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Application of nanoparticles as fluid loss control additives for hydraulic fracturing of tight and ultra-tight hydrocarbon-bearing formations

Reza Barati

Department of Chemical and Petroleum Engineering, Unconventional Resources Laboratory, The University of Kansas, Lawrence, KS 66045, USA

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A B S T R A C T

Fluid loss into the matrix rock and micro-fractures is inevitable during a typical hydraulic fracturing job. This makes the application of a comparable fluid loss additive to reduce the filtrate volumes into microfractures of a shale formation necessary. Injection of polymeric solutions, either as slick water or cross-linked fluids, in order to propagate a fracture and distribute proppants and keep the fracture open is a common practice in hydraulic fracturing of unconventional tight and ultra-tight formations. In addition to propagation of a main fracture, polymeric fluids will be invading the already existing network of micro-fractures and extending the network connected to the main fracture.

Different classes of nanoparticles have been used by several researchers to carry different agents including surfactants and enzymes for hydraulic fracturing purposes. Nano-sized pores and micro-sized fractures in tight and ultra-tight formations require a nano to micro-sized fluid loss additive to improve propagation of the hydraulic fractures by efficiently reducing the fluid loss.

In this study, application of silica and polyelectrolyte complex (PEC) nanoparticles as fluid loss additives for three sets of core plugs with permeability values within the 10^{-5}–10^{-4} mD, 0.01–0.1 mD and 1–40 mD range was investigated. The nano-sized material used in this study significantly reduced the fluid loss volume for the cores with permeability values below 0.1 mD when mixed only with 2% KCl or with low concentrations of guar polymer prepared in 2% KCl.

1. Introduction

Injection of polymeric solutions, either as slick water or cross-linked fluids, in order to propagate a network of fractures and distribute proppants to keep the fractures open is a common practice in hydraulic fracturing of unconventional tight and ultra-tight formations (Economides and Nolte, 2000; Palisch et al., 2008). During injection of the viscous fracturing fluid, fluid loss to the matrix occurs and filter cake forms. Filter cakes with high polymer concentration form on the two faces of the fracture during the injection but normally a small path in the middle of the fracture has the properties of the injected polymer unless the fracture is totally plugged by filter cakes from both faces (Ayoub et al., 2006).

Filtration of fluids on the surface of formation rock causes invasion of filtrate from fracturing fluids into the reservoir while generating filter cake. Carter (Howard and Fast, 1957) presented a linear relation between the leakoff volume and the square root of exposure time of rock to fracturing fluid. Equation (1) is a representative of the leakoff volume, V_L, at a point on the fracture wall.

$$V_L = 2C_W\sqrt{t} + S_p \tag{1}$$

Where C_w is the wall-building coefficient and S_p is the volume leaked off while filter cake is being built up.

External filter cakes are known to be more effective in low permeability rocks while internal filter cake forms in rocks of higher permeability. Fluid loss due to filter cake formation damages the formation both physically, due to clays swelling, and hydraulically, due to shifting of the relative permeability and capillary pressure curves (Barati et al., 2009). These effects will be more dampened in shales since shales contain significant amount of clays. This is specifically the case for shale rocks that contain smectite and montromorillonite clays.

Although fluid loss volumes are smaller for tight and ultra-tight formations, damages due to the invasion of filtrate volumes is

E-mail address: rezab@ku.edu.

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Table 1
Particle size and zeta potential measurement for polyelectrolyte complex and silica nanoparticles. Measurements are conducted for three samples.

	Mean size, nm	Standard error size	pH	Mean zeta, mV	Standard error zeta
Polyelectrolyte nanoparticles	545.43	10.57	8.70	37.16	4.93
Silica nanoparticles	110.7	0.5	9	−41.17	−7.21

significantly more important in very low permeability rocks. Moreover, tight and ultra-tight unconventional hydrocarbon reservoirs typically produce from a system of naturally induced microfractures and these fractures can cause significant fluid loss volumes.

Fluid loss control additives are agents that are applied to reduce the volume of filtrate during the propagation of a hydraulic fracture. Longer networks of fractures will be propagated due to this reduction in filtrate volume. Fracture area is reportedly increasing, as fluid loss coefficient and volume decrease (Hawsey and Jacocks, 1961).

