PROPPANT AND FORMATION TREATMENT METHOD USING A PROPPANT

Background

Hydraulic fracturing opens cracks in subterranean formations, which can create massive contact with tight, low permeability formations making such formations productive and economical to drill and produce. Proppant is a solid material that is conveyed downhole during wellbore fracturing, which is intended to lodge in induced cracks in a formation to hold those cracks open.

Historically, the industry has developed reserves using cased wells. Those wells are lined with casing, having a string of tubular casing installed and cement introduced and allowed to set in the annulus between the casing and the wellbore wall. Thereafter, the casing and cement is perforated to provide access between the casing inner diameter and the formation. In the perforation process, the casing, cement and to some degree, the formation are perforated using explosives, called shaped charges. During hydraulic fracturing, fracturing fluid and proppant are introduced at high pressures though the perforation tunnels to access the formation. Generally, higher proppant concentrations result in greater conductivity, which is beneficial to production. However, there are limits to proppant concentrations that can be placed: if concentrations become too high the proppant will begin to bridge off in the fracture, creating a screen-out which stops propagation of the fracture. As such, it is difficult to achieve an acceptable balance between how much proppant can be placed, and how much conductivity can be created.

Vertical wells generally create fractures vertically along the casing with significant height growth and, therefore, two fracturing wings. Since the height growth might be anywhere from a few meters to several hundred meters, the ability to access through a perforation tunnel and connect to the fracturing wings requires careful design and execution, but is generally thought to be achievable.

In wells placed horizontally, fractures often propagate transversely relative to the long axis of the wellbore. A fracture treatment creating transverse fracturing will similarly create two fracture wings, but the only connection point is the circumference of the borehole. Similar fracturing processes can be used to treat these wells, but the very limited contact area with the formation means that it is very difficult to appropriately position a perforation tunnel to directly access a fracturable crack and, likewise and as a result, difficult to achieve the required conductivity to transmit hydrocarbons (or any gas or fluid) from the formation to the well.

Brief Description of the Drawings

The following drawings are attached:

Figures 1a to 1e are sequential sectional views through a well bore undergoing a fracturing treatment;

Figure 2 is an enlarged sectional view of a propped fracture;

Figure 3 is a top perspective view of a proppant particle;

Figure 4a and 4b are a perspective top view of a proppant particle and an in use, sectional view along line II-II, respectively, of the proppant particle in a fracture; and

Figures 5a and 5b are a perspective top view of a proppant particle and an in use, sectional view along line III-III, respectively, of a proppant particle in a fracture.

Detailed Description

It is desirable to generate fractures in a formation of interest with good near wellbore conductivity. The present solution addresses issues and technical challenges relating to fracture conductivity in wellbore applications and seeks to generate a formation fracture with good near wellbore conductivity. The method employs the unique approach of open hole fracturing along with placement of shaped proppant.

With reference to Figures 1 and 2, for example, according to the present solution there is a method for treating a formation 10 accessed by a wellbore with an open hole, uncased section 12, as shown in Figure 1a. The method includes applying a fluid, arrows F, at a high pressure against an open hole, uncased section 12 of the wellbore (Figure 1b) such that a fracture 14 is generated (Figure 1c) in the formation extending along a depth originating from a near wellbore position 14a directly open to the wellbore and including a pair of fracture side walls 14b extending substantially in parallel at least along a portion of the depth; entraining a proppant in the fluid, arrows FP, to deposit the proppant in the fracture (Figure 1d), the proppant including particles 16a (best seen in Figure 2) having a flattened shape with a pair of substantially planar outer surfaces 18 disposed in substantially parallel planes and a rounded leading end 20; and reducing the pressure of the fluid to allow the formation to relax on the proppant such that the proppant is positioned to prop open the fracture (Figures 1e and 2), such process permitting a back flow of fluids, arrows BF, including fracturing fluid and production fluid.

