SACRIFICIAL ISOLATION BALL FOR FRACTURING SUBSURFACE GEOLOGIC FORMATIONS

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ABSTRACT

An embodiment of a fracking ball cooperates with a ball seat to isolate a well first portion of an earthen well drilled into the earth's crust from a well second portion and comprises an interior chamber to receive an explosive charge. The explosive charge may be surrounded by a filler material that is resistant to deformation. A pressure sensor, a circuit, and a battery are also received into the chamber. The ball material, may comprise one of zirconium oxide, aluminum oxide, bulk metallic glass, silicon nitride or tungsten carbide, and the ball is resistant to deformation within the ball seat under the application of a substantial pressure differential across the ball and ball seat. Detonation of the explosive charge fragments the ball to prevent the ball from presenting an obstruction to subsequent well operations. A safety fuse may be included to enable safe handling and transport.
FIG. 7
SACRIFICIAL ISOLATION BALL FOR FRACTURING SUBSURFACE GEOLOGIC FORMATIONS

STATEMENT OF RELATED APPLICATIONS

[0001] This application depends from and claims priority to U.S. Provisional Application No. 61/898,088 filed on 31 Oct. 2013.

FIELD OF THE INVENTION

[0002] The present invention relates to an improved sacrificial isolation ball for use with a ball seat to fluidically isolate a targeted geologic zone for hydraulic fracturing operations to enhance production of hydrocarbons from a well drilled into the targeted geologic zone.

BACKGROUND OF THE RELATED ART

[0003] Hydraulic fracturing is the fracturing of rock by a pressurized liquid. Some hydraulic fractures form naturally. Induced hydraulic fracturing or hydro-fracturing, commonly known as “fracking,” is a technique in which a fluid, typically water, is mixed with a prop-ant and chemicals to form a mixture that is injected at high pressure into a well to create small fractures in a hydrocarbon-bearing geologic formation along which the hydrocarbon fluids such as gas, oil or condensate may migrate to the well for production to the surface. Hydraulic pressure is removed from the well, then small grains of the proppant, for example, sand or aluminum oxide, hold the fractures open once the formation pressure achieves an equilibrium. The technique is commonly used in wells for shale gas, tight gas, tight oil, coal seam gas and hard rock wells. This well stimulation technique is generally only conducted once in the life of the well and greatly enhances fluid removal rates and well productivity.

[0004] A hydraulic fracture is formed by pumping fracturing fluid into the well at a rate sufficient to increase pressure downhole at the target zone (determined by the location of the well casing perforations) to exceed that of the fracture gradient of the rock. The fracture gradient is the pressure increase per unit of the depth due to its density and is usually measured in pounds per square inch per foot or bars per meter. The rock cracks and the fracture fluid continues further into the rock, extending the crack still further, and so on. Fractures are localized because pressure drop off with frictional loss attributed to the distance from the well. Operators typically try to maintain “fracture width,” or slow its decline, following treatment by introducing into the injected fluid a proppant—a material such as grains of sand, ceramic beads or other particulates that prevent the fractures from closing when the injection is stopped and the pressure of the fluid is removed. The propped fracture is permeable enough to allow the flow of formation fluids to the well. Formation fluids include gas, oil, salt water and fluids introduced to the formation during completion of the well during fracturing.

[0005] The location of one or more fractures along the length of the borehole is strictly controlled by various methods that create or seal off holes in the side of the well. A well may be fracked in stages by setting a ball seat below the geologic formation to be fracked to isolate one or more lower geologic zones open to the well from the anticipated pressure to be later applied to a zone closer to the surface. A ball of a predetermined diameter is introduced into the well at the surface and pumped downhole. When the ball reaches the ball seat installed in the bore of a casing, the ball seats in the ball seat to form a seal that isolates geologic formation zones below the ball seat from the anticipated hydraulic fracturing pressure to be exposed on a geologic formation zone above the ball seat.

