Title: DISINTEGRATING BALL FOR SEALING FRAC PLUG SEAT

FIG. 1

Abstract: A composition for a ball that has sufficient rigidity to resist deformation and withstand the high pressure differentials, typically up to 10,000 psi, that are required during well stimulation, but disintegrates, dissolves, delaminates or otherwise experiences a significant degradation of its physical properties over time in the presence of hydrocarbons and formation heat. Extraction from the hole or milling the ball is not necessary upon completion of the well fracturing process. The ball may be used in methods and apparatus for hydraulically fracturing a subterranean zone in a wellbore.

Published:
— with international search report (Art. 21(3))
Disintegrating Ball for Sealing Frac Plug Seat

Field of the Invention

The present invention relates to a ball used in well stimulation to create a seal when dropped down a wellbore onto a frac plug seat. More specifically, it relates to a ball that has sufficient rigidity to resist deformation and withstand the high pressure differentials, typically up to 10,000 psi, that are required during well stimulation, but is capable of disintegrating, dissolving, delaminating or otherwise experiencing a significant degradation of its physical properties in the presence of hydrocarbons and latent heat following well stimulation. Extraction from the hole or milling the ball is not necessary upon completion of the well fracturing process.

Background

In well stimulation, the ability to perforate multiple zones in a single well and then fracture each zone independently, referred to as "zone fracturing", has increased access to potential reserves. Many gas wells are drilled with zone fracturing planned at the well's inception. Zone fracturing helps stimulate the well by creating conduits from the formation for the hydrocarbons to reach the well. A well drilled with planned fracturing zones will be equipped with a string of piping below the cemented casing portion of the well. The string is segmented with packing elements and frac plugs containing ball seats to isolate zones. A ball is dropped or pumped down the well and seats in the frac plug, thereby isolating pressure from above. Typically, a ball seat has an axial opening of a select diameter. To the extent multiple frac plugs are disposed along a string, the diameter of these seats in the respective frac plugs becomes progressively smaller with the depth of the string. This permits a plurality of balls having a progressively increasing diameter, to be dropped (or pumped), smallest to largest diameter, down the well to isolate the various zones, starting from the toe of the well and moving up. When the well stimulation in a particular zone is complete, pressure from within the formation should return the ball utilized in a particular zone to the surface, carrying the ball upward in the flow of return fluids. In order to maximize the number of zones and therefore the efficiency of the well, the diameter of the balls and the corresponding ball seats are very close in size from one zone to another. One-eighth inch increments are common. This means that a given ball has very little
diametrical interference with the seat supporting it since a ball with a diameter of one-eighth inch smaller than the seat’s axial opening must pass through that seat.

Conventional prior art frac balls are typically made of a non-metallic material, such as reinforced epoxies and phenolics, that may be removed by milling in the event the balls become stuck. Such conventional prior art frac balls are made of materials that are designed to remain intact when exposed to hydraulic fracturing temperatures and pressures and are not significantly dissolved or degraded by the hydrocarbons or other media present within the well. When one of these prior art balls does not return to the surface and prevents lower balls from purging, coiled tubing must be lowered into the wellbore to mill the stuck ball and remove it from the seat. In addition, smaller-sized prior art balls that are not stuck in their seats still might not return to the surface because the pressure differential across the ball due to the uprising current in the large diameter casing might not be significant enough to overcome gravity. Consequently, while such smaller-sized balls may not completely block a zone, they are still likely to impede production by partially blocking the wellbore.

Dissolvable balls are sometimes used in a frac process known as pert and plug, where fracturing pressures are not as high. This fracturing process is used when preinstalled perforated casing string is not available and the zones are created through existing casing by perforating the casing to create formation flow paths therethrough. Specifically, using explosives, a relatively large number of small, radial holes are cut through the casing and cement. Typically, these holes have an irregular shape with rough or jagged edges and varying sizes due to the manner in which they are cut. Once the holes are created, the pumping process begins at the surface and the frac fluid fractures that zone through the newly cut radial holes. Upon completion of the zone, relatively small balls are carried in high quantities in fluid pumped from the surface in order to plug the perforated holes. These small balls must be malleable enough to block the irregular perforated holes in the casing. In this regard, these pert and plug balls typically have a high elongation and a low flexural modulus, the reason being that they must deform to plug the irregular shapes of the casing perforations.

