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(54) Title: A METHOD TO ENHANCE PROPPANT CONDUCTIVITY FROM HYDRAULICALLY FRACTURED WELLS

(57) Abstract: A method of mitigating proppant settling in a hydraulic fracture in order to better suspend the proppant as well as ensure a more uniform pack, by mixing a pre-determined volume percent of low density additive, such as glass beads or other suitable material, such as polylactic acid particles, into the fracturing slurry along with the standard high-density proppant, it is anticipated that density gradients can be induced inside the fracture. Upward movement of low density additive due to them having density lower than the carrier fluid will interfere with downward movement of high-density proppant and vice versa. This mutual interference between the two proppants confined in the narrow fracture will significantly hinder the settling/segregation of the high-density proppant. The low density material has a specific gravity of about 0.3, particle size distribution similar to that of standard proppant, and sufficient mechanical strength to survive fracture closure stress.



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TITLE OF THE INVENTION

A Method to Enhance Proppant Conductivity from Hydraulically
Fractured Wells

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CROSS-REFERENCE TO RELATED APPLICATIONS

In the US this is a continuation-in-part of US Patent Application serial number
11/782,151, filed 24 July 2007, incorporated herein by reference, and priority is hereby
claimed.

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Priority of US Patent Application serial number 11/782,151, filed 24 July 2007,
incorporated herein by reference, is hereby claimed.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR
DEVELOPMENT

Not applicable

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REFERENCE TO A "MICROFICHE APPENDIX"

Not applicable

BACKGROUND OF THE INVENTION

1. Field of the Invention

The method of the present invention pertains to hindered settling of proppant in
vertical fractures by the addition of low density material into the fracturing slurry
comprising of fracturing fluid and proppant.

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2. General Background of the Invention

Hydraulic fracturing involves the creation of a crack in a reservoir to enhance
hydrocarbon production. Highly viscous fluids blended with proppant or sand is injected
into the crack. When the fracture closes, the proppant left in the fracture creates a large

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flow area and a highly conductive pathway for hydrocarbons to flow into the wellbore. The proppant or sand is utilized to maintain an open fracture. The viscous fluids are utilized to transport, suspend and eventually allow the proppant to be trapped inside the fracture. the fluids typically follow power law behavior for the range or shear rates encountered in hydraulic fracturing treatments.

Typical fluid volumes in a propped fracturing treatment can range from a few thousand to a few million gallons. Proppant volumes can approach several thousand cubic feet. The goal is to obtain uniform proppant distribution; and therefore, a uniformly conductive fracture along the wellbore height and fracture half-length. However, the complicated nature of proppant settling in non-Newtonian fluids often causes a higher concentration of proppant to settle down in the lower part of the fracture. This often leads to a lack of adequate proppant coverage on the upper portion of the fracture and the wellbore. Clustering of proppant, encapsulation, bridging and embedment are few phenomena that lower the potential conductivity of the proppant pack.

Proppant transport inside a hydraulic fracture has two components when the fracture is being generated. The horizontal component is dictated by the fluid velocity and associated streamlines which help carry proppant to the tip of the fracture. The vertical component is dictated by the terminal particle settling velocity of the particle and is a function of proppant diameter and density as well as fluid viscosity and density. The terminal settling velocity is further complicated by the various phenomena mentioned earlier.

At some point of the fracture generation process, proppant coverage reaches an equilibrium geometry, above which all the proppant injected is carried out farther into the fracture. This potentially restricts the effective propped fracture height as well as greatly increases potential for bridging during treatment.

When pumping ceases, the fracture eventually closes on the proppant pack. The fluid contains viscosity breakers that lower the apparent viscosity and aid the acceleration of fracture closure due to faster leakoff. This reduction in fluid viscosity of the static fluid leads to higher settling velocities causing more proppant to drop to the fracture bottom. The potential for voids and non-uniform packing contribute to a lower effective

propped area and hence significantly lower effective wellbore radius as closure occurs.

Other inventions aimed at prevent proppant settling in a vertical fracture have focused on creating proppant with density equal to that of the carrier fluid. Thus, the proppant in the fluid would be neutrally buoyant in the fracture and stay in place vertically into the fracture closure. The methods of creating neutrally buoyant proppant includes surface-sealing of porous ceramic particles to trap air-filled voids inside the particles, creating composites of strong materials and hollow ceramic spheres, and creating hollow spheres with sufficient wall strength to withstand closure stresses.

These approaches all possess inherent drawbacks in terms of proppant durability and cost to manufacture.

BRIEF SUMMARY OF THE INVENTION

The invention described herein is a method of mitigating the above mentioned effects in order to better suspend the proppant as well as ensure a more uniform pack. By infusing an additive that has a lower density than the fluid medium, it is anticipated that density gradients can be induced inside the fracture. The additives can be any material that will tend to rise up in the fluid mass as opposed to settling down. Upward movement of low density additive will interfere with the downward movement of high density proppant and vice versa. This mutual interference between the proppants and the additive confined in the narrow fracture will significantly hinder the settling/segregation of the high-density proppant. The low density material has a specific gravity less than the carrier fluid medium, particle size distribution similar to that of standard proppant, and may or may not have sufficient mechanical strength to survive fracture closure stress. Therefore, in addition to being buoyant, this material may act as a proppant also.

