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Review of the Proppant Selection for Hydraulic Fracturing

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Abstract: Hydraulic fracturing is not a new technology and has become an essential part of petroleum industry to produce oil and gas. The goal of hydraulic fracturing is to create a highly conductive fracture system that will allow flow of fluid and/or gases through the formation to production well. A proppant is a solid material, typically sand, treated sand or man-made ceramic materials, designed to keep an induced hydraulic fracture open. Many proppants and mesh sizes are available for the design of a fracture stimulation treatment. Proppant types and sizes are effected on the fracture conductivity. This paper describes the factors which are critical to proper proppant selection and ultimately, proppant performance. Proppant fines, Proppant pack cyclic stress, Effective Vs Reference conductivity, Proppant flowback, Proppant pack rearrangement, Proppant embedment and Downhole proppant scaling are explained in relation to proppant selection.

Keywords: Proppant, hydraulic fracturing, sand, man-made, synthetic proppant

1. INTRODUCTION

A proppant is a solid material, typically sand, treated sand, or a manufacture ceramic material that is designed to prevent and keep an induced hydraulic fracture open during and after a fracturing treatment. Proppants are used to hold the walls of the fracture apart to create a conductive path to the wellbore after pumping has stopped and the fracturing fluid has leaked off. Placing the appropriate concentration and type of proppant in the fracture is critical to the success of hydraulic fracturing treatment. Proppants types and grain sizes selection are the key of hydraulic fracturing design, because natural sand or synthetic proppants are the only material left in place downhole after termination of the operation and are the critical agents whose performance decides on success or failure of the job.

2. HISTORY OF PROPPANT

For the first propped fracture treatments in the late 1940s and early 1950s, proppant consisted of sand dredged from riverbeds. Stronger and better processed sand became available in the mid-1950s from the St.Peter sandstone (Fast, 1961; Montgomery and Steanson, 1985). This formation, mined near Ottawa, Illinois, produced a high quality proppant that become known as Ottawa frac sand. Later more angular sand became available from the Hickory Sandstone formation, mined from the Heart of Texas mines near Bardy, Texas, and science that time many supplier for natural sand proppant have come into the market. In the 1960s, a variety of manufactured proppants were introduced including walnut hulls, aluminum pellets, glass beads, iron shot, and plastic beads. As deeper wells were drilled in the 1970s, the shortcomings of sand for high-stress environments became apparent. Other high-strength proppants were also introduced in the 1970s and 1980s including resin-coated sand (curable and procured), zirconia (no longer used), lightweight ceramics, and intermediate density/ intermediate strength proppant(ISP). Currently, the major proppants used for propped fracture stimulations include ISO quality sand, procured resin-coated sand, lightweight ceramics, ISP, sintered bauxite.

3. PROPPANT TYPES AND GRAIN SIZES

3.1 Normal or Body Text

There are basically divided into two group of proppants used for hydraulic fracturing applications: either naturally occurring silica sands or made-made ceramic proppants. In the hydrocarbon stimulation market, presently, five different types for hydraulic fracturing are available in various grain sizes and for different prices from several manufactures:

(1) Natural quartz sand

(2)Synthetic intermediate-strength low-density alumina silicate (ceramic) proppant

(3)Intermediate-strength high-density alumina oxide and silicate proppant

(4)High-strength high-density bauxiteproppant

(5)High-strength low-density zirconia-silicate proppant.

Proppant with larger grain sizes provide a more permeable pack because permeability increases the square of the grain diameter, however, their use must be evaluated in relation to the formation that is propped and the increased difficulties that occur in proppant transport and placement. Larger grain sizes can be less effectives in deeper well because of greater susceptibility to crushing resulting from higher closure stresses (as grain size increases, strength decreases.

The following general guidelines may be used to select proppant based on strength and cost:

Sand ----- closure stresses less than 6000 psi

Resin-coated proppant (RCP) ---- closure stresses less than 8000 psi

Intermediate-strength proppant (ISP) ---- closure stresses greater than 5000 psi, but less than 10000psi