These balls require a large ratio of ball diameter to seat diameter to withstand the pressure from fracturing the zone above. Perf and plug balls must remain intact under latent heat and pressure conditions for long periods of time and are often designed to dissolve in water.
Description of the Drawings

Figure 1 illustrates a ball of the present invention seated in a frac plug.
Figure 2 illustrates a frac plug before the ball has become seated.
Figure 3 shows a non-dissolving, prior art ball after becoming stuck in the seat of a frac plug.
Figure 4 illustrates a disintegration of plug style balls of the prior art.
Figure 5 illustrates a cut-away side view of a composite ball of the present invention in which a fabric is layered in parallel planes.
Figure 6 illustrates a cut-away side view of a composite ball of the present invention in which multiple fabric layers are wrapped around a central axis.
Figure 7 illustrates a cut-away side view of a ball of the present invention in which a strengthening material is embedded in a base material.

Detailed Description

The method and apparatus of the present invention provides a ball that disintegrates, dissolves, delaminates or otherwise experiences a significant degradation of its physical properties over time in the presence of hydrocarbons and formation heat. The term "disintegrate" with respect to the frac ball of the present invention is defined to refer generically to various processes by which the physical properties of the frac ball are significantly degraded such that the frac ball can no longer maintain a seal with respect to its corresponding ball seat, such processes including but not limited to disintegration, dissolution and delamination.

The composition of the ball of the present invention permits it to maintain its strength and shape for the time period required to fracture its assigned zone. In one embodiment, this time period is approximately 10 hours.

The ball of the present invention is dropped down a wellbore onto a frac plug seat whereupon it is caused to seat in the frac plug as described above. Since the ball is immersed in frac fluid and dropped from the surface, when it lands in the frac plug seat, the ball is at approximately the same temperature as the frac fluid. Ambient temperatures on the surface including heat generated from the pumps used the pump the frac fluid down hole, typically heat the frac fluid and consequently the balls of the present invention to a temperature of no greater than 150°F.
Frac fluid is then pumped into the frac zone in a conventional manner to initiate formation fracturing. During the hydraulic fracturing process, the convective frac fluid from the surface pumped to fracture the zone also serves as a coolant for the ball relative to latent high temperatures. Since frac fluid must be continuously pumped to the ball to maintain the ball's position in the seat, the flow of frac fluid will keep the ball at nearly the temperature of the frac fluid. Latent heat from the earth is transferred by convection to the ball and is in turn transferred and removed from the ball by convection to the frac fluid. In addition, the frac fluid displaces hydrocarbons within the well minimizing hydrocarbon contact with the ball, thereby inhibiting disintegration of the ball during the hydraulic fracturing process.

Once the frac zone is complete, a column of hydrocarbons, such as diesel fuel, is pumped onto the top or upper portion of the ball. This column of fluid, sometimes referred to as a pad, effectively "soaks" the portion of the ball exposed to the frac zone and initiates the disintegration of the ball. The next larger ball is then dropped or pumped into place on the frac plug immediately above the disintegrating ball, and hydraulic fracturing procedures in the respective zone are initiated. The newly seated ball functions to block frac fluid flow from reaching the now disintegrating lower ball. Thus, the lower ball sits in its seat and continues to disintegrate in the presence of the pad while the zones above it are fractured. Without the relatively cool frac fluid reaching the lower ball, the lower ball's temperature will climb to the latent temperature in the well bore. The latent temperature in the well bore can reach, for example, in excess of 200°F, in excess of 220°F, or in excess of 350°F. The latent formation heat and pressure, the hydrocarbon pad pumped from the top of the well, and to a lesser extent, hydrocarbons from the formation function to disintegrate the ball and initially soften its exterior, stripping the ball of its rigidity and reducing the likelihood that it could become stuck in the seat. As time elapses, the ball continues to disintegrate and soften towards the core. When the well begins to backflow, the currents effectively disintegrate the ball.

