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Flow-induced proppant carrying capacity

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ABSTRACT

A subclass of viscoelastic surfactant fluids are investigated as flow-dependent proppant carrying fluids. Shear-induced structure networks have the potential to eliminate the need for cross linkers and viscosity breakers associated with traditional fluids because they shear-thicken and shear-thin depending on the fluid pump rates in the fracture. Particle tracking velocimetry is used to visualize proppant settling velocity inside a fracture flow cell. We show that settling velocities in high shear flows are reduced by a factor 20 compared to settling in low shear ones and fluids at rest. Couette cell and oscillatory rheometry are used to investigate the induced viscoelasticity. The critical shear rate required for fluid thickening and the succeeding viscosity contrast ratio determine the extra proppant carrying capacity.

1. Introduction

Unconventional gas is produced from shale formations where reservoir permeability ranges from 1 to 1000 nD compared to > 1 mD for conventional hydrocarbons (King, 2012). Low permeability means that reservoir stimulation is required in the form of hydraulic fracturing. This involves pumping large volumes of fluid at high pressures into the reservoir to generate fractures that increase exposed matrix surface area and provide more permeable paths for hydrocarbons to flow from reservoir to wellbore.

Once a fracture is created, it is packed with proppant that keeps it open when fluid pressures are let down and the fracture partially closes. During the proppant placement stage, pumping the slurry deep into a fracture requires specific rheology. A high proppant carrying capacity, (high viscosity) ensures premature settling does not occur. Once proppant has been placed in the fracture, the fluid must be recovered to the surface in the flowback stage. This requires a low viscosity (Montgomery, 2013). The viscosity and associated proppant pack retention requirements entail the use of complex sequences of chemical treatments.

Due to concerns over damage to proppant packs caused by residue from traditional fluids (such as guar gum), viscoelastic surfactants (VES) fluids have found increasing application for proppant transport in hydraulic fracturing (Barati and Liang, 2014). The work reported here investigates the properties of a subclass of viscoelastic surfactant solutions not previously reported, for use as a self-regulating fracturing fluid in a low concentration range, below what is commonly used. Most VES have very high zero-shear viscosity (Gupta, 2009). The fluids presented here are Newtonian and have very low viscosity and no elasticity at low shear rates. Only above a critical shear rate do they exhibit flow-induced viscoelasticity (FIVE) with correspondingly high proppant carrying ability. In this way they are unlike other VES fluids used for fracturing. We concentrate on the rheological behaviour during proppant placement. We show that the fluid's carrying capacity is flow rate dependent and increases with increasing flow. This obviates the need for viscosifiers and breakers because high carrying capacity is achieved by a shear induced structure network.

We investigate the fluid rheology effects on carrying capacity in a specifically designed fracture flow cell. The questions studied are: (1) how do rheological properties from a Couette cell relate to proppant suspension in fracture flow? (2) Can flow rate in a fracture regulate carrying capacity, and (3) what viscoelastic properties are present in the different shear regimes? Section 2 outlines the background physical and chemical properties. An experimental description follows in Section 3 and the results are discussed and analysed in Section 4.

2. Background

2.1. Hydraulic fracturing processes

In the first stage of stimulation called the “pad”, a proppant-free gel fluid is injected to initiate fracturing. Fractures are on the order

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Nomenclature

Latin

A	particle cross sectional area
C_D	drag coefficient
d	diameter
F	force
g	gravity
G′	elastic modulus
G″	viscous modulus
m	mass
P	pressure
R	particle radius
Re	Reynolds number
R_{vc}	viscosity contrast ratio
t	time
v	velocity
x	x-distance
y	y-distance
z	z-distance

Greek

γ	shear rate
Λ	relative particle settling velocity
μ	viscosity
ρ	density

Subscripts

0	zero shear
cr	critical
d	drag
f	fluid
max	maximum
p	particle
s	settling
t	terminal
x	x-direction
y	y-direction
z	z-direction

of 100 m long but can reach 300 m. Widths range from 1 to 10 mm but average around 2.5 mm (Yu and Sepehrnoori, 2013). These dimensions depend on the reservoir characteristics as well as the treatment type. Low viscosity fluids tend to produce long and thin fractures whereas more viscous fluids produce short and wide ones (Weaver et al., 2002).

