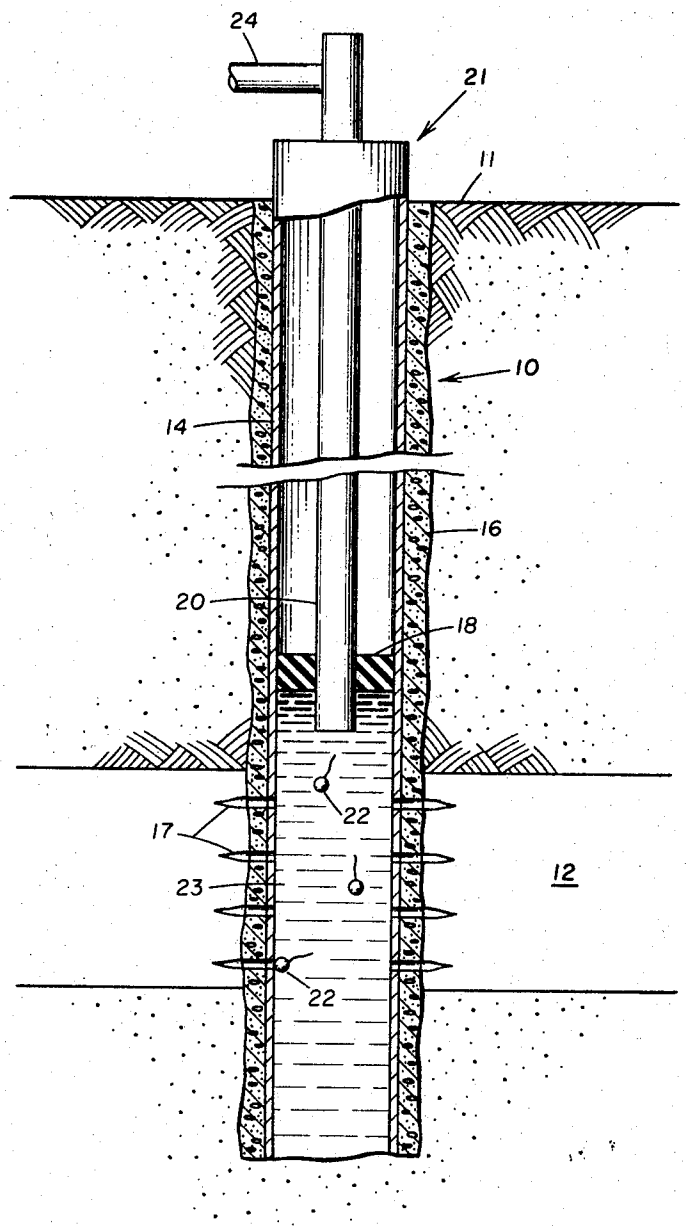
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METHOD AND APPARATUS FOR PLUGGING WELL PIPE PERFORATIONS

Filed Feb. 23, 1967 Sheet 1 of 2

FIG. 1



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METHOD AND APPARATUS FOR PLUGGING WELL PIPE PERFORATIONS

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FIG. 2

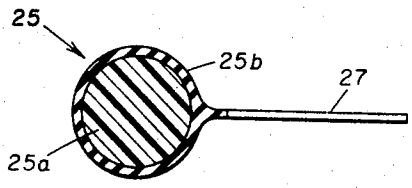
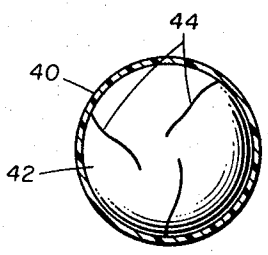


FIG. 4



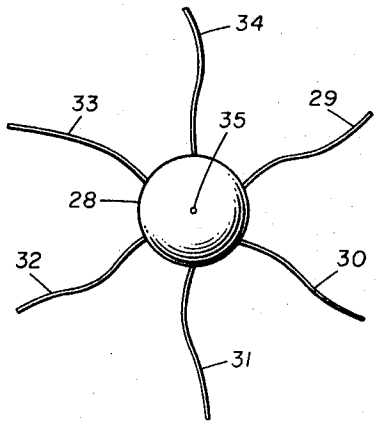
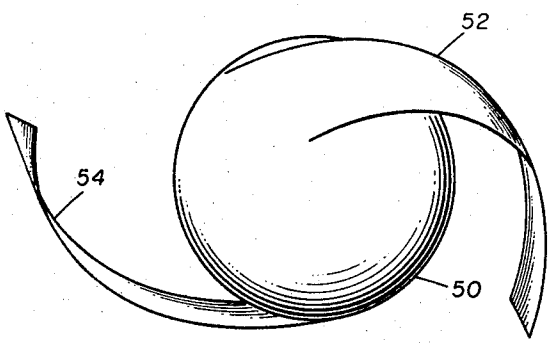