Open hole fracturing is conducted in an open hole section 12 of the wellbore. An open hole section is uncased and, while there may be cased sections in any well, open hole section 12 is without a casing (tubular metal liner) and without a cemented annulus. As such the wellbore wall 22, formed by drilling through the formation, is directly open to the wellbore. For example, in an open hole environment the entire annular surface of the wellbore wall is directly exposed to the borehole such that any fracturing fluid introduced thereto can come into contact with the entire annular surface. By applying a fluid at high pressures to an open hole section of the well, the fracture 14 can initiate at any point along the exposed wellbore wall surface. Generally, the method seeks to permit the fracture 14 to generate its near wellbore portion 14a at the weakest point along the exposed wellbore wall surface. This increases the chance that the fracture will both initiate and propagate at the same point and will, therefore, extend along a substantially linear plane. This reduces the chance of a tortuous path being generated in the fracture, especially in its near wellbore portion 14a, where conductivity is of great importance.

A fracture, generally is in the form a crack having a planar form with a width dimension and a length dimension where walls 14b have separated. Depending on the orientation of the open hole section of the wellbore relative to the formation, the fracture may extend along various lengths of the wellbore wall. In some wells, such as those oriented substantially vertically, the fracture may extend substantially parallel to the wellbore long axis x and, as such, the entry way to the fracture in open hole may extend along a considerable length of the wellbore wall. In a horizontal wellbore, the fracture often will propagate substantially transversely relative to the long axis x of the wellbore. For example, the fracture often intersects with the long axis x of the wellbore at an angle α of between 30° and 90°. Where the fracture intersects the open hole wellbore, fluid access is possible directly from the borehole to the near wellbore portion 14a of the fracture about the full inner diameter of the wellbore.

To generate the fracture, fluid at very high pressure is placed in contact with the open hole wellbore wall. The area of wellbore exposed to the pressurized fracturing fluid may be restrained by mechanical diversion components such as open hole packers, or other restraining methods used to segment the well and focus the fracturing force in a selected length of the open hole wellbore. In one embodiment, a tubular string 24 is installed in the wellbore through which fracturing fluid can be delivered to the open hole section of the wellbore. In one embodiment, tubular string 24 carries external annular packers 26a, 26b that can be set to create a sealed annular area 28 between the string, the wellbore wall and the spaced apart packers. The string also includes a port 30 between the packers though which fracturing fluid can be injected from the string to the sealed annular area. The string, when installed in a wellbore, permits the fracturing force to be focused in the selected, isolated segment defined by annular area 28. In an open hole environment, any fracturing fluid injected to the annular area will contact the entire exposed annular rock face between the packers and can open a fracture at any point along the annular area.

Formation rock, including carbonates, shales, sandstones, etc., are fractured by applying extreme pressures with fracturing fluids which may be any liquid, gas or combination. Once the fracturing initiation pressure is achieved, a crack or series of cracks is created in the rock, which is the fracture. Further fracturing fluids are pumped into the well to extend or propagate the fracture any distance from the well to create contact with the formation rock. In a typical treatment, a pad is pumped with creates and extends the fracture deep into the rock.

Either with the initial fluids, or most often, after fracture initiation and the pad, proppant is injected by carriage in the fracturing fluid, arrows BP. The proppant and fracturing fluid form a slurry that is pumped into the well and into the fracture network. By pumping, the pad and the proppant slurry are displaced to the opening of the fracture and enter directly from the wellbore into the near wellbore region 14a of the fracture, as provided by the open hole environment. The proppant flows with the fracturing fluid and is deposited into the fracture (Figure 1d).

Stresses in the earth will try to force the fracture to close once the pressure is dissipated, either through leak off into the formation or when the fracture fluids are allowed to flow back to surface.

The proppant remains behind in the fracture to hold the fracture open so that the formation contact area and conductive channels from the formation to the wellbore, created by the frac fluid, are maintained when the frac fluid is gone.

During pressure dissipation, many forces effect the propping operation of the proppant. For example, the backflow of fluid out of the fracture may tend to problematically displace the proppant back into the wellbore, termed flowback. Alternately or in addition, the stresses in the rock may be very high to the point that these stresses may crush the proppant or cause the proppant to embed into the formation, creating a closed fracture and restricted flow.

