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(54) **WIPER PLUG ELEMENTS AND METHODS OF STIMULATING A WELLBORE ENVIRONMENT**

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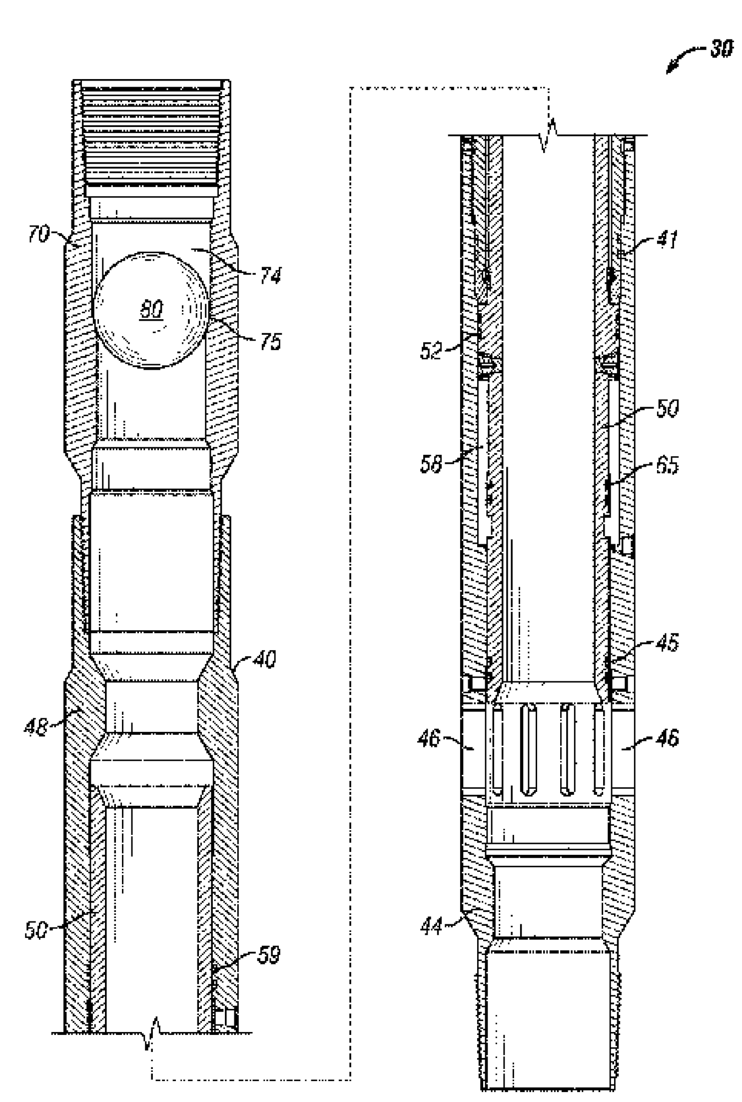
(57) **ABSTRACT**

Methods for preparing a wellbore casing for stimulation operations comprise the steps of cementing a wellbore casing in a wellbore, the wellbore casing having a downhole tool comprising a valve and an apparatus for restricting fluid flow through the valve, such as a ball seat, disposed above the valve. Actuation of the valve opens the valve to establish fluid communication between the wellbore casing and the formation. A plug element is disposed on a seat of the ball seat and a casing pressure test is performed. The plug element then dissolves or disintegrates over time increasing fluid communication between the wellbore casing and the formation, thereby preparing the wellbore casing for stimulation operations without additional wellbore intervention after the casing pressure test. In certain embodiments, during or after dissolution of the plug element, clean-out of the bore of the valve is performed by the plug element.

20 Claims, 5 Drawing Sheets



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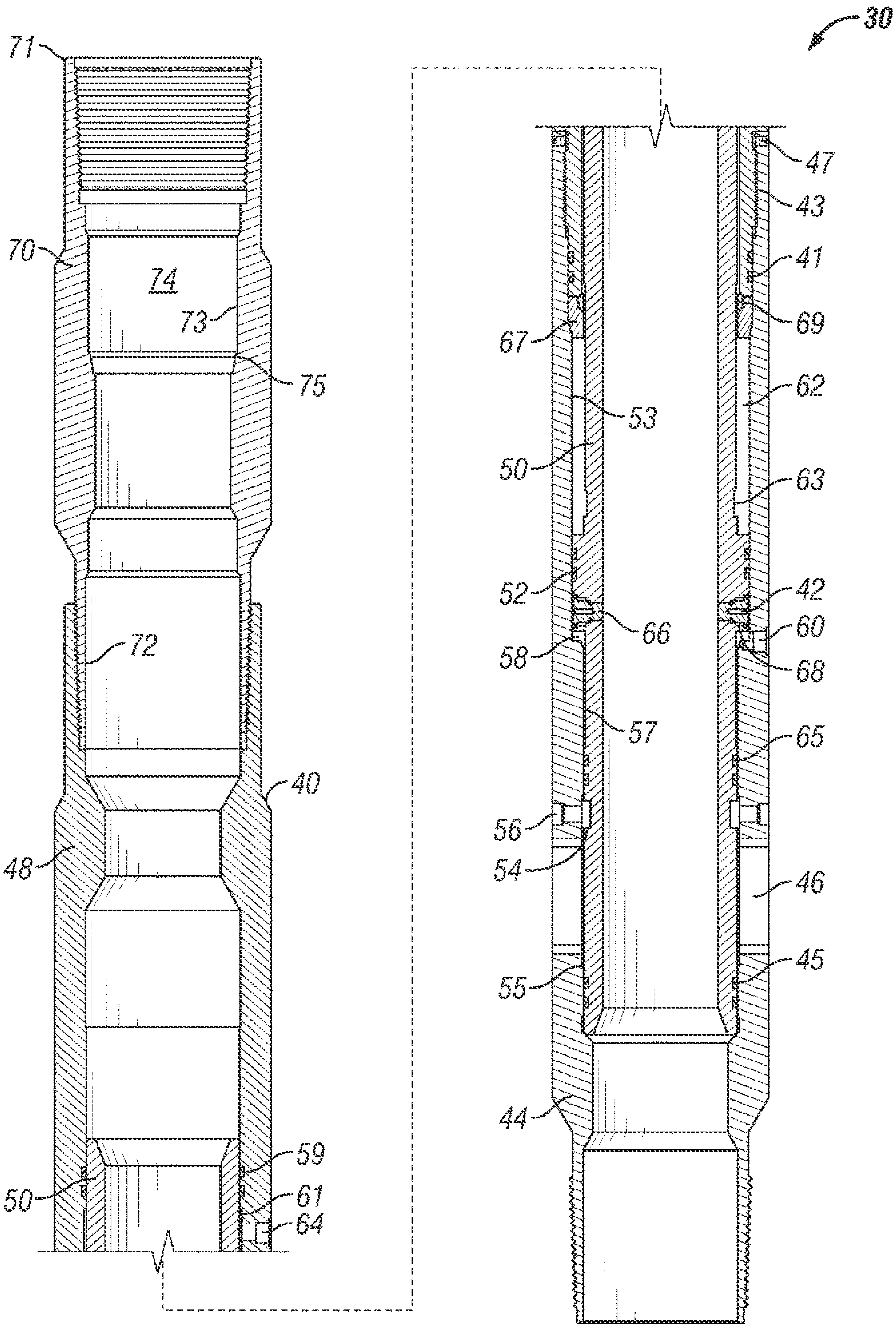
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FIG. 1