It should be noted that for several reasons, the ball will not disintegrate in this controlled manner simply in the presence of formation hydrocarbons acting on the exposed lower surface of the ball, i.e., that portion of the ball that extends below the frac seat. First, the ball is intentionally cooled by the frac fluid pumped down the well. Second, the hydrocarbon pad that is pumped down the well is specifically selected to
yield a controlled disintegration of the ball. In one embodiment, the pad is diesel fuel, which has a composition that ranges from approximately C_{10}H_{20} to C_{15}H_{20}. 

In addition to being subject to controlled disintegration in the presence of hydrocarbons at temperatures in excess of 150°F as described above, and in contrast to the pert and plug balls described above, the disintegrating balls of the present invention are designed for strength, rigidity and hardness sufficient to withstand the high pressure differentials required during well stimulation, which typically range from about 1,000 pounds per square inch (psi) to about 10,000 psi. According to certain embodiments, the ball of the present invention is formed of a material or combination of materials having sufficient strength, rigidity and hardness at a temperature of from about 150°F to about 350°F, from about 150°F to about 220°F or from about 150°F to about 200°F to seal in the frac plug and then withstand deformation under the high pressure ranging from about 1,000 psi to about 10,000 psi associated with hydraulic fracturing processes. For this reason, according to some embodiments of the present invention the ball is formed of a material having a Rockwell Hardness of M 75 or greater.

According to one embodiment, the disintegrating ball of the present invention comprises polystyrene. Polystyrene is a relatively high strength, rigid, high modulus resin that is not compatible with hydrocarbons and disintegrates in the presence of a hydrocarbon, such as diesel, particularly at elevated temperatures, such as temperatures above 150°F and/or pressures, such as 1,000 psi to 10,000 psi where the hydrocarbon acts as a solvent.

According to one embodiment, the ball of the present invention is made of general purpose (GP) polystyrene, which may be substantially pure without other significant additives. According to another embodiment, the ball of the present invention is made of high impact polystyrene (HIP) which may include additives. The following chain represents a suitable polystyrene for making the ball of the present invention:

```
\[
\text{many} \quad \text{polymerization} \quad \text{styrene} \quad \text{polystyrene}
\]
```
With respect to degradation at latent temperatures in the wellbore, the disintegrating ball of the present invention can be formed of any base material or combination of base materials that is sufficiently strong and rigid to support and not deform at a pressure of from 1,000 psi to 10,000 psi at a temperature of less than 150°F, but that undergoes a significant degradation of physical properties at temperatures in excess of 150°F, such that the disintegrating ball breaks apart into a plurality of particles, fragments or pieces that may easily be pumped to the surface. For example, the base material may undergo a significant degradation of physical properties at a temperature range of from about 150°F to about 350°F, from about 150°F to about 220°F, or from about 150°F to about 200°F. This can include polystyrene, as indicated above. Other base materials that have suitable strength and rigidity while also being subject to physical degradation at the appropriate temperatures, include thermosetting polymers, thermoplastic polymers, elastomers and adhesives. Suitable thermosetting polymer materials include phenolic resins, urea-formaldehyde resins, epoxy resins, melamine resins, crosslinked polyesters, polyimides, polyurethanes, cyanate esters, polycyanurates and melamine formaldehyde. Suitable thermoplastic polymer materials include acrylonitrile butadiene styrene, acrylates such as poly methyl methacrylate, polyoxymethylene, polyamides, polybutylene terephthalate, polyethylene terephthalate, polycarbonate, polyester, polyethylene, polyetheretherketone, polypropylene, polystyrene, polyvinylidene chloride and styrene-acrylonitrile. Suitable elastomer materials include ethylene propylene, polyisoprene, polybutadiene, chloroprene rubber, butyl rubber, styrene-butadiene rubber and nitrile rubber. Suitable adhesives include acrylates, methacrylates, and cyanoacrylate.