[0006] Hydraulic-fracturing equipment used in oil and natural gas fields usually consists of a slurry blender, one or more high-pressure, high-volume fracturing pumps (typically powerful triplex or quintuples pumps) and a monitoring unit. Associated equipment includes fracturing tanks, one or more units for storage and handling of proppant, high-pressure treating iron, a chemical additive unit (used to accurately monitor chemical addition), low-pressure flexible hoses, and many gauges and meters for flow rate, fluid density, and treating pressure. Chemical additives are typically 0.5% percent of the total fluid volume. Fracturing equipment operates over a range of pressures and injection rates, and can reach up to 100 megapascals (15,000 psi) and 265 litres per second (9.4 cu. ft./sec or 100 barrels per min.).

[0007] A problem that can be encountered in a fracturing operation involves the impairment to subsequent operations that can result from the presence of the ball. After the fracturing operation is concluded, the surface pressure is restored to a pressure at which the well will flow and produce formation fluids to the surface for recovery. A fracturing ball having a sufficiently low density can be floated or back-flowed from the well, but a ball having a low density may be deformed by the large pressure differential applied across the ball and ball seat and thereby compromised during fracturing operations. If the ball is of a material that is more dense so that it cannot be floated or back-flowed from the well to the surface, then the ball may present an unwanted obstruction that has to be removed from the well to prevent impairment of subsequent well operations.

[0008] A workover operation can be implemented in which a drilling instrument is introduced into the well to drill out and to mechanically destroy the ball, but a workover operation requires that a workover rig be brought to the surface location of the well for downhole operations. The need for the rental, transportation, rigging up and use of a rig imposes substantial delays and substantial costs.

[0009] What is needed is a fracturing ball that has a sufficient density and resistance to deformation so that it can be used in conjunction with a ball seat to reliably isolate geologic formation zones below the ball seat from anticipated large fracturing pressures applied to geologic formation zones above the ball seat and that does not impair subsequent well operations.

BRIEF SUMMARY

[0010] One embodiment of the present invention provides a fracturing ball for sealing with a ball seat in a well. The fracturing ball contains an explosive charge for fragmenting the fracturing ball after use. The fracturing ball is constructed in a manner that provides sufficient resistance to deformation of the ball as a large pressure differential is applied across the ball and the engaged ball seat.

[0011] An embodiment of the present invention provides a fracturing ball that can be fragmented by detonation of an explosive charge provided within an interior chamber of the ball to produce, upon detonation of the explosive charge, a plurality of ball fragments that do not interfere with subsequent well operations. In one embodiment, the use of a
ceramic spherical body provides sufficient resistance to fracking ball deformation under large pressure differentials across the fracking ball and ball seat applied during fracking operations. In addition, these materials can provide for favorable fragmentation of the ball upon detonation of the explosive charge stored within an interior chamber of the ball to prevent unwanted obstacles having a substantial size from obstructing flow in the well.

[0012] In one embodiment of the ball of the present invention, a battery, a pressure sensor and a circuit are included within the interior chamber of the fracking ball along with the explosive charge. The pressure sensor is disposed in fluid communication with an exterior surface of the ball through an aperture in the ceramic structure. The pressure sensor detects a predetermined pressure threshold and initiates a predetermined timer delay period prior to detonation. Upon elapse of the predetermined timer delay period, a circuit is completed that generates an electrical current from the battery to the explosive charge to detonate the explosive charge and to thereby fragment the ball. In one embodiment in which the ball is a dissolvable ball, the fragmentation of the ball dramatically increases the aggregated surface area exposed to the fluids in the well to provide a much more rapid rate of dissolution as compared to a dissolvable ball that is not fragmented.