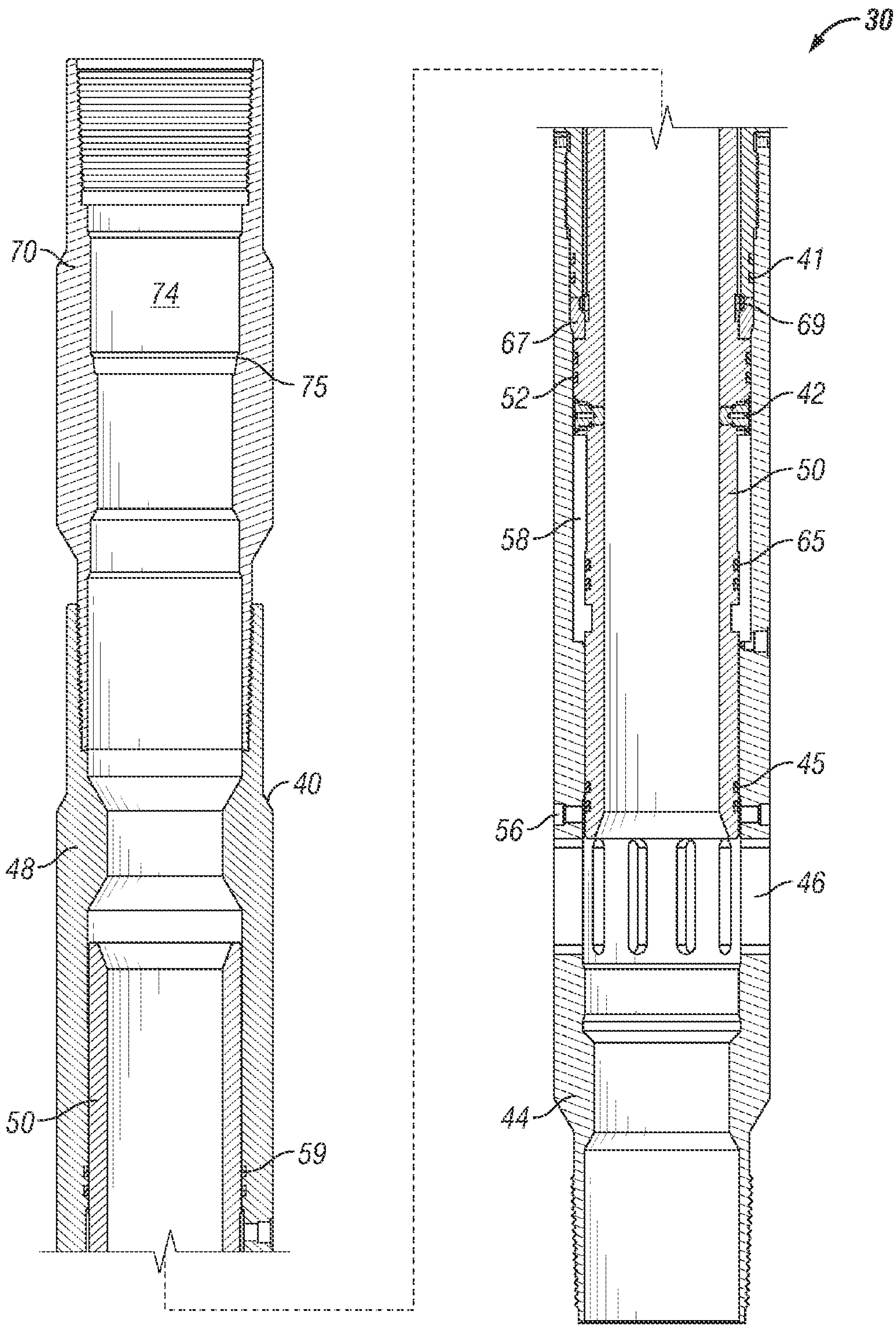

FIG. 2

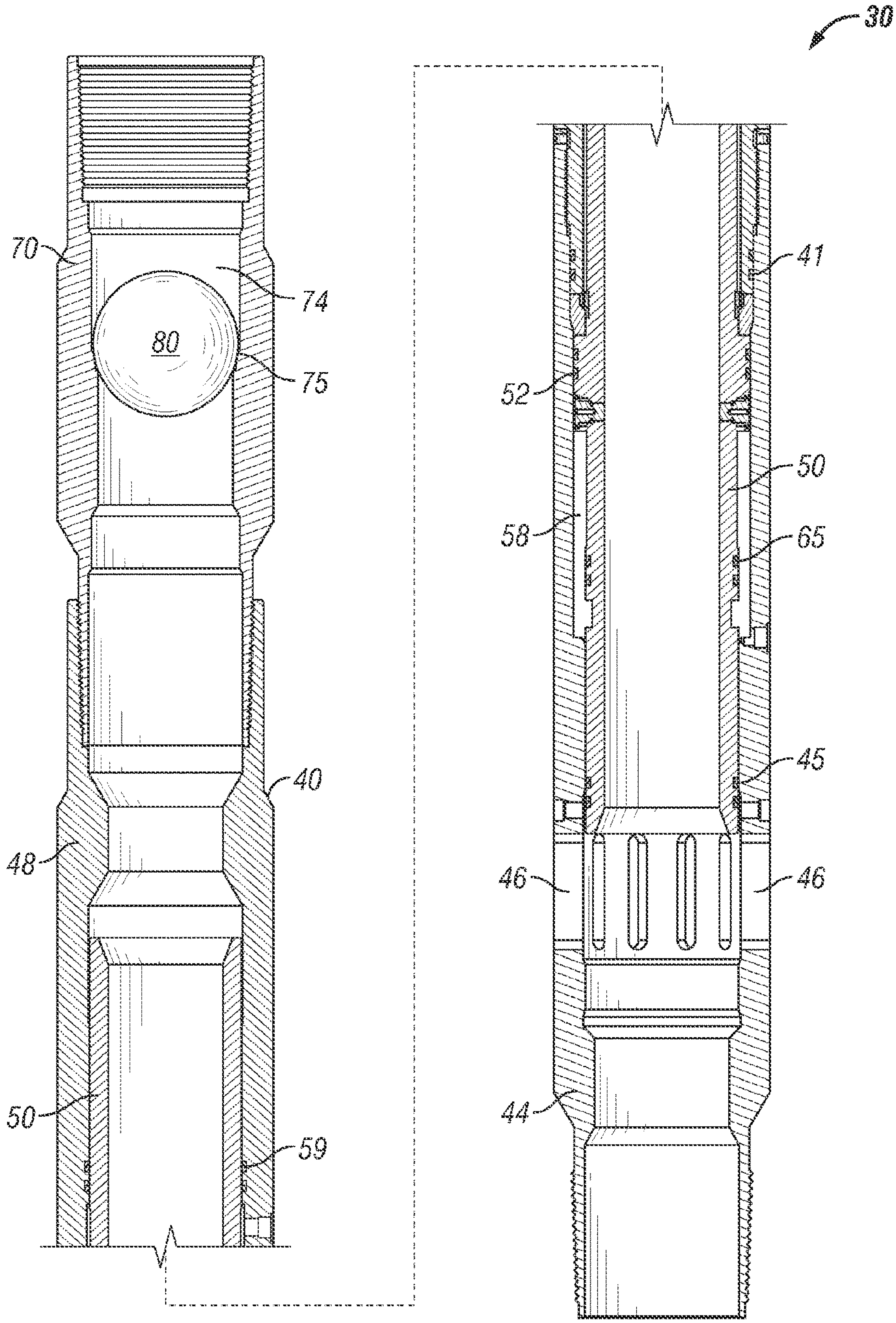

FIG. 3

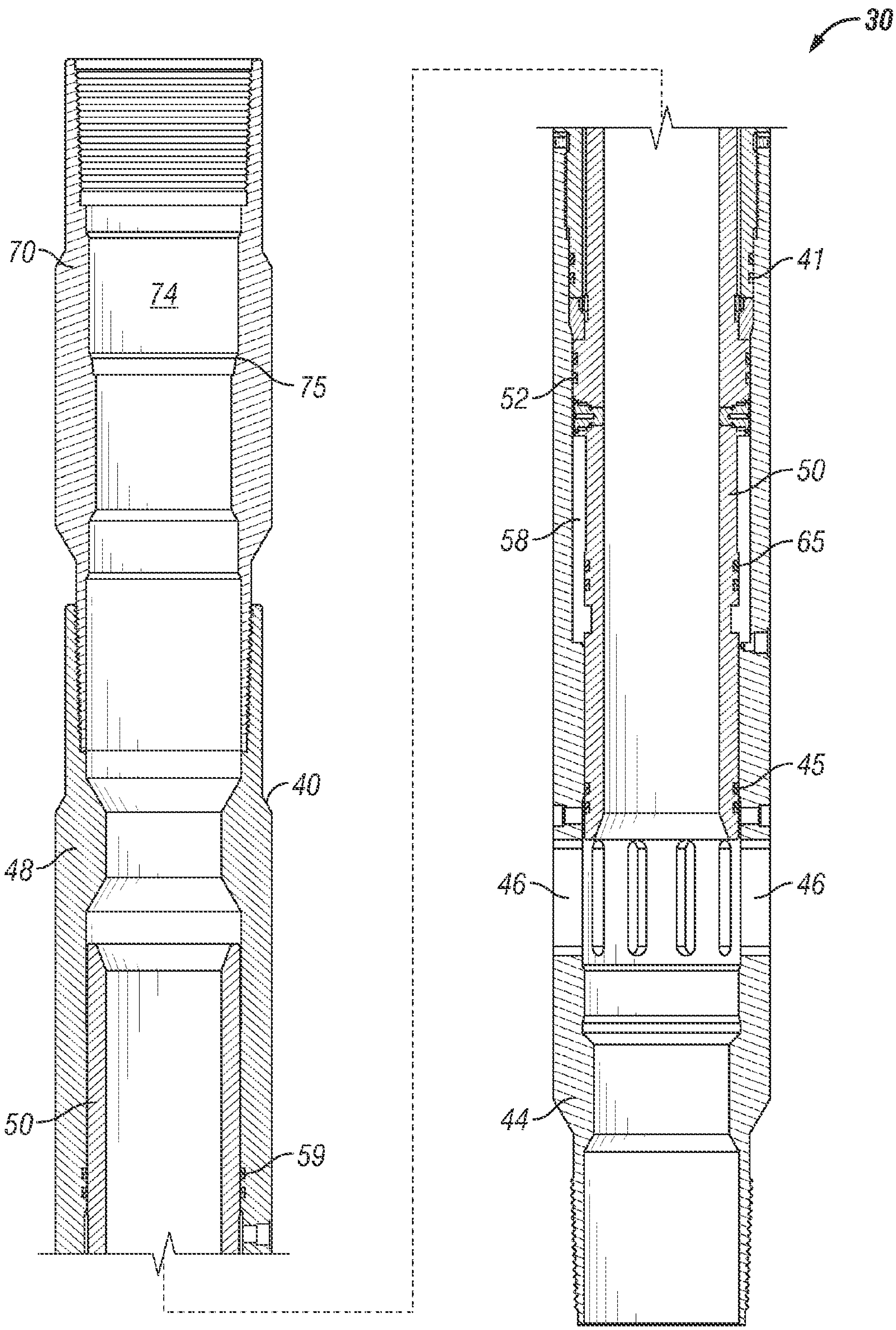

FIG. 4

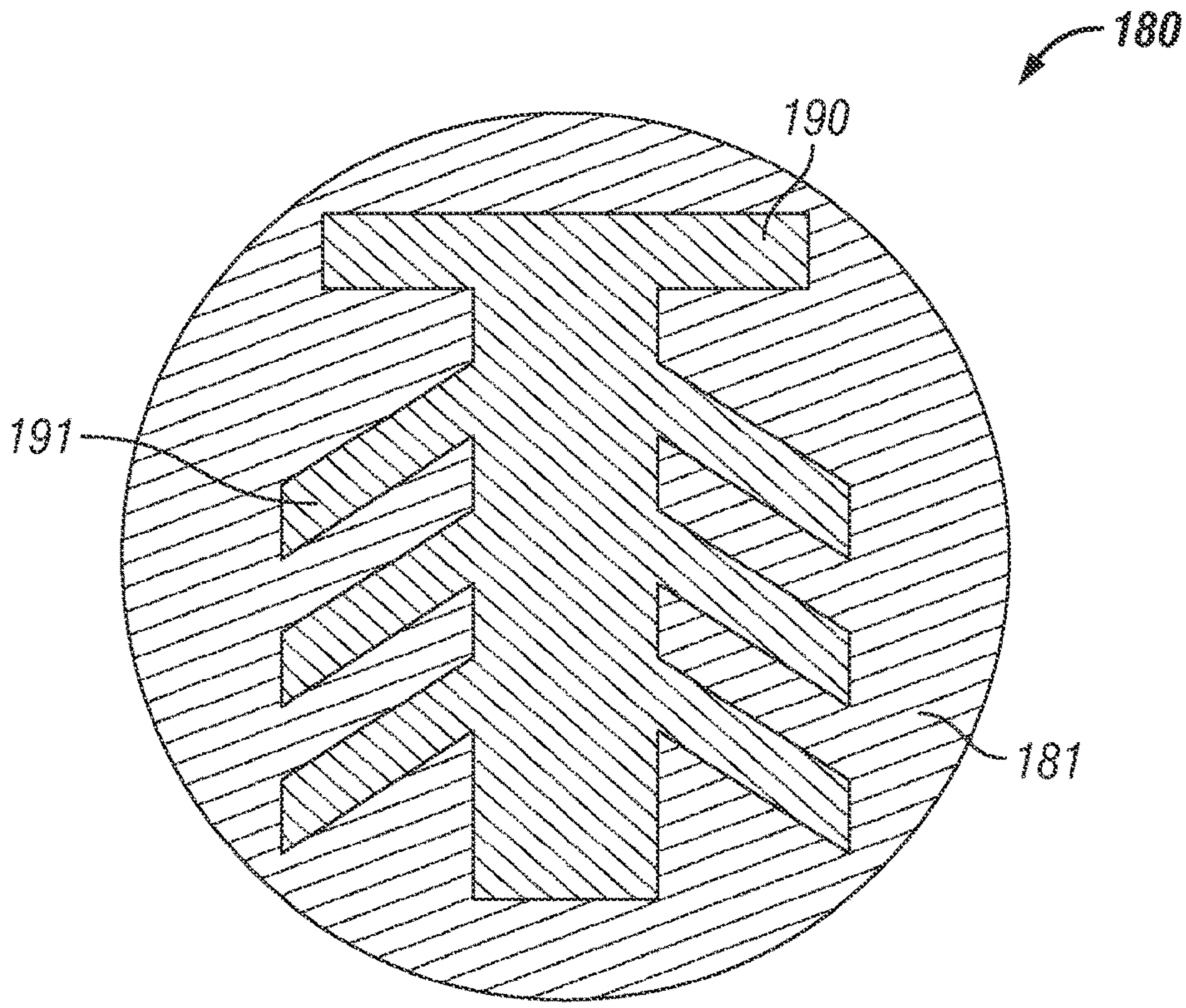

FIG. 5

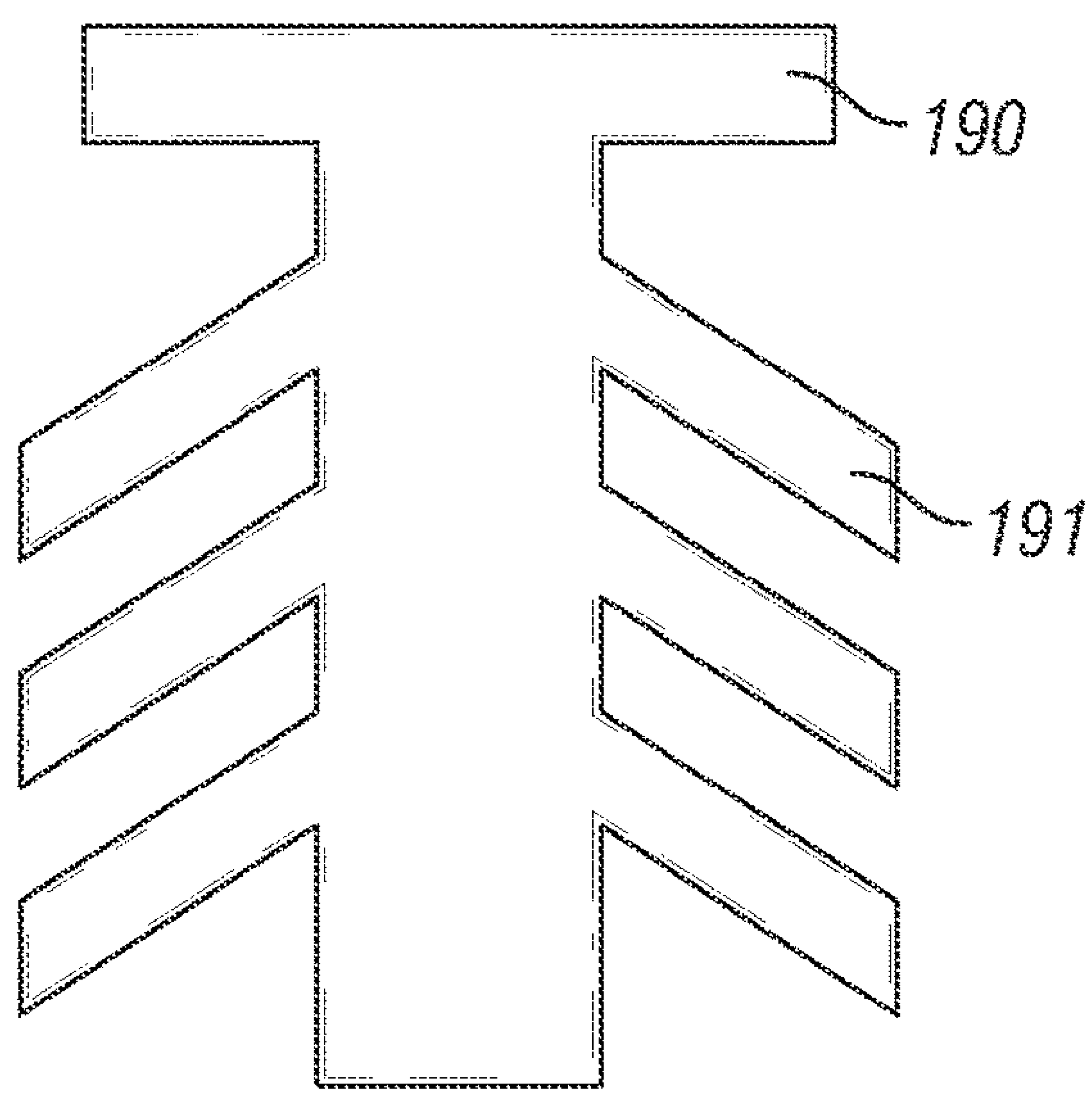

FIG. 6

WIPER PLUG ELEMENTS AND METHODS OF STIMULATING A WELLBORE ENVIRONMENT

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

BACKGROUND

1. Field of Invention

The present invention is directed to methods of preparing a cased wellbore for stimulation operations and, in particular, to interventionless methods for preparing the cased wellbore for stimulation operations using pressure actuated sleeves and apparatuses for temporarily restricting fluid flow through the wellbore casing to prepare the wellbore casing for stimulation operations as opposed to using additional wellbore intervention methods such as tubing conveyed perforation.

2. Description of Art

Ball seats are generally known in the art. For example, typical ball seats have a bore or passageway that is restricted by a seat. The ball or plug element is disposed on the seat, preventing or restricting fluid from flowing through the bore of the ball seat and, thus, isolating the tubing or conduit section in which the ball seat is