High strength Proppant ---- closure stresses at or greater than 10000 psi

Table I. Mechanical Properties of Proppants for Hydraulic Fracturing

Mechanical Properties of Proppants for Hydraulic Fracturing			Mechanical Properties			
Proppant Type			Specific Gravity (g/cm^3)	Bulk Density (lb/ft^3)	API Crush Test: %fines at 10000 psi (20/40) Grain Sizes	Closure Stress Resistivity and Field Application Boundary (psi)
Provenance	Strength	Type				
Natural	Low-strength	quart sand	2.65	96.03 - 103.0	40.8 - 59.0	3000 - 5000
Synthetic	Intermediate-strength	Low-density alumina silicate Proppants	2.70 - 2.75	99.0 - 102.4	4.3 - 9.5	8000
		High-density alumina oxide and silicate proppants	3.15 - 3.27	112.5 - 116.8	3.5 - 6.1	10000 - 12000
	High-strength	Alumina oxide proppants	3.60 - 3.80	130.0 - 144.0	1.5 - 5.0	15000
		Zirconia-silicate proppants	3.15 - 3.17	106.0 - 120.0	0.3 - 4.6	15000

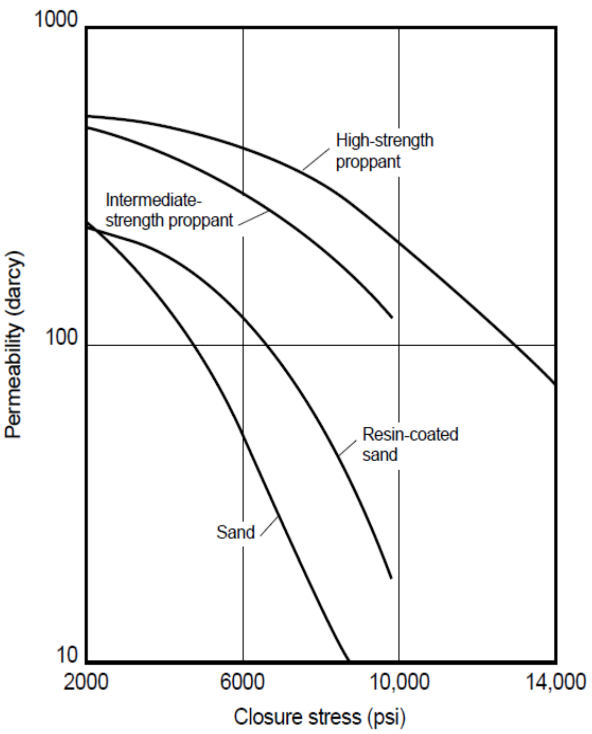

Fig1. Strength comparison of various types of proppants (Reservoir Stimulation, Third Edition, 2010, Michael J. Economides)

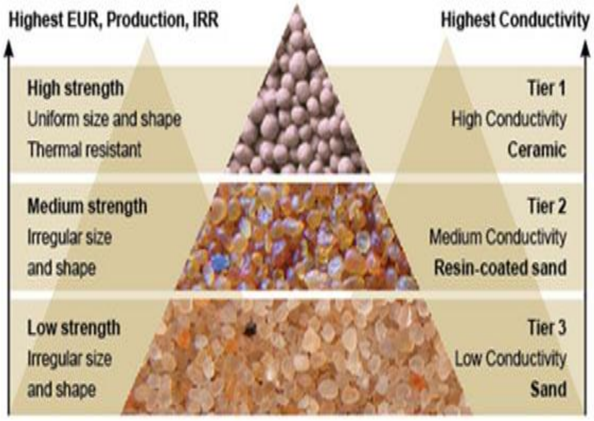

Fig2. Different types of proppant (Retsch Technology, 2012-11)

Proppants are specified in grain diameter sizes of less than 1/16 of an inches. Some common mesh sizes are 16/20, 20/40, 30/50, 40/70, and 100. Treatments may use one size or a multitude of sizes during pumping. The smaller sizes are intended to reach closer to the fracture trip. Proppant size is an important consideration for design and depends on the degree of stress target conductivity, and achievable fracture width. Large-mesh proppants have greater permeability than small-mash proppants at low closure stresses but will mechanically fail and produce very fine particulates at high closure stresses such that smaller-mesh proppants overtake large-mesh proppants in permeability after a certain threshold stress. Proppant mesh size also affects fracture length: proppants can be bridged out if the fracture width decreases to less than twice the size of the diameter of the proppants.

Table II. Typical proppant sizes

Tylar Mesh Size	Particle Size Range (μm)
10/40	1400-2000
12/18	1000-1700
16/20	850-1180
16/30	600-1180
20/40	420-850
30-50	300-600
40/70	212-420
70/140	212-106

4. CRITICAL PROPPANT SELECTION FACTORS

Fracturing proppant selection is crucial to optimizing well productivity. Besides the traditional proppant selection factors of size, strength, and density, there are many other important factors to be consider such as:(1) Proppant fines, (2) Proppant pack cyclic stress, (3) Effective Vs Reference conductivity, (4) Proppant flowback, (5) Proppant pack rearrangement, (6) Proppant embedment and (7) Downhole proppant scaling.