In certain embodiments, the disintegrating ball of the present invention may be formed of a material having a glass transition temperature (the temperature at which the amorphous phase of a polymer is converted between glassy and rubbery states) or a melting point temperature (the temperature at which a material transitions from a solid state to a liquid state) in the appropriate temperature range, that is, in excess of 150°F (65.5X), for example in the range of from about 150°F to about 350°F (about 65.5°C to about 176.7°C), from about 150°F to about 220°F (about 65.5°C to about 104.4°C), or from about 150°F to about 200°F (about 65.5°C to about 93.3°C). Such materials may include, but are not limited to, the materials listed in Table 1 below.
In another embodiment of the present invention, reinforcing material can be added to the base material of the ball to increase the strength and rigidity of the ball so it can support higher pressures, such as from about 1,000 psi to about 10,000 psi when plugging a seat in a frac plug. Specifically, relatively high percentages of aramid, glass, carbon, boron, polyester, cotton and ceramic fibers or particles can elevate the pressure threshold the ball can sustain. Such fillers do not dissolve in hydrocarbons, but when the base material disintegrates, these fillers become inconsequential silt in the wellbore fluid. According to other embodiments of the present invention, the ball can include

<table>
<thead>
<tr>
<th>Repeating Unit</th>
<th>Glass Transition Temperature (T_g) (°C)</th>
<th>Melting Point (T_m) (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>tert-Butyl vinyl ether</td>
<td>88</td>
<td>250</td>
</tr>
<tr>
<td>3-Chlorostyrene</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Cyclohexyl methacrylate</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>Cyclohexyl vinyl ether</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>N,N-Dimethylacrylamide</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>4-Ethoxystyrene</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>Ethylene terephthalate</td>
<td>72</td>
<td>265</td>
</tr>
<tr>
<td>Ethyl methacrylate</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>4-Fluorostyrene</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>2-Hydropropyl methacrylate</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>Indene</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Isobornyl acrylate</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>N-Isopropylacrylamide</td>
<td>85-130</td>
<td></td>
</tr>
<tr>
<td>Isopropyl methacrylate</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>Phenylene vinylene</td>
<td>80</td>
<td>380</td>
</tr>
<tr>
<td>Phenyl vinyl ketone</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Styrene, atactic</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Styrene, isotactic</td>
<td>100</td>
<td>240</td>
</tr>
<tr>
<td>Trimethylsilyl methacrylate</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Vinyl alcohol</td>
<td>85</td>
<td>220</td>
</tr>
<tr>
<td>Vinyl benzoate</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>81</td>
<td>227</td>
</tr>
<tr>
<td>Vinylcyclohexanoate</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>Vinyl pivalate</td>
<td>86</td>
<td></td>
</tr>
</tbody>
</table>
composite fabric layers made of aramid, glass, carbon, boron, polyester, cotton or ceramic fibers disposed within the base material. Such composite fabric layers enable the ball to retain high strength at high pressures, such as from about 1,000 psi to about 10,000 psi when plugging a seat in a frac plug.

According to certain embodiments, the ball of the present invention may include one or more of (a) imbedded aramid, glass, carbon, boron, polyester, cotton or ceramic fibers, (b) one or more layers of fabric formed of aramid, glass, carbon, boron, polyester, cotton or ceramic fibers wrapped around the core of the ball, and (c) one or more layers of fabric formed of aramid, glass, carbon, boron, polyester, cotton or ceramic fibers disposed in adjacent parallel planes.

According to certain embodiments, the ball of the present invention includes about 30 to about 90 percent by weight of the base material and about 10 to about 70 percent by weight of fibers, particles or layers of fabric. According to certain other embodiments, the ball of the present invention includes about 50 to about 70 percent by weight of the base material and about 30 to about 50 percent by weight of fibers, particles or layers of fabric. In still other embodiments, the ball of the present invention includes about 60 percent by weight of the base material and about 40 percent by weight of fibers, particles or layers of fabric.

