determined that at the chosen concentrations for this study, aluminum, iron, phosphorous, potassium, and sodium all have negative impacts on fracturing fluid stability. Calcium and magnesium improved fluid stability until a critical concentration was reached, resulting in lowered viscosities and a less stable fluid. The carboxymethyl cellulose (CMC) fluid was more resilient to aluminum, potassium, and sodium, and other ions that negatively impacted stability than the guar based fluid. The guar based fluid also benefited from divalent cations more than the CMC fluid. The effect of using concentrated gel hydrated with fresh water and then diluted with concentrated ion solutions was also evaluated and did not show any improvement in fluid stability.

It appears that specific cations compete for crosslink sites on the gel polymer either through shielding or complexing with active sites that the crosslinker metal would normally complex with. This results in less crosslink sites available for the quatrovalent metal and a less stable fluid. In addition to crosslinked sites that an added crosslinker would complex with, hydrogen bonds can also make a weak crosslink. In the case of calcium and magnesium, the added cations displace hydrogen bonds and form a slightly stronger crosslink. However, this crosslink is not as strong as the ones made by the added crosslinker, and when a critical concentration of calcium or magnesium is reached, the cation competes with the added crosslinker as well, reducing fluid stability.

1. Introduction

A better understanding of how treated produced water quality influences the stability of hydraulic fracturing fluids is essential for exploration and production companies to reduce their demand on local fresh water resources, while maintaining oil and gas production (Esmaeilirad et al., 2015a, 2015b; Huang et al., 2005). Characterizing the spectrum of water qualities that are likely to occur when using produced water from several potential sources and is treated at varying fixed and mobile water treatment facilities, will allow oil and gas operators to optimize frac fluid formulations, water treatment operations and management strategies for produced water that achieves acceptable frac fluid stability, while minimizing cost of treatment and reducing the potential for screen outs. Water treatment technologies have been developed and refined for decades in a variety of other industrial applications that may provide assistance in optimizing frac fluid formulations and performance to achieve the operating objectives defined within this study.

Produced water treatment in the oil and gas industry has often focused on improving the water quality to fresh water standards, while service companies have been developing hydraulic fracturing fluids that are less sensitive to water quality, reducing treatment requirements and minimizing associated costs to the operator (Esmaeilirad et al., 2015a, 2015b; Lebas et al., 2013). By studying water quality and water treatment in conjunction with frac fluid formulation, water reuse can be maximized in a cost-effective and environmentally responsible manner. Furthermore, the temporal and spatial variability of recycled water (Esmaeilirad et al., 2015a, 2015b; Haghshenas and Nasr-El-Din, 2014a; Huang et al., 2005), including Early Time Flow Back (ETFB) and Produced Water (PW), can be better managed to meet an operator's water-

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related field development objectives, with fluid formulation optimization for preferred frac fluids.

The impact of using produced water with specific hydraulic fracturing fluids is not universally understood in the industry, nor documented effectively in the literature that is available. Some hydraulic fracturing fluids today are able to use water with total dissolved solids (TDS) values exceeding 270,000 mg/l (Acharya et al., 2011) but tradeoffs may exist with these fluids when considering costs, scaling tendencies, collection of sufficient volumes of produced water to prepare for particular treatment events, etc. Even though a variety of TDS reduction methods are available to achieve any water quality desired, salt removal is expensive and is typically avoided if possible (Pearce, 2008). Although the use of produced water for oil and gas drilling and slickwater-based fracturing have been explored in the Denver basin (Esmaeilirad et al., 2015a, 2015b), little has been done to use the high-TDS produced water with linear-gel based and crosslinked-gel-based hydraulic fracturing fluids (Erskine et al., 2002; Lebas et al., 2013). A limited number of reports have placed wide ranging water quality limits on other inorganic parameters (Boschee, 2012; Fontenelle et al., 2013; Haghshenas and Nasr-El-Din, 2014a, 2014b; Huang et al., 2006; Kakadjian et al., 2013; Lebas et al., 2013), but few studies have examined the influence of specific water quality parameters beyond the scope of solids and a few inorganic parameters.