FIG. 3

FIG. 5



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METHOD AND APPARATUS FOR PLUGGING WELL PIPE PERFORATIONS

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Int. Cl. E21b 33/138
U.S. Cl. 166—305 6 Claims

ABSTRACT OF THE DISCLOSURE

This specification describes certain perforation plugging elements and methods of using the same. The plugging elements comprise a body member and one or more tentacles which are secured to the body member and function to guide the body member to a perforation through which fluid is flowing. In one embodiment, the tentacles may be temporarily confined in proximity to the body by a jacket of material soluble in the well fluid.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to the plugging of well pipes set in subterranean wellbores and, more particularly, to new and improved perforation plugging elements and the utilization of such elements.

Description of the prior art

Wellbores penetrating to subterranean locations within the earth's crust often are provided with pipes having perforations to allow for the ingress or egress of fluids. For example, in the oil industry a well is conventionally provided with a pipe string, commonly termed a casing, which is set within a hydrocarbon-bearing formation. The casing string normally is cemented within the well and provided with perforations for the recovery of fluids from the formation, as in the case of a production well, or the introduction of fluids into the formation, as in the case of an injection well. The perforations may be formed by the conventional gun or jet perforating techniques after the casing string is set and cemented within the well. Alternatively, the casing may be perforated before insertion thereof into the well, in which case the casing normally will be cemented by the so-called "scab cementing" techniques.

In the utilization of such wells it often is desirable to plug one or more of the casing perforations. For example, in U.S. Patent No. 2,754,910 to Derrick et al. there is disclosed a method of temporarily closing casing perforations during the employment of well treating processes such as acidizing and hydraulic fracturing. In such processes a fluid treating medium is injected into the well and forced through the casing perforations into the surrounding formation in order to effect an increase in permeability thereof. In carrying out such processes it has been found that oftentimes a disproportionately high quantity of treating fluid flows through certain "high-volume" perforations with the attendant result that the formation sections adjacent the remaining "low-volume" perforations receive little or no treating fluid. In accordance with the techniques disclosed in the aforementioned patent to Derrick et al., such perforations are closed temporarily by introducing into the treating fluid perforation plugging elements. These plugging elements, which normally take the form of balls of a diameter larger than the diameter of the perforations, follow the flow of treating fluid through the well until they are seated by fluid pressure against the high-volume perforations in the casing string. After such seating of the plugging elements, commonly termed "ball sealers," continued injection of treating fluid results in fluid flow through the perforations which remain open. After the treatment of the well is completed, injection of the treating fluid may be terminated and the attendant decrease in casing pressure results in disengagement of the ball sealers from the perforations.

While this plugging technique has met with some success, experience has shown that in many instances the plugging elements fail to seat in the casing perforations as desired. To overcome this it has been a practice in the past to utilize an excess of plugging elements, e.g., 25% to 50% more plugging elements than casing perforations within the zone of treatment, in order to ensure at least some plugging of the high-volume perforations with the attendant diversion of the treating fluid to the low-volume perforations. However, the utilization of an excess of plugging elements carries with it the danger that the elements may function with unusual efficiency and plug all of the perforations, thus, sealing off the formation completely and leading to failure of the treating process.

SUMMARY OF THE INVENTION

In accordance with the present invention, there are provided new and improved plugging elements of the so-called "ball sealer" type which function with an increased consistency and efficiency. The perforation sealing elements of the present invention comprise an enlarged body member, preferably spherical in shape and of a diameter greater than the casing perforations, and one or more reduced elongated flexible tentacles extending outwardly from the body member and terminating in a free end remote from the body member. The tentacle or tentacles present an increased surface area to fluid flowing through a perforation and thus facilitate seating of the body member against a perforation to seal the same. Thus, in carrying out the method of the present invention in plugging one or more perforations in a well pipe such as a casing, fluid is flowed from the interior of the pipe through the perforations to the exterior thereof and one or more of the aforementioned plugging elements are disposed in the fluid within the interior of the pipe. The tentacles of the plugging elements are more easily entrained within the fluid flow than the body members and, hence, tend to drag or guide the body members to their seating positions in the perforations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is an illustration, partly in section, of a well structure within which the invention may be carried out;

FIGURE 2 is an illustration, partly in section, showing one form of plugging element;

FIGURE 3 is an illustration showing another form of plugging element.