In the second stage, called “placement”, proppant sand is transported into the fracture by fluid suspension. These particles form a porous proppant pack that holds open the fracture through which unconventional gas is produced. It is therefore critical to the success of the treatment that the proppant pack fills the whole fracture while providing optimum permeability and structural integrity. Finally, in the third stage called “flowback”, the fracturing fluid is pumped back through the proppant pack to the surface.

The most common fluids used for placement are polymers such as guar gum. Borate ions are added to increase viscosity by creating a cross-linked polymer network (Kefi et al., 2004). Subsequently, time-delayed viscosity breakers (acids or specific enzymes) are used to thin the fluid (Montgomery, 2013). Thus for both placement and flowback, additional chemicals are added to create the required rheology. Polymer often remains inside the proppant pack greatly reducing permeability. Polymers also concentrate on the fracture walls in the form of a filter cake that can prevent diffusion of gas from the matrix into the fracture. As productivity and environmental concerns associated with fracking increase, it is important to look for alternative fracturing fluids that can both eliminate residue in the proppant pack and reduce the chemicals needed.

Recently, alternative fracturing fluids used for proppant suspension have been developed. These include slickwater fluids which have very low viscosity, hybrid fracturing (a combination of slickwater and traditional fracturing stages), foamed fluids and viscoelastic surfactants (VES) (Gupta, 2009). VES fluids are composed of molecules that self-assemble into structured micelles. This self-assembly is concentration dependent and structures range from small balls and rod-like micelles, at low concentrations, to worm-like micelles and extended networks at high concentrations (Lin et al., 1994; Vasudevan et al., 2008). Fracturing fluid applications rely on concentrations that give rise to very high zero-shear viscosity due to micellar aggregates. Such fluids are shear thinning (Gupta, 2009) and formulations are simple compared to polymer based fluids. Cationic, anionic or zwitterionic surfactants have been used in combination with an inorganic salt, but also in combination with each other. To boost high temperature stability, organic salts have also been added to VES formulations (Samuel et al., 2000). Since VES fluids have high zero-shear viscosity, breaking the fluid during flowback is still required. This is commonly done by contact with hydrocarbons or with added internal breakers (Barati and Liang, 2014). An example of such a fluid is ClearFRAC®, a purely shear thinning VES based fracturing fluid produced by Schlumberger (Kefi et al., 2004).

Whereas VES fluids were developed as a high viscosity alternative to polymeric fluid (to overcome the damage due to residue in the proppant pack), slickwater fluids were developed as a low viscosity alternative. Slickwater fluids are essentially water with very few additives, most commonly a “slickening” agent to reduce friction in the wellbore. To compensate for the low viscosity which results in poor proppant transport, slickwater jobs are pumped at much higher rates: 100 bbl/min or higher compared to 10–50 bbl/min for other fluids and much lower proppant loading (Palisch et al., 2010). In this way, slickwater relies on the inertial transport of proppant at high flow rates due to higher forces of fluid on the particle.

2.2. Shear-induced structure viscoelastic fluids

Different kinds of slickwater and VES fluids have been applied in countless stimulation treatments and literature spans laboratory development to field tests. Such fluids have shown improved production due to higher retained proppant conductivity post-stimulation (Crews et al., 2008; Dayan et al., 2009; Gomaa et al., 2011, Kaufman et al., 2008, Omeiza and Samsuri, 2014; Samuel et al., 1999, Woodworth and Miskimins, 2007). Here, we aim to couple the low viscous properties of slickwater (for easy injection and recovery) with the high viscoelasticity of VES fluids (for adequate proppant suspension) to develop a new class of fracturing fluids whose rheology is regulated by flow rate. In earlier work we showed that these shear induced structure fluids have increased fluid resistance (and therefore proppant carrying ability) in the near wellbore compared to Newtonian fluids of the same zero shear viscosity (Dogon and Golombok, 2016). In this work we show that at the lowest flow rates, such fluids have very low viscosity and Newtonian behaviour, comparable to slickwater. Above a critical flow rate they thicken into a flow induced