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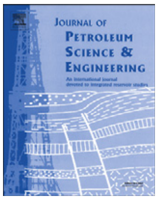

Evaluation of ultra-light-weight proppants for shale fracturing

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ABSTRACT

The goal of the present work is to evaluate ultra-light-weight proppants for fracturing of shale gas reservoirs. Three proppants (ULW-1, ULW-2, and ULW-3) have been studied. Mechanical properties of proppant packs as well as single proppants have been measured. Conductivity of proppant packs has been determined as a function of proppant concentration and confining stress at 95 °C. ULW-1 and ULW-2 are deformable; ULW-3 is comparatively brittle. The proppant conductivity decreases as the confining stress increases; the conductivity ranges from 1 to 500 mD-ft at 6000 psi. For ULW-1 and ULW-2, the conductivity first decreases (from partial monolayer to monolayer) and then increases (from monolayer to multilayer) with an increase in proppant concentration. A partial monolayer (0.07 lbm/ft^2) of ULW-2 provides almost as much conductivity as a thick proppant pack with a concentration of 0.7 lbm/ft^2 at various stress levels. The conductivity of ULW-3 increases as the proppant concentration increases. A partial monolayer of ULW-3 is about 10 times as conductive as the partial monolayers of other two proppants, but at higher concentrations, ULW-3 is many hundred times more conductive than the other two proppants. The conductivities of ULW-1 and ULW-2 packs are too low, but that of ULW-3 at high concentrations appears to be high enough for stimulating 1 μD permeability shales.

1. Introduction

US natural gas production peaked in 1970s at about 22 Tcf/yr, declined to about 16 Tcf/yr in 1980s and has rebounded to about 20 Tcf/yr last year. This rebound is due to the production of natural gas from tight gas and shale reservoirs. For example, 8000 wells are producing gas from Barnett shale (Wang, 2008). The key to success in Barnett Shale can be attributed to horizontal drilling and multi-stage vertical fracture stimulation (Rickman et al., 2008). Major gas shale plays are unfolding in the Woodford, New Albany, Haynesville, Fayetteville etc. (Wright, 2008). Integration of shale geology, petrophysics, drilling, and fracturing technology is needed to develop the optimum stimulation of these very tight reservoirs (Britt and Schoeffler, 2009; Hudson and Matson, 1992; Kundert and Mullen, 2009).

Various types of fracturing fluids are available. Water based fluids (e.g., water with a small amount polymer or slickwater) are popular for they are cheaper, easy to handle, and give good performance. Addition of water soluble polymers to these fluids increases their viscosity enhancing proppant transport (Kundert and Mullen, 2009). At higher temperatures, use of crosslinkers offsets the decrease in viscosity due to thermal effects. Potential problems with the use of water based fracturing fluids are formation damage of water sensitive zones, residual damage and filter cake formation with the polymers, and usage/disposal of large amounts of water. There are special chemicals and breakers which can reduce some of these problems. There are oil-based and alcohol-based fracturing fluids for water sensitive formations. Finally, gas energized water-based fluids (also known as foams) have been used for the ease in clean-up, low water consumption, and low proppant/formation damage (Shah et al., 1992).

Slickwater fracturing produces long skinny fractures, whereas gelled water produces wider and shorter fractures (Kundert and Mullen, 2009). In some shale formations (e.g., Barnett shale) many natural fractures exist; thus slickwater fractures connect the long hydraulic fractures to these natural fractures and create a large stimulated reservoir volume. The use of slickwater fracturing has increased over the last decade due to large stimulated volume and lower cost fluids. A potential drawback of using slickwater lies in its inability to transport conventional proppants deep into the fractures (Gadde and Sharma, 2005). Use of gels can help in proppant transport but introduces large formation damage by blocking pores in nano-darcy shales (Kaufman and Penny, 2008). A potential solution to this problem can be the use of light weight proppants which can easily be transported by slickwater (Aboud and Melo, 2007; Brannon et al., 2004; Rickards et al., 2006). Cawiezel and Gupta (2010) have suggested the use of viscoelastic

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foamed fracturing fluids with ultra-light-weight proppants for ultra-low permeability reservoirs. It is not clear whether these proppants can endure the stresses expected in various shale formations and at the same time be able to provide enough fracture conductivity.

The goal of the present work is to evaluate ultra-light-weight proppants for fracturing of shale gas reservoirs. Proppant strength has been measured for proppant packs and individual proppants. The conductivity of proppant packs is measured as a function of proppant concentration under reservoir pressure and temperature conditions. In Section 2, we describe the methods used to evaluate the proppants. In Section 3, the results are discussed.