4.1 Proppant Fines

Proppant fines generation and the resulting migration in the fracture are considered to be one of the major contributors to poor treatment results and well performance. It has been noted by Coulter & Wells that just 5% fines can decrease fracture flow capacity by as much as 60%. Hexion’s advanced grain-to-grain bounding technology reduces proppant fines generation and migration through the proppant pack. The fines generated by the light-weight ceramic (8.2%) and uncoated frac sand (23.9%) greatly decrease well production.

4.2 Proppant pack cyclic stress

During the life of a well, numerous events such as well shut-in during workovers, connections to a pipeline or possible shut-in due to pipeline capacity lead to cyclic changes in fracture closure stress. Curable resin coated proppnts resist these cyclic stress changes by forming a flexible lattice network that redistributes the stresses through the proppant pack, reducing individual point loads on each proppant grain. This feature leads to improved proppant pack integrity and well production.

4.3 Effective Vs. Reference conductivity

The fracture conductivity is a measusre of proppant performance, and proppant selection is deemed successful only with can achieve substantial fracture conductivity. It depends on the fracture width proppant distribution, and proppant concentration. Traditionally, proppant performance has been measured using baseline or reference conductivity testing. Effective conductivity is a much more accurate measurement of downhole proppant performance. Unfortunately, the low flow rats during the baseline conductivity test do not simulate downhole flow rates. High flow rates downhole can cause proppant fines to migrate and severely decrease fracture conductivity.

4.4 Proppant Flowback

Proppant flowback is the movement of proppants back to the wellbore and the higher the pump velocity, the more the change of flowback occurring. Futhermore, proppant flowback and pack rearrangement is the main cause of well production decline, equipment damage, as well as lockdown of the well for repair. Thus flowback reduces conductivity at the wellbore and decrease connectivity to the reservoir. Proppant flowback can be prevented by the use of resin-coated proppant. Resin-coated proppants that have grain-to-grain bounding can eliminate proppant backflow, if applied properly, by forming a consolidated proppant pack in the fracture. Post treatment proppant flowback is a leading cause of production decline, equipment damage, and well shut-in for repair. Proppant flowbackcan also cause loss of near wellbore conductivity and reduced connectivity the reservoir. Curable resin-coated proppant eliminate proppant flowback by forming a consolidated proppant pack in the fracture. This grain-to-grain bonding occurs under a combination of reservoir temperature and closure stress.

Fig3. Proppant Flowback (Critical Proppant Selection Factors, HexionFracline)

4.5 Proppant pack rearrangement

Proppant pack rearrangement in the fracture can cause a significant reduction in propped width, which can also lead to reduce fracture flow capacity and connectivity to the wellbore. As a well is produced, high flow velocities in propped microfractures may cause uncoated or procured proppant packs to shift or rearrange, causing the microfractures to narrow or possibly closed completely. Curable resign-coated proppants will prevent the proppant grains from shifting, keeping the microfractures propped open. This unique bonding technology provides additional proppant pack integrity, enhance fracture flow capacity, and increase productionduing the life of the well.

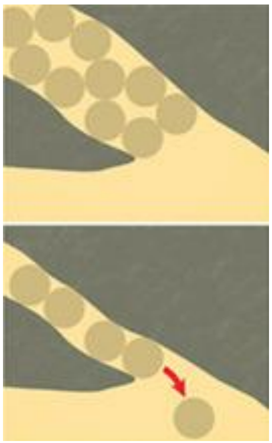

Fig4. Proppant pack rearrangement. (Critical Proppant Selection Factors, HexionFracline)

4.6 Proppant embedment

Proppant embedment occurs as a result of the proppant embedding into the fracture face, especially in soft shale formation, leading to reduced fracture width and lower fracture flow capacity. In the embedment process the proppant partially or completely sinks into the formation through displacement of the formation around the grain. Proppant embedment is caused by an interaction between the formation and the proppant at the face of the fracture, which cause a loss in conductivity. Uncoated proppant and precuredresin coated sand often deeply embed into softer formation due to the increased single point loading between the proppant grain and the soft fracture face. Light weight ceramic proppants embed deeply into soft shale formation, and an additional issue with proppant embedment is the spalling of formation fines, which can migrate and cause additional loss of fracture conductivity. When curable resin-coated proppants are used, there are multiple grains bonded together instead of just single-grain point loading.