It may be desirable to form a monolayer of proppant, as in some cases it will provide the highest conductivity, or ability to move fluid through the proppant pack. One common problem with monolayer placement of proppant is that the formation tends to exert extreme pressures on the proppant material. In proppants with spherical particles, the result is point loading of the proppant, and one of two unfavorable outcomes – (i) proppant crushing and/or (ii) proppant embedding. If the proppant crushes, the fracture can collapse back to a closed position and proppant dust is produced, both of which reduce fracture conductivity. If proppant embedment occurs, this means that the formation rock is not strong enough to handle the point loading on the proppant. In such a case, the proppant deforms the formation face and becomes indented into the formation rock, allowing full or partial closure of the fracture, again with the loss of conductivity.

In this method, the shape of the proppant is selected to resist detrimental forces of displacement, crushing and embedment. Further, the proppant may be particularly suited to placement in open hole environments. In particular, in one aspect as shown in Figure 2, a proppant is employed that includes particles 16a having a flattened shape with a pair of substantially planar outer surfaces 18 disposed in substantially parallel planes and a rounded leading end 20.

A particle with a flattened shape, has a pair of outer surfaces 18 that, at least in one section through the particle, are substantially planar and disposed in substantially parallel planes. Such a particle tends to be controllably oriented in fluid flows, as will be discussed in further detail herein below. It is to be noted that in other sections, the proppant particle may not exhibit substantially parallel and/or substantially planar configurations across surfaces 18. For example, the particular may be somewhat wedge-shaped such that in a side to side section, the surfaces are substantially planar and substantially parallel, but in an orthogonal section, from end to end, the surfaces are not substantially parallel, tending to converge. However, such a particle still tends to have a flattened shape.

In addition, in a flattened particle, there is at least another pair of sides 30 extending between surfaces 18 and those other sides may have various shapes and orientations. For example, sides 30 may be rounded, faceted, substantially planar or non-planar and they may be non-parallel or parallel with each other, as desired.

Rounded leading end 20 is defined in at least one section through the particle. The leading end in other sections may be more angular, or may be entirely rounded. Such rounding facilitates placement of proppant, as will be discussed hereinbelow.

The proppant particle of Figure 2, for example, is disc shaped: having a height H less than its width and length. The width and length dimensions may be generally equal, creating a circular body in plan view. Alternately, the width and length dimensions may be different to form an elongated form. Surfaces 18 are therefore considered to be the upper and lower surfaces, defined by the expanse of the length and width dimensions and sides 30 defined by the height dimensions. The particle being a disc, it has a generally rounded leading end across defined across the section parallel to surfaces 18. The disc can have sharp or smooth (radiused) edges 32 at the transition from height to width/depth. Generally, smooth edges 32, as shown, may have better carrying capability and resist catching on discontinuities on the fracture walls 14b, thus tend to move further into a fracture.

The shape of the proppant particle can be selected to enhance proppant placement and to permit some degree of control over placement orientation. For example, the flattened shape enhances carrying capability of the proppant such that the proppant particles tend to remain suspended in fracturing fluids for a longer time. It is believed that in much the same way as an airplane wing exerts forces on the plane in a flow of air, the proppant moves along with the fracturing fluid in an efficient manner with resistance to premature settling. Proppant settling resistance has been achieved in the past primarily by enhancing the viscosity of the gel, or by reducing the weight of the proppant.

The method of using shaped proppant in open hole fracturing permits the use of a proppant particle oversized compared to traditional methods. A larger size further enhances a particle's carrying capability. Proppant is typically measured in mesh size. A proppant of 20/40 mesh is common for proppant utilized in oilfield fracturing, although finer grained proppants such as 100 mesh are also used. In this method, proppants in the range of 8/12 mesh or even 6/10 mesh may be used. In one embodiment, shaped proppant may be 1/4 to 1/2 inch long by 1/8 to 1/4 inch in width by 1/16 or 1/8 inch in thickness. The shape may be selected to effectively carry proppant particles that are larger in size due to its effective carrying capability. While proppants of such large sizes may not have been useful when fracturing through a perforation tunnel (the convergence of proppant causing bridging off), in the current method using open whole fracturing, the proppant can immediately enter the fracture, without passing through a convergent point such as is present in a tunnel.