[0013] The higher fracking pressures achievable by use of embodiments of the fracking ball of the present invention, along with the lack of obstruction of subsequent well operations due to fragmentation, increase the success and effectiveness of the fracking process, lowers or eliminates workover rig rental costs, and prevents unwanted delays in subsequent well operations after the fracking process.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0014] FIG. 1 is a sectional view of a well drilled into the earth’s crust and illustrating a series of hydraulic fractures disposed at a predetermined spacing to enhance production and recovery of formation fluids from a hydraulically fractured subsurface geologic formation.

[0015] FIG. 2 is the sectional view of the well of FIG. 1 illustrating the lack of fractures within the targeted geologic formation prior to the creation of the hydraulic fractures and illustrating a location of a desired placement of a ball and a ball seat to receive that ball to thereby isolate zones deeper in the well than the ball seat (to the right) from zones shallower in the well than the ball seat (to the left).

[0016] FIG. 3 is a sectional elevation of an embodiment of a ball of the present invention received in a ball seat within the casing of the drilled well illustrated in FIG. 2 to create an isolating seal.

[0017] FIG. 4 is a sectional view of an embodiment of a ball of the present invention.

[0018] FIG. 5 is a sectional view of an alternate embodiment of a ball of the present invention.

[0019] FIG. 6 is an illustration of the fragments resulting from the detonation of the explosive charge contained within the interior chamber of the ball of the present invention.

[0020] FIG. 7 is an illustration of a safety feature that may be used to enhance the safety of personnel that may handle, prepare and deploy an embodiment of the ball of the present invention.

[0021] One embodiment of the present invention provides a ball having an outer surface of sufficient smoothness to enable the ball to seat within and to seal with a ball seat, wherein the ball has substantial resistance to deformation by an applied pressure differential across the seal created by the ball received within the ball seat. The embodiment of the ball contains an explosive device that can be detonated to destroy the ball from within and to thereby fragment the ball into a large plurality of small fragments. The embodiment of the ball may include a filler material received within the hollow interior of the ball, along with the explosive device, wherein the filler material comprises a non-compressible fluid such as, for example, a gel, or particles or pieces of such a small size that they can be released in the well without concern for the particles or pieces interfering with the function or operation of any downhole components that might be contacted. The filler material may comprise one of sand, ceramic beads or some other filler material that exhibits substantial resistance to deformation and resistance to compression. The filler material may also comprise an incompressible fluid, such as water. It will be understood that the temperature at which the ball will reside prior to detonation of the explosive charge should be considered when choosing a filler material as an incompressible fluid may result in excessive internal pressure at elevated temperatures.

[0022] The manner in which an embodiment of the fracking ball of the present invention is made may vary, but will generally include the steps of providing a ceramic outer shell having a hollow interior and, optionally, a hole through which a pressure sensor may be inserted into the fracking ball. An embodiment of a fracking ball of the present invention may include an explosive device and a filler material that can be disposed within the hollow interior. In one embodiment of the ball, a first hemispherical portion and a second hemispherical portion are secured together to form a spherical ball.

[0023] In one embodiment, a ceramic sphere may consists of two or more pieces secured together to form a spherical body. In another embodiment the ceramic sphere consists of a unitary spherical body having a hole for insertion of a safety fuse such as, for example, a pressure sensor, to enable the explosive charge and the timer-controlled detonator. It will be understood that the pressure sensor may be provided to generate a signal that enables or initiates the circuit that ultimately delivers the detonating current flow from the battery to the explosive charge, and that the provision of the pressure sensor to complete and thereby enable the fracking ball circuit would cause the pressure sensor to function as a safety fuse without which the fracking ball would be unable to self-destruct.