FIGURE 4 is an illustration showing a plugging element provided with restraining means in accordance with one embodiment of the invention; and

FIGURE 5 is an illustration showing another form of plugging element.

DESCRIPTION OF SPECIFIC EMBODIMENTS

With reference to FIGURE 1, there is shown a well bore **10** which extends from the earth's surface **11** and penetrates a subterranean stratum **12**, such as an oil-bearing formation. The well bore is provided with a well pipe or casing string **14** which may be cemented, as indicated by reference numeral **16**. The casing string and the surrounding cement sheath are provided with a plurality of perforations **17** adjacent the formation **12**. The well also may be provided with a suitable packer **18** which isolates the zone

of treatment from the remainder of the well and a tubing string **20** which extends from the surface or wellhead **21** of the well through the packer **18**. The tubing string **20** is provided with a suitable flow line **24** for the introduction and withdrawal of fluids to and from the well.

By way of illustrating the present invention, it will be assumed that the well **10** is an oil production well which is to be treated by a hydraulic fracturing operation in order to increase the permeability of the adjacent formation **12** and, thus, increase the productivity of the well. It is to be understood, however, that the following description of such fracturing operation is merely exemplary and that the invention may be used in other well treating procedures such as matrix acidizing, for example.

The fracturing of the formation is accomplished by injecting into the well a liquid medium such as indicated by reference numeral **23** and building up a pressure on the face of the formation sufficient to cause fracturing thereof. As is well known to those skilled in the art, the fracturing medium may flow predominately through certain of the perforations **17** with little or no flow through the remaining perforations. In order to close off the perforations selectively taking fluid and thus divert the treating fluid to the remaining perforations, one or more plugging elements **22** are disposed within the treating fluid within the interior of the casing **14**. This may be accomplished by any suitable technique. For example, the plugging elements may be introduced into the casing **14** via flow line **24** and tubing **20** by means of a wellhead dispensing device, such as that disclosed in U.S. Patent No. 2,976,928 to Gilbert. Alternatively, the plugging elements may be disposed in the treating fluid by means of a suitable downhole dispensing system, such as disclosed in U.S. Patent No. 3,086,587 to Zandmer et al. Also, the plugging elements may be disposed in the treating fluid by suspending them on a wire line anl thereafter injecting the treating fluid into the casing as disclosed in the aforementioned patent to Derrick et al.

One or more plugging elements may be utilized in carrying out the present invention depending upon the number of perforations involved. Because of the relatively high efficiency of the herein disclosed plugging elements, an excess of such elements normally will be unnecessary. In fact, it usually will be preferred in carrying out the invention to use the plugging elements in an amount less than the number of perforations in the treating zone.

As described in greater detail hereinafter, the plugging elements **22** comprise an enlarged body member and one or more reduced elongated tentacles extending outwardly from the body member. The tentacles provide an increased surface area to the treating fluid as it flows through the perforations into the adjacent formation such that the plugging elements are guided to and seat in the casing perforations. The plugging elements are held in place against the perforations by the fluid pressure within the casing string **14** which is greater than the pressure exteriorly of the casing string within the formation. The plugging elements will remain thus seated until such time as the treating method is completed and injection of fracturing fluid terminated. As the pressure within the casing string **14** decreases, the pressure gradient across the perforations will be reversed and the plugging elements will be released from seating engagement with the perforations.

Subsequent to the treating procedure, it may be desirable to ascertain the number of perforations actually sealed by the plugging elements. In this event, the plugging elements are recovered from the well and examined to ascertain the presence or absence thereon of markings indicative of their seating against the perforations. The plugging elements are recovered by placing the well on production to recover the previously injected treating fluid and fluids indigenous to the formation **12** through the tubing **20** and flow line **24**. The tentacles aid in recovery of the plugging elements from the well by again presenting an increased surface area to the flow of fluid as it travels upwardly through the well. The presence of the tentacles during this phase of operation is particularly important where, as is preferred, the plugging elements are of a density greater than that of the treating fluid.

With reference to FIGURE 2, there is shown one embodiment of a plugging element formed in accordance with the present invention. The plugging element comprises a central body member **25** formed of an inner core **25*a*** and a cover **25*b*** disposed about the inner core. The body member **25** preferably is deformable in order that it may adjust to any irregularities in the perforation against which it seats and also accommodate any tentacles which may become interposed between the body member and such perforation and while still providing an effective seal. Thus, the core **25*a*** and/or the coating **25*b*** may be made of suitable deformable materials. As an example of a plugging element which has worked satisfactorily, the core may be made of nylon and the coating of rubber.