disposed. As force is applied to the ball or plug element, the conduit can be pressurized for tubing testing or tool actuation or manipulation, such as in setting a packer. Ball seats are used in cased hole completions, liner hangers, flow diverters, fracturing systems, acid-stimulation systems, and flow control equipment and other systems.

Although the terms "ball seat" and "ball" are used herein, it is to be understood that a drop plug or other shaped plugging device or element may be used with the "ball seats" disclosed and discussed herein. For simplicity it is to be understood that the terms "ball" and "plug element" include and encompass all shapes and sizes of plugs, balls, darts, or drop plugs unless the specific shape or design of the "ball" is expressly discussed.

Stimulating, which as used herein includes fracturing or "fracing," a wellbore using stimulation systems or tools also are known in the art. In general, stimulating systems or tools are used in oil and gas wells for completing and increasing the production rate from the well. In deviated wellbores, particularly those having longer lengths, fluid, such as acid or fracturing fluids, can be expected to be introduced into the linear, or horizontal, end portion of the well to stimulate the production zone to open up production fissures and pores therethrough. For example, hydraulic fracturing is a method of using pump rate and hydraulic pressure created by fracturing fluids to fracture or crack a subterranean formation, or the wellbore environment.

Prior to stimulating a wellbore, a stimulation tool is cemented into the wellbore. Thereafter, a pressure test of the wellbore casing containing the stimulation tool is performed. To perform this step, the pathway through the stimulation tool must be closed off. After the casing test establishes the integrity of the wellbore casing, fluid communication of the pathway through the stimulation tool is reestablished so that the stimulation fluid can be pumped down through the stimulation tool and into the formation. Currently, the steps involved in reestablishing fluid flow through the stimulation tool require additional wellbore intervention such as by using tubing conveyed perforation.

SUMMARY OF INVENTION

Broadly, the methods for preparing a wellbore for stimulation operations disclosed herein comprise the steps of cementing into a wellbore casing a downhole tool comprising a valve having an apparatus for restricting fluid flow through the valve, such as a ball seat, disposed above the valve. The valve is actuated to its opened position to establish fluid flow between the casing bore and the formation or wellbore environment. Thereafter, a plug element is disposed on the seat of the ball seat and a casing pressure test is performed. The plug element then dissolves or disintegrates over time thereby increasing fluid communication between the formation and the wellbore casing through the valve, thereby placing the wellbore casing in condition for stimulation operations without additional wellbore intervention after the casing test.

In one specific embodiment, the plug element also functions as a wiper member to facilitate additional clean-up of the bore of the valve after the pressure test has been performed. The plug element dissolves into a predetermined shape that, when pushed through the seat and the bore of the valve, the plug element wipes away debris within the bore of the valve.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a cross-sectional view of one specific embodiment of the downhole tool disclosed herein showing an exemplary valve in its closed position.

FIG. **2** is a cross-sectional view of the downhole tool of FIG. **1** showing the valve in one of its opened positions.