The proppant particle may tend, due to fluid dynamics, to become positioned in a crack with its broader upper and lower surfaces generally in plane with the length/width of fracture. In particular, flow through fracture 14, especially deeper into the formation, tends to become laminar, arrows F, parallel with the plane of sides 14b. Under laminar flow conditions, a particle having opposing substantially planar, substantially parallel sides tends to become oriented with the planar, parallel sides aligned with the direction of flow and with even fluid pressures thereabout. As such the substantially planar sides tend to become oriented parallel with the side walls 14b of the fracture. When placed, the substantially planar surfaces 18 of the proppant particle therefore will be contacted by the formation, when the crack closes against the proppant. The breadth of the upper and lower surface, therefore accepts the load, arrows L, of the closing force of the formation.

The form of the proppant tends to distribute the load of the closing force over a surface area greater than spherical proppants and tends to avoid crushing and embedding to a greater degree than previous spherical proppants. Proppant shaping permits increased contact area, and thereby reduced point loading, overcoming the problems encountered with spherically shaped proppants and their point loading problems. Distributing the load forces over a larger area reduces the loads and thereby reduce the tendency for crushing. The flattened shape also permits a monolayer proppant bed to be produced more readily. This also can reduce crushing and enhance conductivity. In horizontal wells, the ability to reduce proppant concentrations while reducing crushing and enhancing conductivity are important.

The present proppant may be formed of natural or manufactured materials including, for example, sand, bauxite, polymers or ceramic. The material may have a hardness and perhaps a specific gravity less than previous spherical proppants because of the particle's enhanced load distribution characteristics and fluid carrying capabilities. For example, typical proppant has a specific gravity of two to five times the specific gravity of water. Thus, these proppants settle relatively quickly when placed in either water or gel. The current method can employ materials with a lower specific gravity, such as less than two times the specific gravity of water and in one embodiment, materials are employed with a specific gravity of 0.8 to 1.2 times the specific gravity of water.

With respect to hardness, normal silica sand might have a strength allowing it to withstand fracture closure stresses up to about 5000 psi. In normal oilfield operations, synthetic proppants are used where closure forces are expected to be above about 5000 psi. With shaped proppant, point loading can be reduced or eliminated in favor of face loading. This greatly diminishes the stress forces exerted by the formation on the proppant. As such, it is possible to use shaped proppants with a hardness equivalent to silica sand but in fracture conditions with closure stresses up to approximately 10,000 psi. In lower closure stress environments, it is possible to run proppant formed of a material, which if spherically shaped, could only withstand 3000 psi of closure stress, but can withstand more than 5000 psi of closures stresses due to the shape that addresses point loading. As such, a proppant useful in the present solution may be formed of a material of lower hardness but its particles are shaped to withstand closures stresses that are more than double what could be handled by a spherically shaped proppant of similar hardness. As an example, shaped proppants useful in the present solution may have a hardness of approximately 3, but are useful to handle closure stresses where previously spherically shaped quartz (silica sand), having a Moh's hardness of approximately 7 was used.

Materials having a lower resistance to crushing may also have a lower density, but the shape of the proppant particles also serves to enhance the proppant's carrying capacity. Since point loading is reduced or eliminated, shaped proppants with low crush resistance and low specific gravity can be used where previously harder and more dense materials had to be used. Using the present shaped proppant, the cross-sectional area contacted by the formation is greatly enhanced and a proppant can be used that is formed of a material with a low crush resistance but a lower specific gravity and, therefore, offers a better carrying capability such that the proppant particles are transported to further depths in the fracture.

In a further aspect of the solution, carrying capabilities can be selected by surface contouring and/or roughening. Such surface treatments can modify friction of the particle movement with the fracturing.

In yet a further aspect of the solution, carrying capabilities can be enhanced by addition of force capturing protrusions on the proppant. Force capturing protrusions are surface discontinuities relative to the surface contour having, relative to the leading end, a rearward-facing, angular side formed to capture fluid pressure to resist fluid bypassing about the particle and rather, harnesses the fluid pressure to carry the particle along. Force capturing protrusions may for example, define a fin, a wing, a parachute having a rearward facing high pressure side that captures the fluid flow force and creates reduced fluid pressures ahead of the particle that carry and push the proppant along in the fracturing fluid flow. The force capturing protrusions may be positioned at various positions on the proppant particle. The force capturing protrusions may be positioned on the particle symmetrically to form a symmetrical force over the surface of the particle, such that a balanced effect is achieved and particle tumbling is resisted.