Additionally, aluminum may be used to strengthen the disintegrating ball since the corrosive environment in the well hole causes the aluminum to disintegrate as well.

Figure 1 illustrates a polymeric, disintegratable frac ball 10 of the present invention in service. Frac ball 10 is seated on a frac plug seat 12 which is sealably housed in a sleeve 14 carried in a tube 16 of a pipe string 18. Sleeve 14 is slidable between a second position (illustrated in Figure 1) and a first position (illustrated in Figure 2). Those of ordinary skill in the art will appreciate that as fluid, such as frac fluid, is pumped down the well as shown by the directional arrow 20, a pressure differential between the upstream fluid 22 and the downstream formation fluids 24 as applied across the ball 10 and seat 12 urges sleeve 14 into the second position. In this second position, sleeve 14 abuts shoulder 26 of the tube 16. The tube 16 is provided with a plurality of radial apertures or holes 28 that serve as a conduit from the interior 30 of tube 16 to the formation 32, thereby permitting frac fluid pumped from the surface to infiltrate the annulus 34 between the pipe string 18 and the formation 32. Moreover, as will be appreciated in Figure 2, when sleeve 14 is in the second position, apertures 28
are fully open to permit fluid flow therethrough. Packing element 36 is one of many packing elements that partition annulus 34 into zones. A second packing element (not shown) is disposed down stream of perforations 28 so that the packing elements straddle the frac zone and seal the frac zone from the remainder of annulus 34.

In Figure 2, sleeve 14 is shown in a first position, where a ball has not been dropped and the upstream fluid pressure from the frac pumps has not been applied to a seated ball to shift sleeve 14 to the second position. Radial apertures 28 are sealed from communication with interior 30.

In Figure 3, a prior art ball 38 not capable of disintegrating is illustrated as distorted and wedged in seat 12 from the upstream pump pressure during the frac process. When the frac process is complete and the upstream pump pressure is relieved, frac fluid and hydrocarbons with accumulated pressure from the fracturing process and formation pressure purge from the zones below. The wedged ball 38 restricts the return flow from the formations below, requiring expensive milling to remove the ball.

Figure 4 illustrates the prior art where pert and plug balls 40 shown disposed in radial apertures 42 formed in casing 44 and cement 46 adjacent formation 32 by perforation procedures. Prior art balls 40 must distort in order to plug the perforated apertures 42 and typically have a large ball diameter to aperture diameter ratio. Fluid from inside the casing 44 is normally passed through the perforated apertures 42 and into the formation 32 while fracturing that zone. Typically, a large number of balls 40 are dropped into the stream from above with the hope of blocking the apertures 42.

Figures 5 and 6 illustrate embodiments of a ball 10 of the present invention where fabric layers 46 partition material 48 for enhanced strength. In Figure 5, fabric layers 46 have a horizontal lay-up, while in Figure 6, fabric layers 46 are wrapped around a center axis.

Figure 7 illustrates an embodiment of ball 10 of the present invention in which reinforcing material, such as glass, ceramic or carbon fibers or particles 50 is embedded in material 48.

While the ball 10 of the present invention has been described in the foregoing embodiments as including certain specific materials and the pad utilized to initiate degradation of the ball as diesel, those of ordinary skill in the art will appreciate that other ball material and pad solvent combinations may be utilized so long as they satisfy
the requirements of the system described herein. In this regard, styrene is known to have a solubility parameter of 8.7 6(cal/cm³)½. Although a pad of diesel is a preferred embodiment for a ball made of polystyrene as described herein, solvents with the same or similar solubility parameters as polystyrene may also be satisfactory for the purposes of the present invention, such as for example, other hydrocarbons, oils, ketones, esters and inorganic acids. In one embodiment, hydrocarbons are preferred because hydrocarbons are generally acceptable fluids under various regulatory standards for pumping into a wellbore and are typically readily available at a well site, and are present naturally in the well. In any event, materials with similar solubility parameters may also be satisfactory for ball 10 of the present invention. Finally, so long as the material used to form the ball of the present invention satisfies the other criteria set forth herein, particularly strength and rigidity, the ball may be formed of other polymeric or other materials with a pad selected to have the same or similar solubility parameters as the polymeric or other material of the ball.