FIG. **3** is a cross-sectional view of the downhole tool of FIG. **1** showing a plug element landed on a seat above the valve so that a casing test can be performed.

FIG. **4** is a cross-sectional view of the downhole tool of FIG. **1** showing the downhole tool in position for stimulation operations after the pressure test has been performed and the plug element shown in FIG. **3** dissolved.

FIG. **5** is a cross-sectional view of a specific embodiment of a plug element as disclosed herein.

FIG. **6** is a side view of the wiper member shown in FIG. **5**.

While the invention will be described in connection with the preferred embodiments, it will be understood that it is not intended to limit the invention to that embodiment. On the contrary, it is intended to cover all alternatives, modifications, and equivalents, as may be included within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF INVENTION

Referring now to FIGS. **1-4**, in one specific embodiment, downhole tool **30** comprises valve **40** and bore restriction apparatus **70**, shown as a ball seat in FIGS. **1-4**. FIG. **1** shows valve **40** in a closed position, and FIGS. **2-4** show valve **40** actuated to an open position.

Valve **40** includes lower ported housing **44** having fluid communication ports **46**, and upper body **48**. Pressure integrity of valve **40** is maintained by body seals **41**. Body set screws **47** keep the body connection threads **43** from backing out during installation. Captured between lower ported housing **44** and upper body **48** is inner shifting sleeve **50**. Inner shifting sleeve **50** has several diameters that create piston areas that generate shifting forces to open valve **40**. Port isolation seals **45** located on the lower end of inner shifting sleeve **50** and lower internal bore piston seals **65** above fluid communication ports **46** both act to isolate the inside of valve **40** during and after cementation. Port isolation seals **45** and lower internal bore piston seals **65** operate within their respective polished bores **55**, **57** within lower ported housing **44**. The larger intermediate internal bore piston seals **52** are used to drive up inner shifting sleeve **50** along the upper internal polished bore **53** within lower ported housing **44** after burst disc **42** is ruptured.

Upper external rod piston seals **59** located within upper body **48** act to prevent cement from entering upper atmospheric chamber **62** and wipe the outside diameter of upper sleeve polished bore **61** during opening of valve **40**. Inner shifting sleeve **50** also has shoulder **54** that shears shear screw **56** during the opening shift of inner shifting sleeve **50**. External sleeve lock ring retention groove **63** is located between internal bore seals **52** and upper sleeve polished bore **61** diameter. Lock ring retention groove **63** accepts sleeve lock ring **69** that is retained by lock ring retainer **67** after valve **40** has been fully opened. Thus, sleeve lock ring **69** prevents inner shifting sleeve **50** from closing after valve **40** has been opened (FIGS. **2**-**4**).

Located between lower internal bore piston seals **65** and intermediate bore piston seals **52** is lower atmospheric chamber **58** which contains air that can be independently tested through lower pressure test port **60**. Located between intermediate internal bore piston seals **52** and upper external rod piston seals **59** is upper atmospheric chamber **62** which also contains air that can be independently tested through upper pressure testing port **64**. A rupture or burst disc **42** is held in place within a port located on the outside of inner shifting sleeve **50** by load ring **66** and load nut **68**. Burst disc load nut **68** is sized to allow significant torque and load to be transferred into burst disc **42** prior to installation of inner shifting sleeve **50** within valve **40**.

Those skilled in the art will appreciate that the use of the rupture disc for piston access is simply the preferred way and generally more accurate than relying exclusively on shearing a shear pin. A pressure regulation valve can also be used for such selective access as well as a chemically responsive barrier that goes away in the presence of a predetermined substance or energy field, temperature downhole or other well condition for example, to move the sleeve. Burst or rupture discs **42** also can be replaced by any other pressure control plug known in the art such as those disclosed and taught in U.S. patent application Ser. No. 13/286,775, filed Nov. 1, 2011, entitled "Frangible Pressure Control Plug, Actuatable Tool, Including Plug, and Method Thereof" which is hereby incorporated by reference in its entirety.

After burst disc **42** is ruptured, lower chamber **58** is under absolute downhole pressure so wall flexure at that location is minimized. Even before burst disc **42** breaks, the size of lower chamber **58** is sufficiently small to avoid sleeve wall flexing in that region. The use of a large boss to support intermediate internal bore piston seals **52** also strengthens inner shifting sleeve **50** immediately below upper chamber **62**, thus at least reducing flexing or bending that could put inner shifting sleeve **50** in a bind before it is fully shifted. The slightly larger dimension of external rod piston seals **59** as compared to port isolation seals **45** that hold inner shifting sleeve **50** closed initially also allows a greater wall thickness for inner shifting sleeve **50** near the upper chamber **62** to further at least reducing flexing or bending to allow inner shifting sleeve **50** to fully shift without getting into a bind.

The intermediate internal bore piston seals **52** can be integral to inner shifting sleeve **50** or a separate structure. Upper chamber **62** has an initial pressure of atmospheric or a predetermined value less than the anticipated hydrostatic pressure within inner shifting sleeve **50**. The volume of upper chamber **62** decreases and its internal pressure rises as inner shifting sleeve **50** moves to open ports **46**.

Ball seat **70** is secured to the upper end of valve **40** through any known device or method in the art, such as a threaded connection. Ball seat **70** comprises upper end **71**, lower end **72** which is secured to valve **40**, and inner wall surface **73** defining bore **74**. Seat **75** is disposed along inner wall surface **73** for receiving a plug element such as ball **80** shown in FIG. **3**.

In operation, downhole tool **30** is connected to casing at its upper and lower ends and run in open-hole cementable completions just above float equipment. After being disposed within the wellbore at the desired location, downhole tool **30** is cemented into place within the well.

After cementation, a clean-out operation is performed to remove debris from the flow path through valve **40**. The clean-out operation can be performed by pumping fluid through downhole tool **30** to clean up any debris remaining from the cementing operations. In addition, or alternatively, a wiper plug can be transported down the bore of the casing, past seat **75** to and through the bore of valve **40** to wipe away and debris, including residual cement.