Force capturing protrusions can move the proppant along with the fluid by providing fluid capturing flares such as tail fins on the proppant particle. For example, with reference to Figure 3, a proppant particle has a flattened shape with a pair of substantially planar upper and lower surfaces 118 disposed in substantially parallel planes, a leading end 120 having a rounded form both parallel to and orthogonal to the planes of surfaces 118 and a trailing end 134 defined opposite the leading end with force capturing protrusions 136 positioned thereon. Force capturing protrusions 136 are positioned substantially symmetrically relative to a long axis x^p of the proppant particle and are formed as tail fins having an apex 136a, a front-facing side 136b and a rearward-facing side 136c with a surface contour extending from apex 136a that extends at less than or equal to a right angle relative to axis x^p. When entrained in a fluid flow, force capturing protrusions 136 capture the fluid force, generating a high pressure area against side 136c and a low pressure area against side 136b, that urges the proppant particle along. In this embodiment, the distance between the tips of apexes 136a is greater than the distance from side to side (width w) across the main body portion and leading end such to enhance the tendency for the proppant particle to move through the fracture with its leading end advancing ahead of the remaining proppant structure. Also, it is noted that the thickness, from surface 118 to surface 118 is less than the width w and the width is less than the length from end 120 to end 134.

With reference to Figures 4a and 4b, another proppant particle has a flattened shape with a pair of substantially planar upper and lower surfaces 218 disposed in substantially parallel planes, a leading end 220 having a rounded form both parallel to and orthogonal to the planes of surfaces 218 and a trailing end 234 defined opposite the leading end with force capturing protrusions 236 positioned thereon. In this embodiment, there are further force capturing protrusions 236 each having an apex 236a, a front-facing side 236b and a rearward-facing side 236c. The rearward facing sides each have a surface contour extending from apex 236a that extends at less than or equal to a right angle relative to axis x^p. When entrained in a fluid flow, force capturing protrusions 236 capture the fluid force, generating a high pressure area against side 236c and a low pressure area adjacent side 236b, that urges the proppant particle along forwardly in the flow. In this embodiment, protrusions 236 extend out of the planes of the surfaces 218 such that the thickness T_t of the trailing end is greater than the thickness T_m of the main body.

In addition to the enhanced carrying capacity of the shaped proppant, once the proppant is in place in a fracture, the formation closes upon the proppant. The planar surfaces 218 permit a distribution of the closing forces, arrows L, over a significant area of the proppant body and the protrusions 236, allow the partial embedment of the proppant into the formation. The protrusions having an upper limit in the form of an apex and a thickness greater than the thickness of the main body, the walls 214b of the fracture, during closing, bear first against the protrusions, which dig into the walls. When the fracture is relaxed, walls 214b come to bear on surfaces 218 and the proppant props open the crack to maintain fluid conductivity therethrough.

The proppant particle shape allows the proppant to be oversized relative to spherical proppant, to be effectively carried into the fracture network, to more effectively resist crushing by distribution of load across a surface area and to be locked in place. The protrusions 236 therefore offer both the benefit of greatly enhanced flow conductivity with large fluid pressure induced forces on the proppant to facilitate carrying capability into the fracture and the benefit of resisting dislodgement during backflow wherein the protrusions act as retaining locking points, anchoring the proppant to the formation to prevent flowback. In particular, once the hydraulic fracture job is completed, and the fracturing fluid begins to flow out of the well, it is common that the back flow of fluid at least in some areas will create a force against the placed proppant urging it out of the fracture and into the wellbore. The protrusions 236 resist flowback, anchoring the particle against the forces exerted by back flow of fluid toward the wellbore.

