Effects of Proppant Selection on Shale Fracture Treatments
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The oil and gas industry has strived to provide methods to test the proppants used in shale formation fracturing, but they still do not adequately address many of the factors that impact their effectiveness. There are many factors that occur downhole that need to be considered, such as:

- Proppant fines generation and migration in the fracture
- Proppant resistance to cyclic stress changes
- Effective conductivity vs. reference or baseline conductivity
- Proppant flowback and pack rearrangement in the fracture
- Proppant embedment in the fracture face
- Downhole proppant scaling

The hypothesis of this study was that because of the formation characteristics in the three areas studied, curable resin-coated sand (CRCS) with its grain-to-grain bonding technology should provide higher downhole fracture conductivity leading to increased postfracture treatment well production. To verify the hypothesis, laboratory tests outside the traditional long-term baseline conductivity were conducted with proppants and formation core samples from each area. The objective was to more accurately simulate proppant performance under specific downhole conditions of temperature, pressure, fluid, and rock properties pertaining to each area.

Proppant Selection Factors Studied
Proppant fines generation and migration, as well as proppant flowback, were studied in the Fayetteville Shale of Arkansas. Proppant fines and embedment were studied in the Bakken Shale of North Dakota. And finally, proppant pack cyclic stress, embedment, and scaling were examined in the Haynesville Shale of Louisiana.

Proppant Fines Generation and Migration
Proppant fines are the small particles that break off from the proppant grain when subjected to fracture closure stress. The small broken pieces reduce pack porosity and permeability, and cause major degradation in the conductivity of proppant packs. When proppant fines migrate down the proppant pack toward the wellbore, they accumulate and reduce flow capacity.

Proppant Pack Cyclic Stress
When comparing proppants, one factor often overlooked is a proppant’s performance under cyclic stress changes. The forces of cyclic stress exerted on proppants downhole can cause them to fail. Events often occur multiple times throughout the life of a well, such as shut-ins because of workovers or connections made to a pipeline; in some cases, a well could be shut in because of pipeline capacity. These events lead to cyclic changes in fracture closure stress. This varying amount of pressure and stress can cause the proppants to shift or rearrange, resulting in a decrease in fracture width as well as additional proppant fines and proppant flowback.

Effective Conductivity
Reference or baseline conductivity is often used to predict how much hydrocarbon can flow through a proppant pack. Typical reference conductivity laboratory tests are run at a low flow rate of only 0.1 ft³/D per perforation, which does not simulate realistic downhole flow conditions. High pressure, temperature, and flow rate downhole cause proppant fines to migrate and severely decrease fracture conductivity.

To incorporate the effect of downhole proppant fines, effective conductivity is calculated using the Coulter and Wells (1972) method to reduce the published reference conductivity. It is stated that only 5% fines can cause a 62% reduction in proppant pack conductivity.

Proppant Flowback and Pack Rearrangement
Proppant flowback from fractured wells leads to high operational costs and can compromise safety. However, it can be prevented by the use of CRCS. Proppant flowback is a leading cause of well production decline, equipment damage, and wells shut in for repairs. Uncoated or precured RCS can flow back out of the fracture and into the wellbore as the...
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TECHNOLOGY UPDATE

well is produced. Proppant flowback can cause damage to downhole tools as well as surface equipment. In horizontal wells, flowback of uncoated proppant can deposit along the lateral. All of these issues lead to expensive repairs and cleanouts. Proppant flowback can also cause loss of near-wellbore conductivity and reduced connectivity to the reservoir. CRCS has grain-to-grain bonding that eliminates proppant flowback, if applied properly, by forming a consolidated proppant pack in the fracture.

Proppant Embedment
Proppant embedment is a serious problem that reduces fracture width and conductivity. Proppants can embed into the fracture face, especially in soft shale formations, leading to reduced fracture width and lower fracture flow capacity. Compared with uncoated proppant, CRCS has less embedment into the formation because its grains bond together forming a consolidated proppant pack that redistributes closure stress. Another concern with proppant embedment is the creation of formation fines (spalling), which can migrate and cause additional loss of fracture conductivity.