[0024] In one embodiment, the ceramic ball may comprise one of zirconium oxide, silicon nitride, tungsten carbide, zirconia toughened alumina, bulk metallic glass (BMG) and aluminum oxide. The high compressive strengths of these ceramic materials enable the fracking ball to seat in the ball seat and to cooperate with the ball seat to isolate deeper well zones from shallower well zones to be fracked. This requires the ball and ball seat to withstand a very high fracking pressure on an uphole side of the ball and a substantially lower pressure on a downhole side of the ball. Embodiments of the ceramic fracking ball of the present invention may be manufactured by, for example, but not by way of limitation, isostatic pressing, hot isostatic processing (HIP), injection molding, slip casting or gel casting techniques. In one
embodiment, a ball comprising zirconia with a very thin wall thickness of only 0.060 inches can be gel cast and subsequently hot isostatically pressed to increase the flexural strength of the fracking ball so it can be seated in the ball seat to withstand very high differential pressures while yielding less debris material subsequent to fragmentation by the explosive charge. Less debris material will result in a much lower probability of any debris for fragments of a size sufficient to interfere with or obstruct equipment to be used in fracking other, deeper or lower zones.

[0025] FIG. 1 is a sectional view of a well 20 drilled from the surface 21 into the earth's crust 29 and illustrating a series of proposed hydraulic fractures 26 disposed at a predetermined spacing 28 to enhance production and recovery of formation fluids from a hydraulically fractured subsurface geologic formation 24. The drilled well 20 may include multiple layers of surface casing as is known in the art. The drilled well 20 may include one or more turns or changes in direction to align the portion of the well 20 to be perforated or otherwise to gather fluids within a known geological structure, seam or formation 24. The fractures 26 created in the formation 24 are generally disposed at a predetermined spacing 28 selected for optimal drainage. The targeted formation 24 may reside between a top layer 22 and an underlying layer 23 within the earth's crust 29. It will be understood that fluids entering the well 20 flow according to a pressure gradient in the direction of the arrow 27 to the surface for processing, storage or transportation.

[0026] FIG. 2 is the sectional view of the well 20 of FIG. 1 illustrating the lack of fractures 26 (seen in FIG. 1) within the targeted geologic formation 24 prior to the creation of the hydraulic fractures shown in FIG. 1. FIG. 2 illustrates, using a circle, a location of a desired placement of a ball (not shown) and a ball seat (not shown) to receive the ball to thereby isolate a zone 50, that is deeper in the well than the ball seat (i.e., to the right) from a zone 51 that is shallower in the well 20 than the ball seat (i.e. to the left). It will be understood that the ball and ball seat are to be placed in a portion of the casing 62 that lies within the targeted geologic formation 24 and that the pressure at any given location within the well 20 is approximately equal to the pressure at a wellhead 49 at the surface 21 plus the product of the vertical elevation change 46 times the density (as measured in units corresponding to the unit used to measure depth) of a fluid residing in the well 20, assuming that the well 20 is filled with the fluid.

[0027] FIG. 3 is a sectional elevation of an embodiment of a ball 10 of the present invention received in a ball seat 44 that has been previously set within a section of a casing 62 of the drilled well 20 (not shown in FIG. 3) illustrated in FIG. 2 to create an isolating seal. It will be understood that a number of tools exist for setting the ball seat 44 within the portion of the casing 62 in which the seal is to be affected, and that those tools and the methods of setting those tools are not within the scope of the present invention. FIG. 3 is provided merely to illustrate the manner in which an embodiment of a ball 10 moves through the bore 70 of the casing 62 to engage the ball seat 44 after the ball seat 44 is set in the portion of the casing 62 and after the ball 10 is introduced into the well 20 and moved to the ball seat 44. The ball 10 and ball seat 44 together form a seal to isolate a lower portion of the bore 71 from the upper portion of the bore 70 that is uphole to the ball 10 and ball seat 44.

[0028] FIG. 4 is a sectional view of an embodiment of a ball 10 of the present invention. The ball 10 of FIG. 4 comprises a hollow interior consisting of a hollow interior 15 of a first hemispherical portion 11 and a hollow interior 16 of a second and matching hemispherical portion 12. The circular rim 13 of the first hemispherical portion 11 is manufactured to correspond in shape for mating engagement with the circular rim 14 of the second hemispherical portion 12. Securing of the first hemispherical portion 11 to the second hemispherical portion 12 provides a spherical ball having an exterior surface consisting of the exterior surface 17 of the first hemispherical portion 11 and the exterior surface 18 of the second hemispherical portion 12.

