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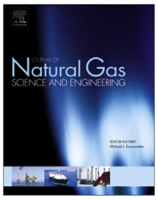

Application of nanoproppants for fracture conductivity improvement by reducing fluid loss and packing of micro-fractures

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ABSTRACT

Hydraulic fracturing has been proved as a successful technology to increase productivity of ultra-tight shale oil and shale gas reservoirs. Although higher concentrations of polymer were traditionally used for conventional fractures, “linear gels”, “waterfracs”, “slick-water” and ”hybrid” fluids have been typically applied for tight shale plays as we produce from formations with lower permeability and higher brittleness. Fracturing jobs in tight shale plays tend to generate or extend a network of fractures while a bi-wing fracture was typically generated in conventional reservoirs. This network of fractures includes a large network of micro-fractures opened during the injection of fracturing fluids. Small fractures tend to close under closure stress unless a nano-sized proppant with significant stress resistance is injected to keep these micro-fractures opened. Although very high conductivity is not required for very low permeability formations, an open fracture or micro-fracture performs better than a collapsed fracture.

Proppants with different mesh sizes of 20/40, 30/50, 40/70, 70/140 and 80/200 with grain diameters ranging from 0.033 inch (0.8382 mm) to 0.0041 inch (104.14 μm) have been used during hydraulic fracturing of tight shale formations. These proppants are large enough to create conductivity in the larger generated or existing fractures but not small enough to penetrate into the existing or generated micro-fractures. This will cause the closure of micro-fractures at the end of a fracturing job thus reduction in the length and conductivity of the complex fracture network. This reduction in the fracture network extension will reduce production from tight shale formations.

The objective of this work is to investigate size, nano-hardness, reduced elastic modulus, fluid loss prevention capabilities as well as their induced fracture conductivity by nano-proppants from a currently known waste product.

Transmission Electron Microscope (TEM) images showed that nano-proppants had particle sizes varying from 100 nm to 1 μm. Particles showed hardness and reduced elastic moduli of 1.3 GPa and 20 GPa, respectively. These properties show potential for these nanoparticles to be used as proppants to keep fractures open under stress.

Fluid loss tests were conducted using 1% (w/w) concentrations of nanoparticles mixed with 2% (w/w) of KCl, cross-linked guar solutions, and cross-linked guar solutions mixed with 1% concentration of nanoparticles and significant fluid loss reduction was observed for one of several types of nanoparticles. These nanoparticles generated significant conductivity when used as proppants in an API fracture conductivity test. Fracture permeability values of 27–33 mD were generated using these nano-proppants.

Use of nanoparticles prior to the placement of larger proppants is recommended in order to prevent fluid loss into the formation, and also increase the conductivity of the fissures and micro-sized fractures.

1. Introduction

Hydraulic fracturing increases the hydrocarbon production from shale plays by connecting the already existing fissures and fractures and generating new small fissures. It is believed that hydraulic

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fracturing fluids can dilate the already existing systems of small fissures and fractures which are initially filled with calcite, quartz or other minerals. Large surface areas and sustainable production from horizontal wells may be caused by the large fracture networks created by the dilation of filled fractures or dissolution of fracture filling minerals (Jaripatke et al., 2010).

Although higher concentrations of polymers were traditionally used for conventional fractures, “linear gels”, “waterfracs”, “slick-water” and ”hybrid” jobs have been typically applied for tight shale plays as we produce hydrocarbons from formations with lower permeability and higher brittleness (Jaripatke et al., 2010). These fracturing fluids are comparatively less viscous and aid in creating fractures with smaller width and longer fracture length. This helps in interconnecting a network of created and natural fractures, generating a larger stimulated reservoir volume. Thus, fracturing jobs in tight shale plays tend to generate or extend a network of fractures while a bi-wing fracture is typically generated in conventional reservoirs (Jaripatke et al., 2010).

Although a very high conductivity is not required for very low permeability formations, an open fracture or micro-fracture performs better than a collapsed fracture. During fluid injection into the reservoir during hydraulic fracturing, the opening of the natural fractures and the pressure applied inside them decreases as the distance increases from the point of injection. Injecting nano-sized particles, followed by the conventionally used larger proppants, would help to sequentially fill the widened natural fractures, allowing deeper percolation of nano-proppants, thus propping more of the fracture length (Khanna et al., 2013). This increases the seepage area thereby enhancing well productivity (Keshavarz et al., 2014).