Similarly, with respect to degradation at latent temperatures of the wellbore, so long as the material used to form the ball of the present invention satisfies the other criteria set forth herein, particularly strength and rigidity, the ball may be formed of other polymeric materials with a glass transition temperature and/or melting temperature in the appropriate temperature range such that the materials undergo significant physical degradation at temperatures in excess of 150°F, such as from about 150°F to about 350°F, from about 150°F to about 220°F, or from about 150°F to about 200°F.
Claims

What is claimed:

1. A fracturing system for a wellbore, said system comprising:
   a tube having a wall comprising an interior surface and an exterior surface;
   a ball seat carried by the tube, the ball seat comprising an opening of a first diameter; and
   a ball having a second diameter larger than the first diameter, the ball comprising a first material, wherein the first material is disintegrated by hydrocarbons.

2. The system of claim 1, wherein the first material comprises polystyrene.

3. The system of claim 2, wherein the first material comprises general purpose polystyrene.

4. The system of claim 2, wherein the ball further comprises a second material, wherein the second material comprises fibers or particles of at least one member selected from the group consisting of aramid, glass, carbon, boron, polyester, cotton and ceramics.

5. The system of claim 2, wherein the ball further comprises a second material, wherein the second material comprises one or more layers of a composite fabric material, said composite fabric material comprising at least one member selected from the group consisting of aramid, glass, carbon, boron, polyester, cotton and ceramic fibers.

6. The system of claim 2, wherein the ball comprises from about 30 percent to about 90 percent by weight of the first material.

7. The system of claim 2, wherein the ball comprises from about 50 percent to about 70 percent by weight of the first material.
8. The system of claim 2, wherein the ball comprises about 60 percent by weight of
the first material.

9. The system of claim 4, wherein the ball comprises about 60 percent by weight of
the first material and about 40 percent by weight of the second material.

10. The system of claim 1, wherein the ball is seated in the opening of the ball seat
so that a first portion of the ball is exposed above the opening and a second portion of
the ball is exposed below the opening, the system further comprising a volume of
hydrocarbon disposed in the tube and in contact with the first portion of the ball.

11. The system of claim 1, wherein the ball is seated in the opening of the ball seat
and prevents fluid communication between a first portion of the tube above the ball and
a second portion of the tube below the ball.

12. The system of claim 11, wherein the ball prevents fluid communication between
the first and second portions of the tube at a pressure of up to about 10,000 psi.

13. The system of claim 1, wherein the ball seat comprises a flange disposed around
the interior surface of the tube wall.

14. The system of claim 1, wherein the ball seat comprises a sleeve slidingly
mounted within the tube between a first position and a second position.

15. The system of claim 14, wherein the sleeve has an interior surface and an
exterior surface, and further comprises a shoulder defined adjacent the interior surface.

16. The system of claim 15, wherein the ball seat further comprises a collar abutting
the shoulder and in which the opening is defined.

17. The system of claim 14, wherein the tube further comprises a plurality of
apertures disposed in the tube wall, wherein the sleeve in the first position is adjacent
the apertures so as to impede fluid flow therethrough.
18. The system of claim 14, further comprising a plurality of ball seats, wherein each of the plurality of ball seats has an opening of a diameter different from those of the other ball seats; and

5 a plurality of balls, each disposed to seat within one of the openings of the ball seats, wherein each of the plurality of balls has a diameter different from those of the other balls.

19. The system of claim 18, further comprising a pipe string in which the seats are disposed, wherein the plurality of seats are arranged consecutively along the pipe string from the seat with the largest diameter opening to the seat with the smallest diameter opening.

