Fuel 185 (2016) 211–218

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Optimization of carboxylmethyl cellulose frac fluid in low TDS water sources based on pH and crosslinker concentrations

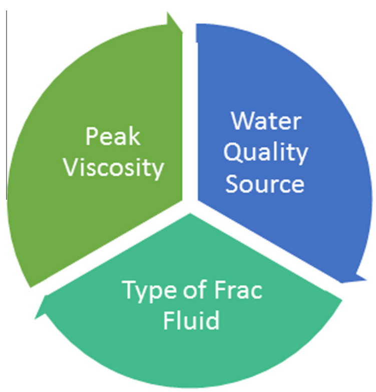
Nasim Esmaeilirad [a,*], Clay Terry [b], Ken Carlson [a]

[a] Colorado State University, United States
[b] Halliburton Inc., United States

HIGHLIGHTS

- Brackish water could be used as an alternative to freshwater resources in hydraulic fracturing operations.
- Chemical composition of gelled frac fluid can be optimized based on water quality source.
- Formation damage can be prevented by reducing loads of chemical injected downhole.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 April 2016
Received in revised form 26 July 2016
Accepted 27 July 2016
Available online 3 August 2016

Keywords:
Hydraulic fracturing
CMC
Zirconium
Brackish water
Apparent viscosity

ABSTRACT

Hydraulic fracturing uses a large volume a water to extract the oil and gas deposited in shale gas and oil formations. Many oil and gas developments are located in semiarid to arid areas in the United States (US), where freshwater resources are scarce. Using lower quality waters, such as brackish water during hydraulic fracturing, could be a good alternative to freshwater resources, reducing the competition on these sources and easing the public concerns with water shortages. This article examines using brackish water with total dissolved solids (TDS) of 2500 mg/L, optimization of carboxylmethyl cellulose (CMC) based fracturing fluid at different pH ranges and polymer concentrations. Five three dimensional (3D) contour maps were generated for peak viscosity at a polymer loading of 25–45 pounds per thousand gallons (ppt) of water. These viscosity maps are the first of their kind and help demonstrate that using poor quality water can be managed by optimizing the chemical composition of the fracturing fluid.

1. Introduction

This is the second part of a two-part article describing optimization of the chemical composition of fracturing fluid for use in lower salinity waters, such as briny ground water or any industrial treated water. The first part focused on replacing freshwater resources with higher salinity water sources with a TDS value of 15,000 mg/L, i.e., produced and flowback waters [8]. An average of two to six million gallons of water can be used for a single horizontal multistage well in hydraulic fracturing [6,7]. Dedication of this amount of water in areas with water scarcity issues can be controversial, particularly if agricultural activity is the largest water consumer in that area. Moreover, environmental activists'

* Corresponding author at: Department of Civil & Environmental Engineering, Colorado State University, 1372 Campus Delivery, Fort Collins, CO 80523-1372, United States.

E-mail address: nasimrad@colostate.edu (N. Esmaeilirad).

http://dx.doi.org/10.1016/j.fuel.2016.07.107
0016-2361/

and public concerns associated with water depletion and consumption of freshwater resources is another challenge oil and gas operators face in semiarid to arid areas. Oil and gas operators should consider alternative water sources to fresh water; the availability of sufficient volume is the first important characteristic of an alternative water resource. Low organic content is also an important property of the replacement water source, while TDS values in the brackish water range (2500–15,000 mg/L) can also be important.

Formulating fracturing fluids for acceptable rheological performance can be very sensitive to water quality. The composition of a typical gelled frac fluid consists of water, proppant, gelling (polymer) agent, crosslinkers, buffers, surfactant, breakers, biocides, friction reducers, scale inhibitors and potentially other additives based on geological and technical considerations [11,14,19,20,21,4]. A fracturing fluid should provide sufficient viscosity to suspend and transport proppant into the fracture, and should break into a low-viscosity fluid after the proppant has been placed. This will facilitate cleanup of the fracture by allowing rapid flowback of fluid to the surface. The viscosity of gelled frac fluid is a criterion for stability regarding transporting proppant while it is pumped downhole and having the ability of fracturing the formation in which the optimum production occurs [9]. Although a minimum viscosity of 500 cP has been reported for optimally placing the proppant downhole [13], and creating the desired conductivity, a lack of sufficient evidence and knowledge of downhole conditions has led to ambiguity regarding the required viscosity of a frac fluid system.