With reference to Figures 5a and 5b, another proppant particle has a flattened shape with a pair of substantially planar upper and lower surfaces 318 disposed in substantially parallel planes, a leading end 320 having a rounded form both parallel to and orthogonal to the planes of surfaces 318, a trailing end 334 defined opposite the leading end and force capturing protrusions 336 positioned on its outer surface. In this embodiment, trailing end 334 is concave, curving inwardly toward end 320 and acts to generate a fluid pressure force to push the proppant particle forwardly. Further, force capturing protrusions 336 protrude out from the plane of each surface 318. Protrusions 336 are formed as wings each having an apex 336a in the form of an elongated crest, a front-facing side 336b and a rearward-facing side 336c. Protruding from surfaces 318, the thickness T_a between the apex of a wing on the upper surface to the apex of a wing on the opposite surface is greater than the thickness T_m from surface 318 to surface 318. The rearward facing side 336c has a surface contour that extends no more than right angles from surface 318 toward apex 336a. The rear facing side defines an angle μ relative to surface of less than or equal to a right angle. When entrained in a fluid flow, force capturing protrusions 336 capture the fluid force, generating a high pressure area against side 336c and a low pressure area adjacnet side 336b, that urges the proppant particle forwardly in the fluid flow. These protrusions form wings, but could be elongated to form parachute-type protrusions, etc. on the surface of the proppant. Such proppant shapes enhance the fluid transportability of the proppant, improved over spherical shapes that tend to settle very quickly. Proppant shaping beneficially offers a proppant that can be carried to further depths in a fracture network. With such a proppant, a lower viscosity fracing fluid, closer to that of water than cross-linked gel, can be used to transport the proppant.

Also, as shown in Figure 5b, the proppant shape also resists displacement of the proppant during backflow, arrows BF, such as production of the well. In particular, the right angled surfaces 336c cause the proppant to be positioned in the fracture with the leading end facing toward the depth of the fracture and surfaces 336c, facing rearwardly, act against reverse movement caused by backflow. In particular, the angled faces, extending away from apex 336a, catch on discontinuities on the fracture faces

314b. Also, if the fracture closes on the proppant particle, protrusions 336 become embedded in the fracture walls. As such the wing-type protrusions 336 serve numerous purposes: enhancing the ability of the proppant to be carried in a fluid flow; permitting predictable front-facing placement of the proppant particle in a fracture and resisting reverse movement during backflow.

The use of shaped proppants provides for better distribution of fracture propping forces to resist crushing, predictable orientation of proppant in the fracture, better ability to carry the proppant along with the fluid to greater depths in the fracture and resistance to flowback.

This solution provides the ability, through strategically shaped proppant to carry out the proppant transport during hydraulic fracturing, as well as mechanism or mechanisms to retain the proppant in a monolayer form or multiple layered form by allowing partial embedment or partial locking of proppant through strategic design.

When the shaped proppant is placed using a fracturing fluid in an open hole environment, the proppant passes directly from the borehole into the fracture at any point along the crack's length in the bore hole, which is fully exposed. The application of fracing and placing shaped proppant in open hole may avoid problems with very limited near wellbore conductivity as was encountered utilizing conventional proppants, while allowing successful and reliable placement. In addition, other benefits can be created utilizing shaped proppants such as controlled proppant embedment as well as the ability to create single component proppant islands, where the proppant particles have large spaces between them which provide a significant flow space between deposited proppant for further unrestricted fluid production. Shaped proppant can also be specifically designed to provide for better transport both in the borehole as well as in the fracture, permitting the use of lower viscosity fluids to create greater effective fracture length.

As such, a method is provided wherein a subterranean formation is treated as by increasing fluid pressure against the formation to generate a fracture therein; conveying proppant with a flow of fluid to position the proppant in the fracture, the proppant including a plurality of proppant particles at least some particles of which are shaped in accordance with one or more of the embodiments noted above; and allowing fluid pressure to dissipate to allow the fracture to close on the proppant, leaving the proppant in a propping position in the fracture.

Providing high conductivity for hydraulic fracturing becomes very difficult due to the shape of the borehole and the limited contact length between the horizontal borehole and a transverse fracture. Although wells can be oriented so that fractures can be created to form longitudinally (along the direction of the horizontal borehole), most wells are oriented such that any fractures generate transverse to the wellbore. Although this technology can be used to great benefit for any borehole orientation, it has extraordinary benefit for transverse fractures because of the very limited contact to the fracture. This contact distance is generally limited to the circumference measurement of the borehole. Existing processes using sand or generally spherical shaped proppant, and create convergence flow issues while attempting to connect massive formation contact area with conduit to surface – the horizontal and vertical wellbore.