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Effect of nanoparticle inclusion in fracturing fluids applied to tight gas-condensate reservoirs: Reduction of Methanol loading and the associated formation damage

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ABSTRACT

Hydraulic fracturing is one of the most common stimulation operations for increasing the productivity of a well. The fracturing fluid is one of the key factors in the operation and must accomplish some special requirements and behavior. The fluid that remains inside the fracture and the reservoir after the fracturing operation is finished, causes severe damage to the proppant pack and the formation, leading to a lower efficiency of the stimulation. This study presents experimental research on adding nanoparticles to a commercial fracturing fluid commonly used for tight gas-condensate reservoirs, aiming to enhance its performance in rheological behavior and its capacity to reduce the formation damage associated with the use of fracturing fluids. Nanoparticles with mean particle sizes of 8 and 19 nm with basic and acidic surface modifications were employed for modifying a commercial fracturing fluid. Rheology tests were performed at pressure and temperature conditions of 1.38 MPa and 104 °C, respectively, for the different nanoparticles at dosages of 100 and 200 mg/L. The improvement of those properties enabled the modification of the original formulation of the fluid, reducing the amount of methanol, one of most expensive and hazardous additives, by up to 33%, and reducing the formation damage by approximately 71%. Furthermore, this modified fluid was evaluated in terms of its impact in the wettability of the rock and its relative permeability to water and oil through static (contact angle measurements) and dynamic tests (relative permeability curves). The modified fracturing fluid showed an excellent capability to improve the water-wettability of the rock and also decreased the relative water permeability by 83%. This work demonstrates the suitability of adding nanoparticles to fracturing fluid for stimulations where it is necessary to reduce the relative permeability of water, acting as a Relative Permeability Modifier (RPM) in a conformance for a fracturing operation.

1. Introduction

Over the last decades, generating a wider contact surface between a wellbore and reservoir has been a major concern to the oil and gas industry in regard to hydraulic fracturing to increase hydrocarbon production (Fink, 2013; Paktinat et al., 2005a; Le et al., 2012). This technology is applied to reservoirs with low and medium permeability that cannot provide profitable production rates (Le et al., 2012; Uren, 1934). In this sense, the International Energy Agency (IEA) established that 41.5% of the total world technically recoverable gas corresponds to unconventional gas sources where hydraulic fracturing is needed (IEA, 2012). Additionally, it was estimated that by 2035, approximately 70% of the total gas production will be from unconventional gas in the United States; for China, this number is even higher, i.e., 73%, and in the case of Argentina, this proportion is 43% (IEA, 2012), supporting the

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importance of improvements to hydraulic fracturing and related technologies. In Colombia, hydraulic fracturing has been successfully applied in the central region of the country, including two of the largest fields, namely, the Cupiagua and Cusiana fields, which produce retrograde gas-condensate and light oil, and are mainly characterized as having productive horizons with low porosities and relatively low permeabilities (tight reservoirs) (Ballin et al., 2001; Fan et al., 2005; Giraldo et al., 2000; Osorio and Lopez, 2009; Zabala et al., 2014). Nevertheless, different sources of formation damage have negatively impacted the production rate in this region, including organic deposition, fines migration, geomechanical damage and low flowback of the hydraulic fracturing fluids (Ballin et al., 2001; Fan et al., 2005; Giraldo et al., 2000; Osorio and Lopez, 2009; Zabala et al., 2014).

One of the primary components in a hydraulic fracturing operation is the fracturing fluid (FF), which must guarantee some basic aspects, such as compatibility with the reservoir rock, specific rheological behavior for proppant transportation, low pressure drops caused by friction, and adequate breaking that facilitates flowback (Montgomery and Smith, 2010). These characteristics are desirable in all kinds of FFs, of which, aqueous polymeric-based fluids and oil-based fluids have been the most commonly used since several decades ago, especially the former (Harris, 1988; Lafitte et al., 2012a; Huang et al., 2010). Usually, these type of FF should present certain rheological properties that make possible proppant transportation and its location in the fracture when armed, and after the flowback when disarmed (Harris, 1988; Crews and Gomaa, 2012; Kesavan and Prud'Homme, 1992). The FFs commonly exhibit non-Newtonian pseudoplastic behavior, more specifically shear thinning behavior (Barati and Liang, 2014; Gong et al., 2012). However, there are many problems in hydraulic fracturing operations associated with the use of FF, which are the principal causes of formation damage in this kind of operation (Le et al., 2012; Quintero et al., 2009), including mudcake formation around the fracture due to the high concentration of the remaining polymer and its deposition (Huang et al., 2010) and water blocking due to low flowback of water-based FF. For this reason, flowback of injected fluids or post-hydraulic fracturing recuperation is vital to prevent formation damage, considering that only 15%–30% of the total FF employed in hydraulic fracturing operations returns to the surface (Quintero et al., 2009; Zelenev et al., 2010; Penny et al., 2006; Fink, 2011). To avoid the aforementioned issues in hydraulic fracturing operations, different approaches have been studied by researchers to reduce traditional guar gum (Ely, 1989; Loveless et al., 2011; Holtsclaw et al., 2011; Qun et al., 2008; Williams et al., 2012), reduce the polymer load (Weaver et al., 2002; Weaver et al., 2002; Peles et al., 2002; Economides and Nolte, 2000; Al-Muntasheri, 2014; Nimerick et al., 1997; Harris and Heath, 1998), facilitate the flowback process due to the inclusion of breakers (Economides and Nolte, 2000; Al-Muntasheri, 2014; Gulbis et al., 1992; Sarwar et al., 2011; Nolte, 1985; Hanes et al., 2006; Reddy, 2013) and enhance the cleansing post-fracturing by using microemulsions (Penny et al., 2006; Zelenev and Ellena, 2009; Paktinat et al., 2005b, 2007).