Researchers have shown that high total organic carbon (TOC) interferes with crosslinking in a gelled fracturing fluid [6], and, therefore, high TOC waters, such as produced water, should not be used during hydraulic fracturing without due consideration. Any brackish water resources comprised of treated produced water, seawater, or municipal waste water, could be one important remedy in terms of water sourcing for hydraulic fracturing. These water sources are not suitable for drinking water use because of the high TDS content, but could be of significant interest for oil and gas activities. The solution to water shortages related to hydraulic fracturing seems simple, but because of cost concerns, it requires a thorough understanding of the chemical composition of a fracturing fluid and its interaction with water constituents (e.g., high TDS). There have been few scientific and industrial studies of produced water reuse in hydraulic fracturing where the influence of individual cations on fracturing fluid stability was examined [11,21]. However, this was one feature, among many, associated with poor water resource (i.e., brackish waters) usage in hydraulic fracturing. The freshwater source replacement with brackish waters could be beneficial to oil and gas operators in several ways, yet fracturing fluid chemical composition should be optimized when used in brackish waters based on the different constituents in the water. This work discusses use of a synthetic brackish water. Additionally, the chemical composition of carboxylmethyl cellulose (CMC) fracturing fluid was optimized by varying three primary components of gelled fracturing fluid—pH, polymer concentration, and crosslinker concentration. The results of this study are reported in 3D contour maps of viscosity at different polymer loadings.

It is hoped that the work summarized here will be valuable in terms of enabling the oil and gas industry to better understand the interaction of fracturing fluid chemicals with TDS content across the brackish water spectrum (2500–15,000). Application of these generated viscosity maps with poorer quality water should help assist oil and gas operators in minimizing fracturing chemical costs when using CMC crosslinked gel fluids, and minimizing their dependence on finite freshwater resources.

2. Materials/methods

2.1. Synthetic water

For this set of experiments, a model or synthetic water was developed to be identical to a recycled produced water except for the presence of organic matter. The model water was created using low-TOC tap water and dissolving a specific amount of particular salts to reach the determined concentration such that total ions of modeled water was equal to ionic TDS (total sum of ions concentration) of recycled water. The added salts were NaCl, $FeCl_2$, $NaCO_3$, NH_4Cl, NaBr, Na_2SO_4, $BaCl_2$, $CaCl_2$, KCl, $MgCl_2$, $MnSO_4$, $FeSO_4$, H_3BO_3, aluminum chloride hydrate, and $SrCl_2$ (See Table 1). The stock solution was then diluted with tap water to represent low salinity water samples with a TDS concentration of 2500 mg/L.

2.2. Materials

A fracture package that included CMC polymer and zirconium crosslinker chemicals was used as the base fluid for this study. This fluid consists of CMC based polymer, a buffer to adjust pH, and a metal crosslinker (zirconium) as the base components. Materials for this study were from a frac fluid package called PermStim, and were provided from a service company (Halliburton Inc., Fort Lupton, CO, USA).

2.3. Design of Experiments (DOE)

To generate a well-covered 3D map for apparent viscosity, DOE using a statistical software, Minitab (release 17, Minitab Inc., State Collage, PA), was performed. The following three aspects of this study were analyzed by the DOE: factors, level, and response. Factors (inputs to the experiments) are basically variables in each experiment and typically are classified as controllable or uncontrollable. In this case, there were three controllable factors: pH, crosslinker concentration, and polymer loading. Likewise, there could be other types of factors, such as changes in chemicals purity and viscometer variation, but they were controlled during the experiments by dedicating the same chemicals and conducting control runs on different viscometers. Control runs were used to visually examine the operation of viscometer by comparing viscosity profile for a single frac fluid chemistry at the time of experiments. During this study, levels of each factor were based on practice. However, to simplify the DOE, only two levels, the maximum and minimum of each of three factors,

Table 1
Water quality composition for model water.

Parameter	Model water concentration (mg/L)
Gravimetric TDS	27,354
Ionic TDS	24,706
TOC	0
NH_4	18
Br	67
Cl	14,886
SO_4	73
HCO_3	183
Al	1.3
Ba	10.8
B	8.8
Ca	44.8
Fe	1.8
K	517
Mg	10.2
Mn	Na
Na	8877
Si	3.9
Sr	3.3
Cu	Na