Recycled flowback and produced water have been increasingly used in new gel fracs of oil and gas wells in the Denver-Julesburg Basin. With their increased use, higher ionic loadings have been placed on fracturing fluids, resulting in varied fluid stability. Understanding operational limits with respect to varying base water characteristics is key to the continued use of recycled water in practice (Fontenelle et al., 2013; Huang et al. 2006). The objective of this paper was to evaluate the difficulties and complexity of reuse and recycling produced water in hydraulic fracturing.

2. Materials and methods

2.1. Spiked base water preparation

Table 1 outlines typical water quality concentrations seen in varying sources for fracturing base water in the DJ Basin which was examined in this study. These water qualities were then used to determine the maximum and minimum of an individual ion. To study the effects of individual cation and anions on the viscosity of frac fluid, tap water from Colorado State University (CSU) was chosen as the base water for this study. Reagents were added to achieve varying ionic concentrations in the base tap water. Each sample contained only one specific ion at one specific concentration. Table 2 contains a list of all reagents used to spike the CSU tap water for the study. The concentration of each ions were chosen based on the typical water sources in Colorado, then extreme and minimum conditions were selected to represent a worse, normal and best water quality. The quantity of each compound was calculated based on the desired concentration of the individual ions. All the chemicals were supplied from Fisher and Sigma-Aldrich, (Missouri, USA) and were laboratory grade chemicals.

Table 2
List of added mineral compounds.

Ion of interest	Reagent used	Formula
Aluminum	Aluminum Chlorohydrate Dihydrate	$Al_2ClH_5O_5$*$2H_2O$
Ammonium	Ammonium Chloride	NH_4Cl
Barium	Barium Chloride Dihydrate	$BaCl_2$*$2H_2O$
Bicarbonate	Sodium Bicarbonate	$NaHCO_3$
Boron	Boric Acid	$B(OH)_3$
Bromide	Sodium Bromide	NaBr
Calcium	Calcium Chloride Dihydrate	$CaCl_2$*$2H_2O$
Chloride	Sodium Chloride	NaCl
Iron	Ferric Chloride	$FeCl_3$
Magnesium	Magnesium Chloride Hexahydrate	$MgCl_2$*$6H_2O$
Nitrate	Sodium Nitrate	$NaNO_3$
Phosphorous	Sodium Phosphate Dodecahydrate	Na_3PO_4*$12H_2O$
Potassium	Potassium Chloride	KCl
Sodium	Sodium Chloride	NaCl
Strontium	Strontium Chloride Hexahydrate	$SrCl_2$*$6H_2O$
Sulfate	Sodium Sulfate	Na_2SO_4

2.2. Building frac fluid

Metal cross-linked carboxymethyl cellulose (CMC) based and double derivatized guar based polymers were selected as the base fluids. These fluid systems are commonly used in the DJ Basin of Colorado. The base components of these fluids are: Cellulose based gel or guar based gel (Table 3).

The following steps were conducted to prepare all frac fluid samples:

1. 1000 ml of desired water sample or salt water was placed in a 1000 ml blender to prepare the linear gel.
2. A blender was used at between 1300 and 1500 rpm circulating rate, which was needed to establish a vortex shape with no air bubbles trapped. The mixing rate was part of Halliburton Practice.
3. A suggested quantity of CMC/guar gel was added slowly from the shoulder of the created vortex to prepare the desired polymer loading rate. A timer was started at this time. Apparent viscosity was measured at 3, 6 and 9 min of adding polymer to

Table 1
Range of water quality for different water source.

	Municipal water		Surface water		Ground water		Treated produced water		Early time flowback water	
Range (mg/l)	Low	High	Low	High	Low	High	Low	High	Low	High
Al							0.5	15	0.75	4
Fe	0	1	0	1	0	1	0.25	1.1	5	100
Ca	5	70	20	250	25	120	20	175	90	200
Mg	2	25	5	80	5	30	0	50	10	40
Ba							0.5	3	0.1	5.5
Sr							3	22	2	25
Cl	5	80	5	250	10	100	5000	10,000	80	10,000
HCO_3	20	450	125	450	140	330	300	600	300	1400
SO_4	3	150	150	800	5	300	25	125	30	1300
B							7	17	1	20
TDS	2	25	450	2200	300	1100	9000	18,000	1000	18,000