Nano-sized pore throat diameters and micro-sized fractures in shale oil and gas reservoirs can be theoretically plugged using agents that are smaller than the currently used fluid loss additives. In order for the additives to penetrate into the pores of a rock and cause bridging, their diameter must not be larger than one third of the pore throat size (Abrams, 1977). Larger particles can result in external filter cakes and reduce the filtrate volume. However, significantly larger sizes of fluid loss additives compared to the pore throat diameter will result in poor fluid loss prevention.

Pore throat sizes between 10 nm and 1 μm have been reported for different shale rocks (Sensoy et al., 2009; Li et al., 2012). Therefore, particles larger than 3 nm and 300 nm range must be used, respectively in order to plug the pore throats and reduce the filtrate volume, while applying minimum damage to the rock.

Nanoparticles of different size and coatings have been applied successfully as fluid loss additives for drilling applications. Silica nanoparticles have been the most commonly applied type of nanoparticles. These nanoparticles have been reportedly used to plug nano-pores and micro-fractures in shale rocks with the purpose of fluid loss additive for drilling muds of different chemistry (Sensoy et al., 2009; Li et al., 2012; Hoelscher et al., 2012).

Huang et al. (2010) reported successful fluid loss control using nanoparticles by pseudocrosslinking of micellar fluids and improving the visecoelastic surfactant fluid viscosity. However, their nanoparticles were not directly applied as fluid loss control additives.

Barati et al. (2011), (2012) developed a polyelectrolyte complex (PEC) nanoparticle system that delays the release of enzyme breakers for fracturing fluids. Delayed release and degradation of filter cake formed by fracturing fluids have been reported for this nanoparticle system. Fluid loss control capabilities of this nanoparticle system have not been studied.

The main objective of this study is to evaluate the fluid loss control capability of the silica and polyelectrolyte complex nanoparticles. A complete study of fluid loss volumes and coefficients were conducted for core plugs with permeability values ranging from tight to ultra-tight to evaluate the performance of these nanoparticles.

2. Materials and methods

In this section materials and methods used in this paper are summarized.

2.1. Materials

Brine was prepared by mixing potassium chloride (SIGMA-ALDRICH, St. Louis, MO, Lot No. SLBH1238V) with Reverse Osmosis (R.O.) water in a 2% w/w ratio. This brine had a density of 1.0105 g/cm3 and viscosity of 0.95 cP at 25 °C.

A hydroxypropyl guar (HPG) gum blend (Jaguar® 415, Rhodia, Paris, France, Lot No. H0904166E) was used for all of the experiments reported in this research. Jaguar® 415 is a high viscosity,

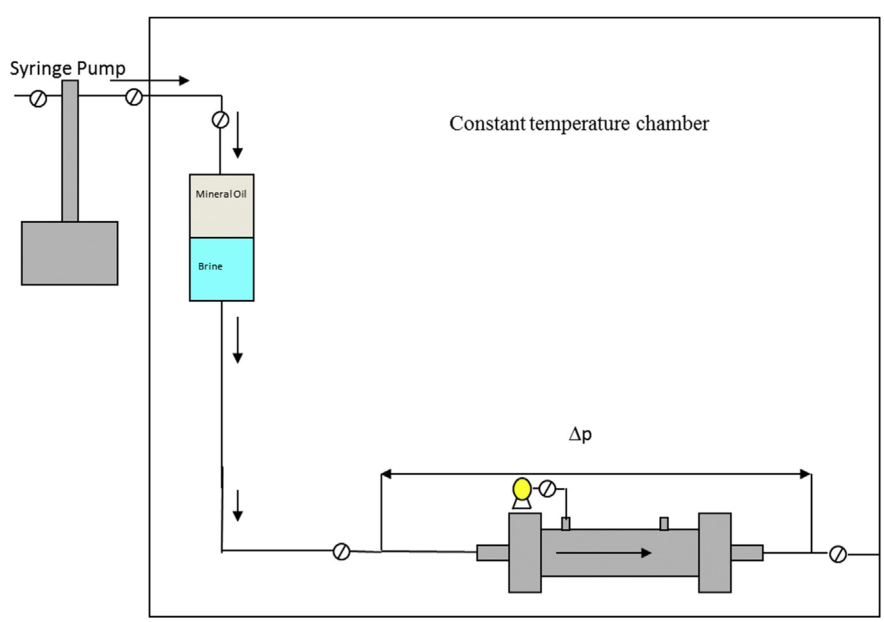

Fig. 1. Schematic of the permeability measurement setup.

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