Downhole Proppant Scaling
A geochemical reaction commonly known as proppant scaling or proppant diagenesis can occur downhole in the fracture in high-pressure/high-temperature wells. A crystalline material can form on uncoated ceramics and, acting like formation fines, plug the porosity and permeability of the proppant pack, thus reducing conductivity. The effects of scaling can occur slowly, but as long-term exposure increases, production decreases more rapidly because of the detrimental effects. A resin coating greatly reduces proppant scaling by providing a hydrophobic layer that prevents water from dissolving the proppant surface and forming scale.

Active Shale Play Analysis
A number of fracturing treatments performed in three active areas in the United States, the Fayetteville, Bakken, and Haynesville shales, were reviewed. Reservoir characteristics, proppant type, and postfracture treatment production results were examined in each area. The proppants compared in this study were used routinely in the three areas. Uncoated fracturing sand (UFS) and CRCS were compared in the Fayetteville, UFS and CRCS were likewise compared in the Bakken, and lightweight ceramic (LWC) proppant and CRCS were compared in the Haynesville.

Fayetteville Shale
Fracture treatments on 17 wells were compared in White County, Arkansas. In addition, proppant fines and proppant flowback in these wells were examined. All the wells had similar characteristics and completion techniques. Ten of the wells used 100% 40/70 UFS, while seven wells had 10% tail-ins using a 40/70 CRCS. The average 14-month cumulative gas production for the CRCS wells was 22% higher than the UFS wells (Fig. 1). CRCS wells are making more oil as a result of less proppant fines and less proppant embedment, compared with UFS.

Bakken Shale
A study was conducted comparing the productivity of 13 Bakken wells in Dunn County, North Dakota, fractured with CRCS and UFS. In addition, proppant fines and proppant embedment in these wells were examined. The test group consisted of five wells using 20/40 CRCS and eight wells using 20/40 UFS. All wells had similar vertical depths, lateral lengths, and completion techniques. The average nine-month cumulative oil production for the CRCS wells was 40% higher than the UFS wells (Fig. 1). CRCS wells are making more oil as a result of less proppant fines and less proppant embedment, compared with UFS.

Proppant Fines.
Wet, hot crush tests were performed comparing 20/40 UFS with 20/40 CRCS. At a fracture closure stress of 8,000 psi, UFS exhibited 16.5% fines while the CRCS showed only 1.4% fines. Twelve times more proppant fines from UFS resulted in less proppant pack conductivity, compared with CRCS.

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Proppant Embedment. Proppant embedment into Bakken core was measured. The UFS embedment depth into the Bakken core was 2.5 times greater than CRCS. Increased embedment from UFS resulted in less fracture width and more formation fines, compared with CRCS.

Haynesville Shale
Fracture treatment production results were studied on 16 wells in the Haynesville Shale. In addition, proppant pack cyclic stress resistance, proppant embedment, and proppant scaling in these wells were examined. All the fracture treatments were completed on wells in DeSoto Parish, Louisiana. All wells had similar characteristics, completion techniques, fracturing stages, and proppant volumes. Eleven of the wells used 40/80 LWC proppant while five used 40/70 CRCS. The average 10-month cumulative gas production for the CRCS wells was 37% higher than the LWC proppant wells (Fig. 2). CRCS wells are making more gas than LWC proppant wells because of less proppant fines, less proppant embedment, and less proppant scaling.

Proppant Pack Cyclic Stress Resistance. The amount of proppant fines generated after cyclic stress was measured for CRCS and LWC proppant. CRCS had only 0.89% fines while LWC proppant had 5.02% fines. A sieve analysis was conducted on these fines to determine the particle size distribution. CRCS had no fines <100 mesh, while LWC proppant had 71.3% fines <100 mesh. Proppant fines <100 mesh are more likely to migrate through the proppant pack and reduce pack permeability, compared with larger particles.

Proppant Embedment. Laboratory testing demonstrated that the 40/80 LWC proppant embedment depth, into Haynesville core, was 2.0 times more than 40/70 CRCS. Increased embedment from LWC proppant results in less fracture width and more formation fines, compared with CRCS.

Proppant Scaling. Laboratory scale tests with CRCS and LWC proppant were conducted at downhole Haynesville conditions. Aluminosilicate scale formed on the LWC proppant while no scale formed on the CRCS.

Conclusion
The analysis shows that in the three shale areas studied, there is a correlation between proppant types pumped, proppant performance under more realistic laboratory tests, and the corresponding post-treatment well production. The study also confirms the hypotheses that curable resin-coated sand outperforms uncoated fracturing sand and lightweight ceramic proppant in the areas studied.

References