20. A fracturing system for a wellbore, said system comprising:

15 a tube having a wall comprising an interior surface and an exterior surface;

a ball seat carried by the tube, the ball seat comprising an opening of a first diameter; and

a ball having a second diameter larger than the first diameter, the ball comprising a first material, wherein the first material degrades at a temperature greater than 150°F.

21. The system of claim 20, wherein the first material degrades at a temperature range of from about 150°F to about 350°F.

22. The system of claim 20, wherein the first material degrades at a temperature range of from about 150°F to about 220°F.

23. The system of claim 20, wherein the first material degrades at a temperature range from about 150°F to about 200°F.

24. The system of claim 20, wherein the ball does not deform at a pressure of up to about 10,000 psi.
The system of claim 20, wherein the first material is selected from the group consisting of thermosetting polymers, thermoplastic polymers, elastomers and adhesives.

The system of claim 20, wherein the first material comprises a thermosetting polymer selected from the group consisting of phenolic resins, urea-formaldehyde resins, epoxy resins, melamine resins, crosslinked polyesters, polyimides, polyurethanes, cyanate esters, polycyanurates and melamine formaldehyde.

The system of claim 20, wherein the first material comprises a thermoplastic polymer selected from the group consisting of acrylonitrile butadiene styrene, acrylates such as poly methyl methacrylate, polyoxymethylene, polyamides, polybutylene terephthalate, polyethylene terephthalate, polycarbonate, polyester, polyethylene, polyetheretherketone, polypropylene, polystyrene, polyvinylidene chloride and styrene-acrylonitrile.

The system of claim 20, wherein the first material comprises an elastomer selected from the group consisting of ethylene propylene, polyisoprene, polybutadiene, chloroprene rubber, butyl rubber, styrene-butadiene rubber and nitrile rubber.

The system of claim 20, wherein the first material comprises an adhesive selected from the group consisting of acrylates, methacrylates, and cyanoacrylate.

The system of claim 20, wherein the first material is selected from the group consisting of polystyrene, tert-butyl vinyl ether, 3-chlorostyrene, cyclohexyl methacrylate, cyclohexyl vinyl ether, α,α-dimethylacrylamide, 4-ethoxystyrene, ethylene terephthalate, ethyl methacrylate, 4-fluorostyrene, 2-hydropropyl methacrylate, indene, isobornyl acrylate, N-isopropylacrylamide, isopropyl methacrylate, phenylene vinylene, phenyl vinyl ketone, atactic styrene, isotactic styrene, trimethylsilyl methacrylate, vinyl alcohol, vinyl benzoate, vinyl chloride, vinylcyclohexanoate and vinyl pivalate.
31. The system of claim 20, wherein the ball further comprises a second material, wherein the second material comprises fibers or particles of at least one member selected from the group consisting of aramid, glass, carbon, boron, polyester, cotton and ceramics.

32. The system of claim 20, wherein the ball further comprises a second material, wherein the second material comprises one or more layers of a composite fabric material, said composite fabric material comprising at least one member selected from the group consisting of aramid, glass, carbon, boron, polyester, cotton and ceramic fibers.

33. A method for fracturing the formation around a wellbore, the method comprising: deploying a pipe string into a wellbore, the pipe string having perforations disposed in a wall of the pipe string and a ball seat positioned in the interior of the pipe string; setting packers above and below the perforations to seal the annulus formed between the pipe string and the formation; introducing a disintegratable ball comprised of a first material into the pipe string; seating the ball on the ball seat by applying a fluid pressure to the ball, which fluid pressure is greater than the pressure of the wellbore, wherein the ball when seated, has an upstream portion and a downstream portion; introducing fracturing fluids into the wellbore to initiate fracturing of the formation adjacent the perforations; cooling the upstream portion of the disintegratable ball during fracturing of the formation to inhibit disintegration of the ball; upon completion of the fracturing, introducing a hydrocarbon pad into the pipe string; contacting the upstream portion of the ball with the hydrocarbon pad to promote disintegration of the ball by the hydrocarbon pad; and allowing disintegration of the ball to continue until the ball unseats from the ball seat.
34. The method of claim 33, wherein a pressure differential across the ball is maintained during fracturing.