It is proposed that by mixing a certain percentage of low density additive having similar mechanical properties as proppant into the fracturing slurry, more effective proppant coverage and fracture half length can be realized.

The high shear rates on the surface, tubulars and perforations would ensure a relatively homogenous mixture of proppant and low density additive in the slurry. As the slurry mixture enters the fracture, the dramatic lowering of shear rates will allow the process of proppant and low density additive migration within the fluid mass. Once

pumping ceases, the inherent density gradients will tend to cause simultaneous migration of the proppant to the bottom of the fracture and the low density additive to the top of the fracture. This creates a process of bimodal hindered settling for the proppant, thereby significantly lowering the proppant settling rates. As the fracture closes on the pack, more proppant material is retained on the upper portion of the fracture.

It is expected that the percent of the low density additive that is added to the slurry would be a function of the fracture closure time. A higher quantity of low density additive would be required for low permeability formations where the time for the fracture to close on the pack may take several hours.

This process ensures more uniform proppant coverage along the height of the fracture, thus contributing to the overall effectiveness of the treatment. Due to the fact that the low density additive has similar size distribution and closure stress characteristics, the conductivity of the pack is not compromised. In fact, due to better sphericity and roundness, it is expected that the overall conductivity of the fracture would be greater than that of conventional fracturing slurries that contain only proppant

BRIEF DESCRIPTION OF THE DRAWINGS

NONE

DETAILED DESCRIPTION OF THE INVENTION

The addition of low density additive into fracturing slurry would involve accurate metering of the additive into the proppant mass. Most field scale equipment that meter solid breakers into the fracturing fluid could be potentially upgraded for the addition of low density additive. The low density particulates may or may not meet or exceed strength requirements in order to ensure minimal embedment and crushing inside the fracture.

As mentioned earlier, fracture closure time would determine the weight percent of additive to be utilized during treatment. Longer closure times typical of low permeability rocks would necessitate higher volume fractions. In addition, higher strength proppants have higher settling rates. This would also necessitate a greater low density additive fraction in order to induce more hindrance to settling. Charts can be developed as a design aid for various formation, fracturing fluid and proppant characteristics.

The following experimental data supports the utility and novelty of the method of the present invention.

Experiment 1: Cross-linked Gel Proppant Settling Test

Static proppant settling tests were conducted in a 1-inch diameter, 5-foot long glass tube. The tube was supported vertically and plugged at the bottom. Reference marks were made throughout the length of the tube in 1-inch increments. Testing was conducted in a 25lb/Mgal (0.00299 grams/mL) cross-linked fracturing fluid. The fluid was guar based with a borate cross-linker. The baseline fluid contained a concentration of 4-pounds per gallon (0.4793 grams/mL) of fluid (PPA) 20/40 mesh proppant. It was loaded into the tube after mixing and a timer was started. The test was left static at room temperature. The proppant/gel interface was monitored as it fell from top to bottom while the proppant settled. Two additional tests were performed under the above mentioned conditions. A low-density (SG = 0.9), spherical additive was incorporated into the cross-linked gel/proppant slurry at concentrations of 1 and 2 percent by weight of proppant. Again, the proppant interface was monitored with time. Results from all three tests are summarized below in Table 3.

Table 3: Experiment 1 Data Summary

Test Number	%(BWOP) Low-Density Additive	Time To Settle 18- inches or 45.7 cm (hr:min)	Time To Settle 23- inches or 58.4 cm (hr:min)	Time To Settle 25.5- inches or 64.8 cm (hr:min)
1	0	2:30	4:00	5:50
2	1	3:30	6:50	8+
3	2	22:00	22:00+	22:00+

The above test results indicate that the low-density additive successfully hindered the proppant settling, resulting in longer times for the proppant to settle.

Experiment 2: Large-Scale, Linear Gel Proppant Settling Test

Proppant settling tests were conducted in an 8-ft tall, 2-ft wide (243.8 cm tall, 61 cm wide) plexiglass window, with a ½-inch (1.27 cm) gap between the plexiglass plates.

The window had a steel-reinforced, wooden frame with four, 7/16-inch (1.11 cm) inlet holes and outlet holes, plumbed with ball valves. Metal supports were fastened across the window in 1-ft (30.48 cm) increments and were used for reference during tests. There were a total of 4 tests performed.

5 Test 1 and 2 were conducted in a 15lb/Mgal guar based linear gel. The apparent viscosity of the gel was 8cP at 511 s⁻¹. The linear gels for testing contained a proppant concentration of 2 PPA, 30/50 mesh. Test 1 contained no low-density additive and test 2 contained 5% by weight of proppant low-density additive. The additive used was sieved to 30/50 mesh and had a specific gravity of 0.8. The linear gel was prepared and
10 proppant was added for a final concentration of 2PPA. Low-density additive was added for test 2 and the slurry was blended until uniform. The slurry was then pumped through the test fixture with a 1-inch diaphragm pump until full. The pump was shut down, and all valves were closed. The proppant interface was watched and monitored with time to determine settling rates. Test data is summarized below in Table 4.