After the cement has set on the outside of valve **40**, it is ready to be opened with a combination of high hydrostatic and applied pressure. Upon reaching the critical pressure, burst disc **42** is fractured and opens lower atmospheric chamber **58** to the absolute downhole pressure. This pressure acts on the piston area created by lower internal bore piston seals **65** and the larger internal bore piston seals **52** and drives inner shifting sleeve **50** upward compressing the air within upper atmospheric chamber **62** and opening fluid communication ports **46** on the ported housing **44**. Thus, the volume of upper chamber **62** decreases and its internal pressure rises as inner shifting sleeve **50** moves to open ports **46**.

After inner shifting sleeve **50** is completely shifted and in contact with the downward facing shoulder on lock ring retainer **67**, sleeve lock ring **69** falls into sleeve lock retention groove **63** on inner shifting sleeve **50** preventing valve **40** from subsequently closing.

After burst disc **42** is fractured, absolute downhole pressure acts on piston seals **52** and piston seals **65** continuously pushing sleeve **50** upward acting as a redundant locking feature preventing valve **40** from subsequently closing.

Upon opening valve **40**, fluid communication between the bore of downhole tool **30** and, thus, the wellbore casing string, and the wellbore formation or wellbore environment is established. Thereafter, a pressure test of the casing can be performed. To do so, plug element **80** is transported down the casing string and landed on seat **75** of ball seat **70** (FIG. **3**). Afterwards, a pressure test is performed. Presuming the pressure test is successful, then the wellbore is capable of having stimulation operations performed. However, the plug element **80** remains on seat **75**. Plug element **80** is removed from seat **75** over time due to the dissolution of at least a portion of plug element **80**. After plug element **80** sufficiently dissolves such that fluid pressure acting downward on plug element **80** can push plug element **80** through seat **75** and through the bore of valve **40**, fluid communication between the casing string and the formation is increased so that stimulation operations can be performed. Thus, after landing plug element **80** on seat **75** and the pressure test is performed, no additional wellbore intervention is required to place the casing string in condition for stimulation operations.

In certain embodiments, plug element **80** completely dissolves. In other embodiments, plug element **80** partially dissolves before passing through seat **75** and through the bore of valve **40**. In still other embodiments, a portion of plug element **80** is formed from a material that is not dissolvable. Dissolution of a portion, or all of plug element **80**, can be accomplished by having plug element **80** formed at least in part by a dissolvable material. "Dissolvable" means that the material is capable of dissolution in a fluid or solvent disposed within the wellbore casing. "Dissolvable" is understood to encompass the terms degradable and disintegrable. Likewise, the terms "dissolved" and "dissolution" also are interpreted to include "degraded" and "disintegrated," and "degradation" and "disintegration," respectively. The dissolvable material may be any material known to persons of ordinary skill in the art that can be dissolved, degraded, or disintegrated over an amount of time by a temperature or fluid such as water-based drilling fluids, hydrocarbon-based drilling fluids, or natural gas, and that can be calibrated such that the amount of time necessary for the dissolvable material to dissolve is known or easily determinable without undue experimentation. Suitable dissolvable materials include controlled electrolytic metallic nano-structured materials such as those disclosed in U.S. patent application Ser. No. 12/633,682, filed Dec. 8, 2009 (U.S. Patent Publication No. 2011/0132143), U.S. patent application Ser. No. 12/633,686, filed Dec. 8, 2009 (U.S. Patent Publication No. 2011/0135953), U.S. patent application Ser. No. 12/633,678, filed Dec. 8, 2009 (U.S. Patent Publication No. 2011/0136707), U.S. patent application Ser. No. 12/633,683, filed Dec. 8, 2009 (U.S. Patent Publication No. 2011/0132612), U.S. patent application Ser. No. 12/633,668, filed Dec. 8, 2009 (U.S. Patent Publication No. 2011/0132620), U.S. patent application Ser. No. 12/633,677, filed Dec. 8, 2009 (U.S. Patent Publication No. 2011/0132621), and U.S. patent application Ser. No. 12/633,662, filed Dec. 8, 2009 (U.S. Patent Publication No. 2011/0132619), all of which are hereby incorporated by reference in their entirety.

Additional suitable dissolvable materials include polymers and biodegradable polymers, for example, polyvinyl-alcohol based polymers such as the polymer HYDROCENE™ available from Idroplax, S.r.l. located in Altopascia, Italy, polylactide ("PLA") polymer 4060D from Nature-Works™, a division of Cargill Dow LLC; TLF-6267 polyglycolic acid ("PGA") from DuPont Specialty Chemicals; polycaprolactams and mixtures of PLA and PGA; solid acids, such as sulfamic acid, trichloroacetic acid, and citric acid, held together with a wax or other suitable binder material; polyethylene homopolymers and paraffin waxes; polyalkylene oxides, such as polyethylene oxides, and polyalkylene glycols, such as polyethylene glycols. These polymers may be preferred in water-based drilling fluids because they are slowly soluble in water.

In calibrating the rate of dissolution of dissolvable material, generally the rate is dependent on the molecular weight of the polymers. Acceptable dissolution rates can be achieved with a molecular weight range of 100,000 to 7,000,000. Thus, dissolution rates for a temperature range of 50° C. to 250° C. can be designed with the appropriate molecular weight or mixture of molecular weights.

Referring now to FIGS. **5-6**, in an alternative embodiment, plug element **180** comprises an initial shape (FIG. **5**) that is capable of landing on seat **75** to restrict fluid flow through seat **75**, and a new or second shape (FIG. **6**) that is sufficient to act as a wiper member as it passes through seat **75** and/or through the bore of valve **40** and/or the bore of inner shifting sleeve **50** upon partial or complete dissolution of the dissolvable material **181** of plug element **180**. In this embodiment, plug element **180** includes wiper member **190** encapsulated by dissolvable material **181**. Wiper member **190** can be formed out of a material **191** that can be a non-dissolvable material or a second dissolvable material that dissolves at a slower rate compared to dissolvable material **181**. Upon sufficient dissolution of dissolvable material **181**, wiper member **190** is capable of being pushed through seat **75** and/or through the bore of valve **40** and/or the bore of inner shifting sleeve **50**. In so doing, wiper member **190** wipes or cleans away debris disposed along these surfaces. Thus, a mechanical clean-out of the valve can be performed after the pressure test without additional wellbore intervention.