2. Material and methods

2.1. Proppants

Three ultra-light-weight proppants (ULW-1, ULW-2, and ULW-3) have been studied. The first, ULW-1 is polymeric and the lightest of all three. The second, ULW-2 is a resin coated and impregnated ground walnut hull. Light and porous walnut hull by itself is extremely weak, but the resin coating and impregnation increases its strength significantly. Resin coating technology on sand proppants has been around for a while. The third, ULW-3 is a porous ceramic particle coated (not impregnated) by a resin. The air trapped in the porous matrix within the resin coating controls the density of the particle and the coating of resin gives extra strength.

Table 1
Nominal density, bulk density, porosity and sphericity for the three proppants studied.

	ULW-1	ULW-2	ULW-3
Nominal density	1.08	1.25	1.75
Bulk density (g/cc) (closure stress = 0 psi)	0.6	0.77	1.19
Porosity of proppant pack (%)	44	36	31
Sphericity	1	0.62 ± 0.7	0.78 ± 0.1

Table 1 shows the bulk density, bulk porosity, and sphericity for the three proppants. Nominal density is the density of proppant particles quoted by the supplier and is approximately the absolute density of individual proppants. ULW-1 is the lightest proppant and ULW-3 is the densest. The porosity of ULW-1 pack is the highest and that of ULW-3 pack is the lowest. A Riley sphericity value of one indicates well roundedness and a smaller value indicates the presence of angularity (ISO 13503-2, 2006). As indicated in Table 1 and Fig. 1a, ULW-1 is completely spherical, ULW-2 is extremely angular, and ULW-3 is intermediately rounded. The spherical pack has the highest porosity. The other two packs have lower porosity.

Fig. 1b shows the sieve size distribution of the proppants. ULW-1 has a sieve size distribution of 18–40. ULW-2 has a sieve size distribution of 16–35 and the distribution is the broadest of the three proppants tested. ULW-3 has a sieve size of 14–25. The average particle size is the smallest for ULW-1; it is also the most spherical proppant.

2.2. Strength of proppants and proppant packs

The crush test of proppant packs was performed at two different temperatures, 25 °C and 95 °C. The crush test was done at a stress level of 15,000 psi. Stress was held at specified stress levels for two minutes. The end product of the crush test was sieved to determine the amount of proppant crushed to form finer particles. The strength of individual particles was also tested at both these temperatures. The equipment shown in Fig. 2 was used. The equipment has three parts, top piston, bottom piston, and cylindrical sleeve. The whole equipment is made out of aluminum to keep the tool light in weight, but the surfaces of the pistons were made of tool steel, so that proppant does not embed into the equipment during the test. The equipment is placed in a Humboldt press machine.

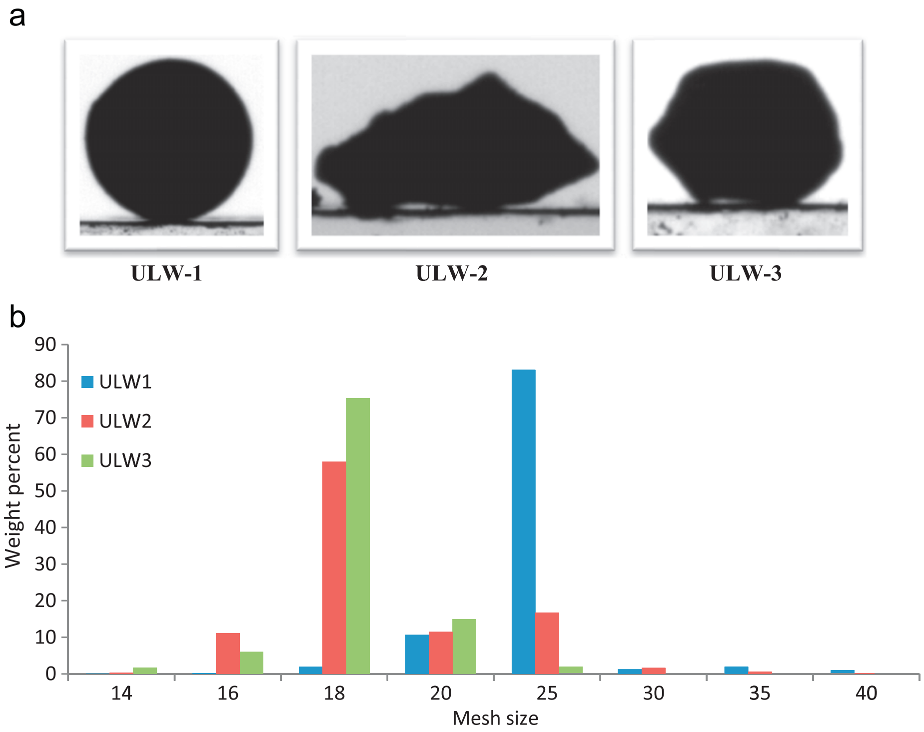

Fig. 1. (a) Two-dimensional close-up images of ULW-1, ULW-2 and ULW-3 with a magnification of 23×. (b) Sieve size distribution for ULW-1, ULW-2 and ULW-3 proppants.