15 **Table 4: Experiment 2, Test 1 and 2 Data Summary**

Time to Settle	0% Low-Density Additive	5% Low-Density Additive	% Increase in Time to Settle
1 ft (30.5 cm)	8 sec	11 sec	38
2 ft (61 cm)	22 sec	42 sec	91
3 ft (91.4 cm)	47 sec	61 sec	30
20 4 ft (122.9 cm)	56 sec	77 sec	38

The above test results indicate that the low-density additive successfully hindered the proppant settling, resulting in longer times for the proppant to settle.

25 Test 3 and 4 were conducted in a 25lb/Mgal (0.00299 grams/mL) guar based linear gel. The apparent viscosity of the gel was 16cP at 511 s⁻¹. The linear gels for testing contained a proppant concentration of 2 PPA, 30/50 mesh. Test 3 contained no low-density additive and test 4 contained 5% by weight of proppant low-density additive. The additive used was sieved to 30/50 mesh and had a specific gravity of 0.8. The linear gel was prepared and proppant was added for a final concentration of 2PPA. Low-density additive was added for test 4 and the slurry was blended until uniform. The slurry was

then pumped through the test fixture with a 1-inch diaphragm pump until full. The pump was shut down, and all valves were closed. The proppant interface was watched and monitored with time to determine settling rates. Test data is summarized below in Table 5.

5 **Table 5: Experiment 2, Test 3 and 4 Data Summary**

Time to Settle	0% Low-Density Additive	5% Low-Density Additive	% Increase in Time to Settle
1 ft (30.5 cm)	15 sec	24 sec	60
2 ft (61 cm)	28 sec	44 sec	57
3 ft (91.4 cm)	48 sec	67 sec	40
10 4 ft (122.9 cm)	65 sec	79 sec	22

The above test results indicate that the low-density additive successfully hindered the proppant settling, resulting in longer times for the proppant to settle.

US Provisional Patent Application Serial No. 60/832,994, filed 25 July 2006, is incorporated herein by reference.

15 All measurements disclosed herein are at standard temperature and pressure, at sea level on Earth, unless indicated otherwise.

The foregoing embodiments are presented by way of example only; the scope of the present invention is to be limited only by the following claims.

CLAIMS

1. A method of delaying proppant settling in a hydraulic fracture, the method comprising the following steps:
 - a. providing a proppant-carrier fluid slurry;
 - 5 b. providing a proppant having a specific gravity that is greater than that of the carrier fluid;
 - c. adding a small percentage of low-density particulate material based on proppant volume to the proppant-carrier fluid slurry, the particulate additive having a specific gravity lower than the specific gravity of the carrier fluid;
 - 10 d. due to the specific gravity gradient between the low density particulates, the carrier fluid and the proppant, causing the additive particles to rise in the carrier fluid while the proppant particles fall in the carrier fluid; and
 - e. through interference from collisions of the upward moving additive particles with the downward moving proppant particles, slowing the proppant settling rate which results
15 in a more uniform vertical distribution of proppant in the fracture at closure.
2. The method in claim 1, wherein the particulate material additive does not require sufficient strength to act as a proppant.
3. The method in claim 1, wherein the additive may crush on closure of the fracture.
- 20 4. The method in claim 1, wherein the additive is designed to dissolve over time thereby eliminating proppant pack damage.
5. The method in claim 1, wherein the particulate material comprises polyesters, such as polylactic acid particles, which will hydrolyze and will be swept from the proppant bed with time.
- 25 6. The method in claim 1, wherein the method alleviates proppant settling and produces a uniformly distributed proppant pack in a hydraulic fracture by means of adding a low specific gravity solid particulate additive to the proppant-carrier fluid slurry.
7. The method in claim 1, wherein the low-density particulate material comprises polylactic acid particles.
- 30 8. The method in claim 1, wherein the low-density particulate material comprises glass beads.

A. CLASSIFICATION OF SUBJECT MATTER**E21B 43/26(2006.01)i, E21B 43/00(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 8 E21B 43/26, E21B 43/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean Utility models and applications for Utility models since 1975

Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS (KIPO internal) "proppant, specific gravity, density, additive"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2006-0073980 A1 (BRANNON; HAROLD D. et al.) 06 April 2006 See claims	1-8
A	EP 0773343 A2 (SOFITECH N.V.) 14 May 1997 See the abstract; and claims	1-8
A	US 4421167 A (ERBSTOESSER; STEVEN R. et al.) 20 December 1983 See claims	1-8
A	EP 1368188 A1 (BORDEN CHEMICAL, INC.) 10 December 2003 See claims	1-8
A	US 5103905 A (BRANNON; HAROLD D. et al.) 14 April 1992 See the abstract; and claims -----	1-8



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

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Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2008/061989

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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