The plugging element of FIGURE 2 also comprises a tentacle **27** which is threadlike or filamentous in shape and which extends outwardly from the body portion **25** and terminates at a free end adapted for remote displacement from the body portion. Preferably, the tentacle **27** is formed integrally with the coating **25*b*** in order to facilitate construction of the plugging element. For example, the tentacle may be formed by molding at the time the coating member is applied to the inner core **25*a***.

Preferably, the tentacle **27** has a bulk density different from the bulk density of the body member **25** in order to facilitate displacement of the end of the tentacle from close proximity with the body member. This may be accomplished by forming the coating and tentacle of a material having a density different than that of the inner core member **25*a***. For example, the coating member and tentacle may be formed of rubber having a specific gravity of about 1.0 and the inner core member may be formed of nylon having a specific gravity of 1.1. Thus, the plugging element will tend to assume an attitude in the treating fluid such that the free end of the tentacle is above the body member. In this case, if the body member should move past a perforation which is taking fluid, the trailing tentacle may come within the flow of fluid through the perforation, thus, drawing the body member back into seating position in the perforation. It is to be recognized that the tentacle **27** may have a higher bulk density than the body member **25**. For example, the free end of the tentacle member may be provided with a piece of lead shot or other high density material such that the tentacle precedes the body member as the plugging element moves downwardly within the well. In this case, the tentacle may first be entrained within a stream of fluid flowing through a perforation and thus serve as a guide to draw the body member into seating position.

With reference to FIGURE 3, there is shown a modified form of plugging element in which a central body member **28** is provided with a plurality of tentacles such as those indicated by reference numerals **29–35**. The tentacles **29–35** may be attached to the body member **28** similarly as explained above with reference to FIGURE 2. It will be recognized, however, that any suitable means may be utilized for attaching the tentacles to the body member. For example, the tentacles may take the form of thin fibers which are threaded through the core of the body member. In the embodiment shown in FIGURE 3, one or more of the tentacles **29–35** may have a bulk density less than the bulk density of the body member **28** and one or more of the remaining tentacles may have a bulk density greater than the bulk density of the body member. For example, where the tentacle **33** is formed of a material having a density less than the density of the material forming the body member **28**, one or more of the opposing tentacles **29–31** may be provided with a lead shot at the free end thereof. Thus, as the plugging element is disposed within the fracturing or other treating fluid, it will tend to assume an attitude in which the free end of the tentacle of higher bulk density is disposed below

the body member and the free end of tentacle **33** above the body member.

The bulk densities of the plugging elements may be either greater or less than the density of the treating fluid. Usually the plugging elements will be disposed in the treating fluid at a level above the perforations, e.g., at the well head, as disclosed in the aforementioned patent to Gilbert, and it is desirable to utilize plugging elements having a bulk density slightly greater than the density of the treating fluid in order to ensure downward movement of the plugging elements through the well. Since most liquids utilized in well treating processes such as fracturing and acidizing have a specific gravity of one or more, it usually will be preferred to utilize plugging elements having a bulk density greater than one.

In most cases, in carrying out the present invention, it will be preferred to utilize plugging elements having a spherical body member. However, the body members may take other shapes such as the polyhedral configurations shown in the aforementioned patent to Derrick et al.

At noted previously, the plugging elements normally should be of sufficient size such that they will not pass through the casing perforations. In most cases, casing perforations are about ⅜" to ⅞" in diameter and the plugging elements preferably are comprised of a body member having a diameter within the range of ½" to 1". Usually it will be preferred to provide the body members with tentacles of a thickness of not more than 0.1" and a length within the range of ½" to 3". Preferably, the length of the tentacles will be at least equal to the diameter of the body member. However, plugging elements having dimensions other than as noted above may be used as experience dictates.

From the foregoing description it will be recognized that the tentacles function to greatly increase the seating efficiency of the plugging elements as they approach the location of the casing perforations. However, the presence of such tentacles may present certain difficulties as the plugging elements are dispersed within the treating fluid. For example, the the plugging elements are introduced into the treating fluid from a dispenser or other suitable injection device the tentacles may tend to become entangled, thus decreasing the efficiency of the plugging elements and perhaps even preventing the separate dispersion thereof in the treating fluid. In order to overcome such difficulties, there is provided, in accordance with another embodiment of the invention, restraining means for confining temporarily the tentacle or tentacles of a plugging element in proximity to the body member until the plugging element is disposed in the treating fluid. Thereafter, the restraining means responds to the presence of the treating fluid to release the tentacles in order that they may assume an attitude relative to the body member in which their free ends are remote from the body member.