35. The method of claim 34, wherein the upstream pressure applied to the ball is greater than the downstream pressure applied to the ball.

36. The method of claim 35, wherein the upstream pressure is up to 10,000 psi.

37. The method of claim 33, wherein a temperature differential across the ball is maintained during fracturing.

38. The method of claim 37, wherein the upstream temperature applied to the ball is less than the downstream temperature applied to the ball.

39. The method of claim 33, wherein the fracturing fluid has a fluid temperature less than the temperature of the wellbore fluid;

40. The method of claim 39, wherein the fracturing fluid is used to cool the ball during fracturing.

41. The method of claim 33, wherein the hydrocarbon pad is diesel.

42. The method of claim 33, wherein the heat of the formation is used to accelerate degradation.

43. The method of claim 33, wherein the first material comprises a thermosetting polymer selected from the group consisting of phenolic resins, urea-formaldehyde resins, epoxy resins, melamine resins, crosslinked polyesters, polyimides, polyurethanes, cyanate esters, polycyanurates and melamine formaldehyde.
44. The method of claim 33, wherein the first material comprises a thermoplastic polymer selected from the group consisting of acrylonitrile butadiene styrene, acrylates such as poly methyl methacrylate, polyoxymethylene, polyamides, polybutylene terephthalate, polyethylene terephthalate, polycarbonate, polyester, polyethylene, polyetheretherketone, polypropylene, polystyrene, polyvinylidene chloride and styrene-acrylonitrile.

45. The method of claim 33, wherein the first material comprises an elastomer selected from the group consisting of ethylene propylene, polyisoprene, polybutadiene, chloroprene rubber, butyl rubber, styrene-butadiene rubber and nitrile rubber.

46. The method of claim 33, wherein the first material comprises an adhesive selected from the group consisting of acrylates, methacrylates, and cyanoacrylate.

47. The method of claim 33, wherein the first material is selected from the group consisting of polystyrene, tert-butyl vinyl ether, 3-chlorostyrene, cyclohexyl methacrylate, cyclohexyl vinyl ether, N,N-dimethylacrylamide, 4-ethoxystyrene, ethylene terephthalate, ethyl methacrylate, 4-fluorostyrene, 2-hydropropyl methacrylate, indene, isobornyl acrylate, N-isopropylacrylamide, isopropyl methacrylate, phenylene vinylene, phenyl vinyl ketone, atactic styrene, isotactic styrene, trimethylsilyl methacrylate, vinyl alcohol, vinyl benzoate, vinyl chloride, vinylcyclohexanoate and vinyl pivalate.

48. The method of claim 33, wherein the ball further comprises a second material, wherein the second material comprises fibers or particles of at least one member selected from the group consisting of aramid, glass, carbon, boron, polyester, cotton and ceramics.

49. The method of claim 33, wherein the ball further comprises a second material, wherein the second material comprises one or more layers of a composite fabric material, said composite fabric material comprising at least one member selected from the group consisting of aramid, glass, carbon, boron, polyester, cotton and ceramic fibers.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - E21B 29/00 (2012.01)
USPC - 166/376

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 29/00 (2012.01)

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>US 7,681,645 B2 (MCMILLIN et al) 23 March 2010 (23.03.2010) entire document</td>
<td>18, 19, 33-49</td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of Box C.

Date of the actual completion of the international search: 17 April 2012

Date of mailing of the international search report: 01 MAY 2012

Name and mailing address of the ISA/US
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450
Facsimile No. 571-273-3201

Authorized officer: Blaine R. Copenheaver
PCT Helpdesk: 571-272-4300
PCT OSP: 571-272-7774

Form PCT/ISA/P2.10 (second sheet) (July 2009)