[0029] FIG. 5 is a plan view of a hollow interior 15 of the first hemispherical portion 11 of FIG. 4. An aperture 30 in the ceramic hemispherical shell 11 is fluidically connected by a conduit 31 to a pressure sensor 32. The pressure sensor 32 closes a switch upon sensing a predetermined threshold pressure through the aperture 30 and the conduit 31.

[0030] Upon receiving the signal from the pressure sensor 32, a timer is activated. After a predetermined amount of time from activation, a signal is sent to a detonator to explode the explosive charge within the fracking ball. Upon detonation of the explosive charge 36, the outer shell of the fracking ball 10 is fragmented.

[0031] FIG. 6 illustrates a fragmented ceramic ball 10A as it might appear immediately after the moment of detonation of the explosive charge 36 within a hollow interior of the fracking ball 10 to fragment the ball 10 into numerous ball fragments 49, which are then dispersed into well fluids moving throughout the interior bore of the casing 62. It will be understood that such fragmentation dramatically increases the cumulative surface area of the ball fragments 49 exposed to the fluids in the well. This will provide a correspondingly dramatic increase in the rate at which any dissolvable material will degrade and dissolve in the fluids in the well.

[0032] FIG. 7 illustrates a safety feature that may be used to enhance the safety of personnel that may handle, prepare and deploy an embodiment of the ball 10 of the present invention. FIG. 7 illustrates the first hemispherical portion 11 of the ball 10 having a fuse aperture 52 to receive the safety fuse (such as a pressure sensor) 53. Upon deployment of the ball 10 from the surface, the safety fuse 53 can be inserted into and through the fuse aperture 52 to engage and enable a critical connection. For example, but not by way of limitation, the safety fuse 53 may be inserted and seated in the fuse aperture 52 to engage, within the hollow interior 15 of the ball 10, a pair of conductive leads bridged by the safety fuse 53 that completes an electrical circuit that will later, after the pressure sensor 32 senses the threshold pressure and after the delay period has run, enable the battery 40 to detonate the preliminary explosive charge 35. Alternately, the safety fuse 53 may engage and enable the circuit 33 so that, upon detection of the threshold pressure by the pressure sensor 32, the circuit 33 will begin the delay period. It will be understood that there are various ways of enabling the explosive charge using a safety fuse 53, that multiple safety fuses 53 may be used. In one embodiment, no safety fuse 53 is used, but this is not recommended for obvious reasons. In the embodiment illustrated in FIG. 7, the safety fuse 53 comprises an enlarged head 54 that limits the extent to which the safety fuse 53 can be inserted through the fuse aperture 52. This head 54 and the safety fuse 53 length may be customized to precisely position the safety fuse 53 relative to the other components 31, 32, 33, 34, 35, 36 and 40 within the fracking ball 10.
[0033] The configuration of the well 20 and the depth at which the ball seat 44 and the ball 10 are to be used determine the size of the ball seat 44 and the ball 10. The range of sizes of the ball 111 may be within the range from 4.45 cm (1.75 inches) to 10 cm (4.0 inches), or larger. The filler material, if any, may comprise particles or beads that vary in size and material, but are preferably in the range from 0.2 mm (0.008 inch) to 1 mm (0.04 inch) diameter. A noncompressible fluid, such as a gel, can also be used as the filler material.

[0034] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components and/or groups, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The terms “preferably,” “preferred,” “prefer,” “optionally,” “may,” and similar terms are used to indicate that an item, condition or step being referred to is an optional (not required) feature of the invention.