As a result, nanotechnology has been widely researched and tested in several kinds of operations in the oil and gas industry (Zabala et al., 2014; Li et al., 2012, 2013; Huang and Crews, 2008; Patil and Deshpande, 2012; Franco et al., 2013, 2014), including hydraulic fracturing (Lafitte et al., 2012b). Nanoparticles have a particle size between 1 a 100 nm with a high surface area to volume ratio and high dispersibility (Wing, 2006), which make them excellent candidates for in-situ applications without risk of reservoir blocking. Fakoya and Shah (2013), studied the inclusion of nanoparticles of silica to surfactant-based fluids (SBF), polymeric fluids and SBF-polymer blends. The authors found that those nanoparticles enhanced the rheological properties in both SBF and polymeric fluids at concentrations of 0.24 and 0.4 wt%, respectively (Fakoya and Shah, 2013). Lafitte et al. (2012a), synthesized boronic acid-functionalized nanoparticles and used them as crosslinkers in a guar-based fluid. They reported that the viscosity of these fluids is higher at lower polymer concentrations, and the optimal amount of boron required was 20 times lower than that with conventional borates (Lafitte et al., 2012a). Barati et al. (2011), developed a nanoparticulated system to delay the release of breaker enzymes, achieving releasing times up to 12 h, and completely breaking borate-crosslinked guar and hydroxypropyl guar (HPG) gels (Barati et al., 2011). Hurnaus and Plank (2015) found that synthesized ZrO_2 nanoparticles have a similar effect on the crosslinking reaction as the commonly used compounds of zirconium-HPG. However, the improvement of FFs with nanotechnology is still in its earliest stages.

Methanol in fracturing fluids is a key component, mainly used for stimulating water-sensitive formations with low permeability (Malone, 2001). However, the reduction of methanol in hydraulic fracturing operations is vital due the its high cost and its role as an environmental and human health hazard (Montgomery, 2013). To the best of our knowledge, there are no studies reporting the improvement of fracturing fluid performance by the inclusion of nanoparticles that have addressed the reduction of methanol load of FF and its associated formation damage. Therefore, this work aims to assess the inclusion of nanoparticles in a commercial fracturing fluid typically used in tight gas-condensate reservoirs, their effect on rheological properties and their impact on the formation damage based on the results of relative permeability in a core-flooding test. A modified methanol-reduced fracturing fluid is proposed as an alternate fluid for fracturing in gas-condensate fields. In addition, it can operate as a relative permeability modifier (RPM) based on the results of static (contact angles) and dynamic tests (relative permeability curves of the core-flooding test). It is expected that this study will provide a better understanding about the use of nanotechnology in hydraulic fracturing operations as a complementary and green solution based on the reduction of the formation damage associated with its use, as well as its ability to increase oil production.

2. Materials and methods

2.1. Materials

Two commercial silica nanoparticles (Sigma-Aldrich, St. Louis, MO) of different sizes were employed for the modification of a commercial FF and are nomenclated as S8 and S19. HCl (37%) and NH_4OH (28%) were used as surface modifiers of the selected nanoparticles and were purchased from Sigma-Aldrich (St. Louis, MO). To determine the surface acidity of the nanoparticles, a 10% NH_3/He mixture and He (99.9%) gases were used (Linde, Medellín, Colombia).

A commercial polymeric water-based FF was employed for hydraulic fracturing operations in a gas-condensate field of very low permeability located in the central region of Colombia. The employed FF included Carboxymethyl Hydroxypropyl Guar Gum (CMHPG) used as polymeric agent in its formulation, and the crosslinker was a basic zirconium sulfate based component. A bauxite porous media of size 20–40 and a core (Ecopetrol, Colombia) extracted from a formation in a field located in the central region of Colombia were employed for the core-flooding tests. Table 1 summarizes the characteristics of the porous media. A 43°API crude oil with saturated, aromatic, resin and asphaltene contents of 40.13, 13.88, 45.82 and 0.17%, respectively, was used in this study. A synthetic brine composed of 1290 mg/L of NaCl, 60 mg/