Fig5. Proppant embedment. (Critical Proppant Selection Factors, HexionFracline)

4.7 Down-hole proppant scaling

Down-hole proppant scaling is the result of a geochemical reaction, which can occur downhole in the fracture in high-pressure/high-temperature wells, especially in a wet, hot downhole fracture environment. The result of proppant scaling is a serve loss of proppant pack porosity and permeability with the creation of fines and debris in the proppant pack. Uncoated light weight ceramics can lose up to 90% of the permeability of the proppant pack, often in a matter of days. However, Resin-coated proppants can drastically reduce the impact of downholeproppant scaling, which result in improved fracture flow capacity and significantly higher long-term productivity.

5. PROPPANT SELECTION

Some general guide line of rule-of-thumb character can be given as a summary for proppant selection for the application in oil and gas well stimulation in hydrocarbon industry. The most important characteristics of natural sand, intermediate-strength low-density alumina silicate proppants, intermediate-strength high-density alumina silicate proppants, high-strength high-density alumina oxide proppants, and high-strength low-density zirconia-silicate proppants are briefly sketch as follows;

Natural sand is the cheapest of all proppant types and has always been available in nearly unlimited quantities due to widespread occurrences, uncomplicated accessibility and easy processing. However, its application is restricted to shallow wells due to its low closure stress resistivity which is the reason for classifying natural sand as low-strength proppant. Nowadays, natural sand is more and more replaced by synthetic high conductivityproppants in all the cases where no extreme cost containment is necessary, and also that give better permeability contrast between fracture and formation can be selected.

Intermediate-strength low density alumina silicate proppants have the best pumping characteristics of all synthetic proppants due to their low specific gravity which is compare to that of sand. The higher closure stress resistivity allows the application of this material in shallow to intermediate depth reservoirs beyond the pressure boundary of natural sand. Effects of proppant settling are still insignificant for a wide variety of carrier fluids and a broad spectrum of proppant concentrations. Thus proppants are the economically most feasible proppant type in any respect if the boundary of closure stress resistivity is not exceeded.

Intermediate-strength high-density alumina oxide and silicate proppants are mainly applied for hydraulic fracturing of gas reservoirs in moderate to high depth. Being cheaper, lighter and less abrasive than sintered bauxite, they are chosen in all the cases where lightweight synthetic proppants are no longer resisting to the closure stress properly, but high strength alumina oxide proppants are not yet necessary, and thus both cost premium and disadvantage of even higher particle density can be avoided. The specific gravity is still low enough to allow good pumping behaviour with little risk of screenout, but depending on carrier fluid composition and weight, effects of proppant settling may already become significant.

High-strength high-density alumina oxide proppants or sintered bauxite have been the first synthetic proppants that were introduced to the oil and gas industry. The high specific gravity of sintered bauxite does not only leads to problems of proppants settling in lighter carier fluids, but also increase the risk of premature screenout termination of the fracture operation when using heavier transport media in order to minimize or to avoid settling. The major disadvantage of sintered bauxite is its considerable abrasiveness to the treatment equipment which further deteriorates its economical feasibility.

High-strength low density zirconia-silicate proppants are an almost idea material for wide range of applications as a consequence of their properties. There are excellent characteristics for usage in shallow to deeps wells without any problem of placement and settling, and the very good conductivity provides in almost all the cases the necessary contrast between formation and fracture in order to allow hydrocarbon flow at economically feasible rates. The major technical disadvantage are the sudden catastrophical failure of the brittle glassy material into powder-like crushing remnants when the boundary closure stress is exceeded, and the low frication angle which does not only guarantee a better entry of the material into the crack, but also an easier subsequent escape from the fracture by flowback.

6. CONCLUSION

Successful hydraulic fracturing requires the integration of technical proppant data with economics to allow the development and implementation of an optimum fracture design. The critical factors affecting fracture conductivity, described in the previous section, such as closure stress, proppant size, proppant concentration, strength, embedment can each be reviewed both from a technical and economic. The major consideration in proppant selection is optimizing permeability or conductivity versus the associated cost and benefit. The cost of propping agents offering enhanced conductivity and well performance in the fractuing operation can be considerably higher, so it is essential to calculate the desired production rate during the life of the well. If a substantial increase in production is expected, it may justify the use of more expensive proppants.

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