As discussed above, plug elements **80**, **180** can be formed completely out of one or more dissolvable materials or plug elements **80**, **180** can be formed partially out of one or more dissolvable materials. In the former embodiment, plug elements **80**, **180** will completely dissolve and fluid flow through valve **40** in the wellbore environment will be increased. In the latter embodiment, upon dissolution, plug elements **80**, **180** can have a new or second shape that is different from the initial shape of plug element **80** that provided restriction of fluid flow through seat **75**. The new shape of plug element **80** can either fall through valve **40** as debris, or it can facilitate wiping or cleaning of the bore of valve **40** by the remaining portion(s) of plug elements **80**, **180**. Thus, plug elements **80**, **180** can remove debris disposed within the valve bore as fluid communication between the wellbore casing and the wellbore environment is increased. In these embodiments, both increase of fluid communication between the wellbore casing and the wellbore environment after removal of plug elements **80**, **180**, and mechanical clean-out of the valve bore, occur without further wellbore intervention.

It is to be understood that the invention is not limited to the exact details of construction, operation, exact materials, or embodiments shown and described, as modifications and equivalents will be apparent to one skilled in the art. For example, the wiper member can have any shape desired or necessary to pass through the valve to remove debris disposed within the bore of the valve and/or inner shifting sleeve. In addition, the wiper can be formed out of a non-dissolvable material or another dissolvable material. Moreover, the valve is not required to have the structures disclosed herein, nor is the valve required to operate as disclosed herein. Further, the ball seats disclosed herein can be modified as desired or necessary to restrict fluid flow through the wellbore casing. Additionally, dissolvable materials not disclosed herein can be used in place of those that are disclosed herein. Accordingly, the invention is therefore to be limited only by the scope of the appended claims.

What is claimed is:

1. A method of stimulating a wellbore environment, the method comprising:

(a) cementing a wellbore casing within a wellbore, the wellbore casing comprising a valve disposed below a fluid restriction apparatus, the valve in direct contact with the fluid restriction apparatus, the fluid restriction apparatus comprising a tubular member having a seat disposed within a bore of the tubular member and a plug element for landing on the seat;

(b) opening the valve to place the wellbore casing in fluid communication with a wellbore environment;

(c) landing the plug element on the seat to restrict fluid communication between the wellbore casing and the wellbore environment;

(d) [without additional wellbore intervention, removing a portion of the plug element] *dissolving a portion of the plug element before forcing the plug element through the seat and thereby* causing an increase in fluid communication between the wellbore casing and the wellbore environment; and

(e) performing a stimulation operation in the wellbore environment.

2. The method of claim **1**, wherein during step (d), the plug element is forced [down through the seat and] through a bore of the valve causing debris to be removed from the bore of the valve.

3. The method of claim **2**, wherein [during removal of the portion of the plug element,] the plug element is dissolved from a first shape to a second shape, the second shape being defined by a non-dissolvable material.

4. The method of claim **3**, wherein the second shape comprises a wiper member.

5. The method of claim **1**, wherein the valve is opened during step (b) by fluid pressure actuating the valve.

6. The method of claim **1**, wherein [additional wellbore intervention includes] *step (d) is performed without* using tubing conveyed perforations.

7. The method of claim **1**, further comprising performing a pressure test of the wellbore casing.

8. A method of stimulating a wellbore environment, the method comprising:

(a) cementing a wellbore casing within a wellbore, the wellbore casing comprising a single downhole tool including a valve and a fluid restriction apparatus, the valve disposed below the fluid restriction apparatus, the fluid restriction apparatus comprising a tubular member having a seat disposed within a bore of the tubular member and a plug element for landing on the seat, the plug element comprising a dissolvable material;

(b) opening the valve to place the wellbore casing in fluid communication with a wellbore environment;

(c) landing the plug element on the seat to restrict fluid communication between the wellbore casing and the wellbore environment;

(d) dissolving a portion of the plug element *before forcing the plug element through the seat, and thereby* causing an increase in fluid communication between the wellbore casing and the wellbore environment; and

(e) performing a stimulation operation in the wellbore environment.

9. The method of claim **8**, wherein during step (d), the plug element is forced [down through the seat and] through a bore of the valve causing debris to be removed from the bore of the valve.

10. The method of claim **9**, wherein during step (d), the plug element is dissolved from a first shape to a second shape, the second shape being defined by a non-dissolvable material.

11. The method of claim **10**, wherein the second shape comprises a wiper member.

12. The method of claim **8**, wherein the valve is opened during step (b) by fluid pressure actuating the valve.

13. The method of claim **8**, further comprising performing a pressure test of the wellbore casing.

14. A method of stimulating a wellbore environment, the method comprising:

opening a valve disposed below a fluid restriction apparatus of a cemented wellbore casing within a wellbore, the valve in direct contact with the fluid restriction apparatus, the fluid restriction apparatus comprising a tubular member having a seat disposed within a bore of the tubular member and a plug element for landing on the seat, wherein opening the valve places the wellbore casing in fluid communication with a wellbore environment;

landing the plug element on the seat to restrict fluid communication between the wellbore casing and the wellbore environment;

forcing the plug element through the seat after dissolving a portion of the plug element and thereby causing an increase in fluid communication between the wellbore casing and the wellbore environment; and

performing a stimulation operation in the wellbore environment.

15. The method of claim 14, wherein during removal of the portion of the plug element, the plug element is forced through a bore of the valve causing debris to be removed from the bore of the valve.

16. The method of claim 15, wherein the plug element is dissolved from a first shape to a second shape, the second shape being defined by a non-dissolvable material.

17. The method of claim 16, wherein the second shape comprises a wiper member.

18. The method of claim 14, wherein the valve is opened by fluid pressure actuating the valve.

19. The method of claim 14, wherein causing an increase in fluid communication between the wellbore casing and the wellbore environment is performed without using tubing conveyed perforations.

20. The method of claim 14, further comprising performing a pressure test of the wellbore casing.

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