Increasing the effective conductivity of the hydraulic fractures propagated in tight oil or gas plays by improving the type and placement of proppants will have the following results:

- It will prevent the collapse of already existing micro and nano-sized natural fractures which are opened up during injection.
- Use of very small proppants before the injection of the larger proppants will prevent the collapse of the fissures that are generated during the injection after the injection is stopped.
- It will improve the production of oil and/or gas from the formation by reducing fluid loss and improving the total fracture conductivity.

To the best of these author's knowledge, there has not been a hydraulic fracturing job performed in unconventional tight shale plays where nano-proppants were used to pack the micro-fractures. Specifically, no proppant system with such a small size has been reported previously. Use of nano-proppants prior to the placement of larger proppants will prevent fluid loss into the formation, increase the total extended length of the fracture network by propagating longer micro-fractures, and also increase the conductivity of those fissures and micro-sized fractures. Fig. 1 demonstrates how the injection of nano-proppants will keep the small fissures open and extend the network of small fissures, while commercial proppants keep the main fracture open.

Silica nanoparticles were found to show significant resistance against compressive stress, and have been used successfully in drilling fluids to decrease water invasion into shale formations (Cai et al., 2012; Ozyildrim and Zgetosky, 2010; Zou and Yang, 2006). Silica nanoparticles are very stable and do not coagulate at pH values above 8 (Zou and Yang, 2006) Additionally, silica nanoparticles will not show precipitation problems during the injection since they are very light. If injected with water or linear gels before the injection of larger proppants, the silica nanoparticles can potentially make the fractures longer and more conductive. Several research groups have demonstrated the capability of silica nanoparticles in reducing the damage caused by fines migration (Habibi et al., 2011; Ahmadi et al., 2011).

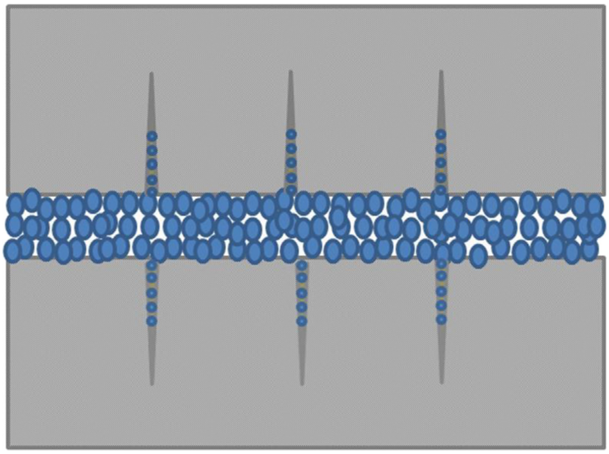

Fig. 1. Schematic picture of proppants and nano-proppants distributed in fractures and micro-fractures, respectively.

1.1. *Fly ash*

Fly ash is a byproduct of coal-fired power plants. After the coal gets burnt, the heavier ash particles fall to the bottom of the burning chamber and the lighter ash particles are carried away with the exhaust gas. The latter is known as fly ash and the former is known as bottom ash. Before getting expelled into the atmosphere, these fly ash particles are removed and collected by electrostatic precipitators (Ladwig, 2010). Fly ash particles are generally spherical in shape as the particles solidify rapidly while being suspended in the exhaust gas (Snellings et al., 2012).

2. Objectives

Fly ash from power plants is considered a waste product. This cheap waste material includes nano-particles of silicon oxide, calcium oxide and aluminum oxide. Application of fly ash nanoparticles as fluid loss minimizing additives and nano-proppants for tight and ultra-tight reservoir rocks is studied in this paper for the first time.

3. Materials

3.1. *Fly ash*

The chemical properties of fly ash are largely influenced by the chemical content of the coal burnt. Two classes of fly ash are defined by ASTM C618: Class C fly ash and Class F fly ash. Class F fly ash is produced when the harder, older anthracite and bituminous coal is burnt. Class C fly ash is produced from the burning of younger lignite or sub-bituminous coal. The main difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash (ASTM C618 – 08, 2008). Fly ash is a heterogeneous material. SiO_2, Al_2O_3, Fe_2O_3 and CaO are the main chemical components present in fly ash. Other components like MgO, TiO_2, arsenic, etc. are also present. Table 1 gives a list of constituents and their typical compositions in class F fly ash.

There are two samples of fly ash donated by Alliant Energy; Class ‘C’ and Class ‘F’, with slight differences in their constituents and compositions. After being washed with 2% KCl, they were imaged using a Transmission Electron Microscope (TEM) followed