With reference to FIGURE 4, there is shown a plugging element which is provided with a preferred form of restraining means. As shown in FIGURE 4, the restraining means takes the form of a temporary jacket **40** which overlies the tentacles **44** of the plugging element and restrains the tentacles adjacent the body member **42** so as to prevent their entanglement with each other, with the tentacles of other plugging elements, or with elements of the dispensing apparatus. The jacket **40** is formed of a material which is readily soluble in the treating fluid. For example, in hydraulic fracturing or acidizing operations where an aqueous treating medium is employed, the jacket may take the form of a thin film of partially hydrolyzed, e.g., on the order of 88% hydrolysis, polyvinyl alcohol. In well treating processes employing an oleaginous liquid such as crude oil, the jacket **40** may be formed of suitable oil-soluble materials such as the paraffin waxes. In any case, as the plugging elements are disposed in the treating fluid the jacket **40** is dissolved leaving the tentacles free to function in the manner described above. The plugging elements themselves are, of course, inert with respect to the treating fluid.

With reference to FIGURE 5, there is shown another form of plugging element in which the tentacle or tentacles are spatular in shape rather than filamentous as in the embodiments described above. As shown in FIGURE 5, the plugging element comprises a body member **50** and one or more spatuliform tentacles such as those indicated by reference numerals **52** and **54**. These tentacles will generally be less subject to entanglement than filamentous tentacles such as those shown in FIGURE 3 and in addition will present a relatively large surface area to fluid flow.

The tentacles **52** and **54** may be attached to the body member **50** by any suitable means. For example, where the body member **50** comprises an inner core and an outer cover, such as shown in FIGURE 2, the tentacles **52** and **54** may be formed integrally with the cover. Also, while the spatuliform tentacles are less subject to entanglement than filamentous tentacles, it may be advantageous to provide the plugging element of FIGURE 5 with temporary restraining means such as described above. Thus, the plugging element may be provided with a jacket similar to that shown in FIGURE 4. Alternatively, such restraining means may take the form of an adhesive which bonds the tentacles to the body member and which is soluble in the treating fluid.

Having described specific embodiments of the instant invention, it will be understood that further modifications thereof may be suggested to those skilled in the art, and it is intended to cover all such modifications as fall within the scope of the appended claims.

What is claimed is:

1. A perforation plugging element for use in plugging perforated well pipe during the injection of a treating fluid in a well treating process comprising:

a body member,

a reduced, elongated flexible tentacle secured to said body member and adapted to extend outwardly from said body member and terminating at a free end adapted for remote displacement from said body member, and

restraining means for confining said tentacle in proximity to said body member and responsive to the presence of said treating fluid for releasing said tentacle from such confinement.

2. The plugging element of claim **1** wherein said restraining means comprises a water-soluble jacket.

3. The plugging element of claim **1** wherein said restraining means comprises an oil-soluble jacket.

4. In a method of plugging a perforation in a treating zone of a well pipe set in a subterranean well, the steps comprising:

flowing fluid from the interior of said pipe through said perforation to the exterior thereof, and

disposing in said fluid within the interior of said pipe a plugging element having an enlarged body member and a reduced, elongated, flexible tentacle secured to said body member and adapted to extend outwardly from said body member, said tentacle terminating at a free end adapted for remote displacement from said body member whereby said tentacle presents an increased surface area to fluid flowing through said perforation and facilitates seating of said body member in said perforation, said plugging element when disposed in said fluid including restraining means for confining said tentacle in proximity to said body member, said restraining means being responsive to the presence of said fluid for releasing said tentacle from such confinement.

5. The method of claim **4** wherein said restraining means comprises a jacket surrounding said body member and tentacle, said jacket being soluble in said fluid.

6. A perforation plug element for use in plugging perforated well pipe comprising:

a spherical deformable body member having a diameter within the range of ½ to 1 inch, and

a plurality of reduced, elongated, flexible tentacles, each tentacle secured to said body member and adapted to extend outwardly from said body member and terminating at a free end adapted for remote displacement from said body member, at least one of said tentacles having a bulk density greater than said body member and at least another of said tentacles having a bulk density less than said body member.

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166—193; 273—58