[0035] The corresponding structures, materials, acts, and equivalents of all means or steps plus function elements in the claims below are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of the present invention has been presented for purposes of illustration and description, but it is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. The embodiment was chosen and described in order to best explain the principles of the invention and the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

What is claimed is:

1. A ball for use with a ball seat set in a tubular string within a well drilled into the earth's crust to isolate a pressure within a first portion of the well from a pressure in a second portion of the well, the ball comprising:
   a spherical body of a solid material and having an interior chamber and an exterior surface to engage the ball seat;
   a battery received within the interior chamber of the body;
   an explosive charge including an explosive material received within the interior chamber of the body and coupled for detonation by the battery;
   a pressure sensor received within the interior chamber of the body in fluid communication with an aperture extending from the exterior surface of the spherical body to the interior chamber of the spherical body; and
   a circuit received within the interior chamber and conductively coupled to receive an electrical current from the battery, conductively coupled to receive a signal from the pressure sensor, and conductively coupled to generate, after a predetermined time interval, a detonating current to detonate the explosive charge in response to detecting a predetermined pressure sensed using the pressure sensor,

   wherein detonation of the explosive charge fragments the spherical body to limit the size of spherical body fragments present in the well.

2. The ball of claim 1, wherein the solid material of the spherical body is a material, that is at least in part dissolveable in one or more fluids introduced into the well.

3. The ball of claim 1, wherein the spherical body comprises a plurality of spherical body portions that are assembled and secured together to form the spherical body.

4. The ball of claim 3, wherein the plurality of spherical body portions includes two hemispherical body portions.

5. The ball of claim 4, wherein the plurality of spherical body portions are securable together using an epoxy adhesive.

6. The ball of claim 1, wherein the solid material of the spherical body comprises at least one of: zirconium oxide, silicon nitride, tungsten carbide, zirconia toughened alumina, bulk metallic glass and aluminum oxide.

7. The ball of claim 1, wherein the ball further comprises: a filler material disposed within the hollow interior of the ball.

8. The ball of claim 7, wherein the filler material includes at least one of sand, gel, ceramic beads and an incompressible fluid.

9. The ball of claim 1, further comprising a fuse aperture in the spherical body for receiving a safety fuse;

10. A ball for landing within a ball seat set in a tubular string to isolate a first portion of a well drilled into the earth's crust from a second portion of the well, the ball comprising:
   a spherical body of a solid material having an exterior surface to engage the ball seat and an interior chamber;
   a battery received within the interior chamber;
   an explosive charge received within the interior chamber and coupled for detonation by an electrical current from the battery;
   a pressure sensor received within the interior chamber and in fluid communication with an aperture extending from the exterior surface to the interior chamber; and
   a circuit received within the interior chamber to receive a signal from the pressure sensor upon detection by the pressure sensor of a predetermined pressure and to generate a detonation signal from the battery to the explosive charge at a predetermined time interval after the detection of the predetermined pressure by the pressure sensor,

   wherein detonation of the explosive charge fragments the ball.

11. The ball of claim 10, wherein the solid material of the spherical body is at least in part dissolveable in one or more fluids introduced into the well.

12. The ball of claim 10, wherein the spherical body includes a plurality of assembled spherical body portions secured together to form the spherical body.

13. The ball of claim 12, wherein the plurality of spherical body portions includes two hemispherical body portions.

14. The ball of claim 13, wherein the plurality of spherical body portions are securable together using an epoxy adhesive.

15. The ball of claim 10, wherein the solid material of the spherical body comprises at least one of: zirconium oxide, silicon nitride, tungsten carbide, zirconia toughened alumina, bulk metallic glass and aluminum oxide.
16. The ball of claim 10, wherein the ball further comprises:
   a filler material disposed within the hollow interior of the ball.
17. The ball of claim 16, wherein the filler material includes at least one of sand, gel, ceramic beads and an incompressible fluid.
18. The ball of claim 10, further comprising a fuse aperture in the spherical body for receiving a safety fuse, wherein the safety fuse enables the detonation of the explosive charge by current provided from the battery.

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