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Wilkinson et al.

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(54) **METHOD FOR SETTING A FRAC PLUG WITH A TUBULAR METAL SEAL**

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E21B 23/06 (2006.01)
E21B 33/12 (2006.01)

(52) **U.S. Cl.**
CPC ***E21B 33/128*** (2013.01); ***E21B 23/06*** (2013.01); *E21B 33/1208* (2013.01)

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CPC E21B 33/128; E21B 23/0414; E21B 23/0417; E21B 33/1291; E21B 33/1293; E21B 23/0412; E21B 23/06; E21B 33/13; E21B 33/12; E21B 33/12955; E21B 33/129
See application file for complete search history.

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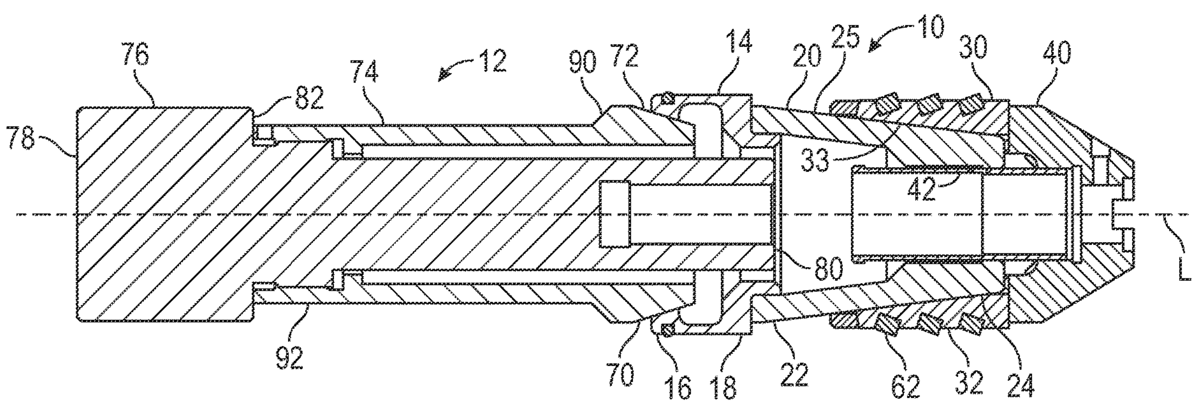
(57) **ABSTRACT**

The present disclosure describes systems and methods for setting and sealing a plug in a casing within a downhole bore. This includes deploying into the casing a plug assembly comprising a tubular metal seal and deploying into the casing a setting tool. The tubular metal seal can be expanded radially to a first radial diameter with the setting tool by moving the setting tool longitudinally such that a tapered exterior portion of the first end of the setting tool engages a tapered interior portion of the first end of the tubular metal seal. The setting tool can then be removed from the casing. The method may comprise expanding the tubular metal seal radially to a second radial diameter by pumping fluid into the plug assembly such that the exterior of the tubular metal seal engages an interior of the casing.

18 Claims, 13 Drawing Sheets



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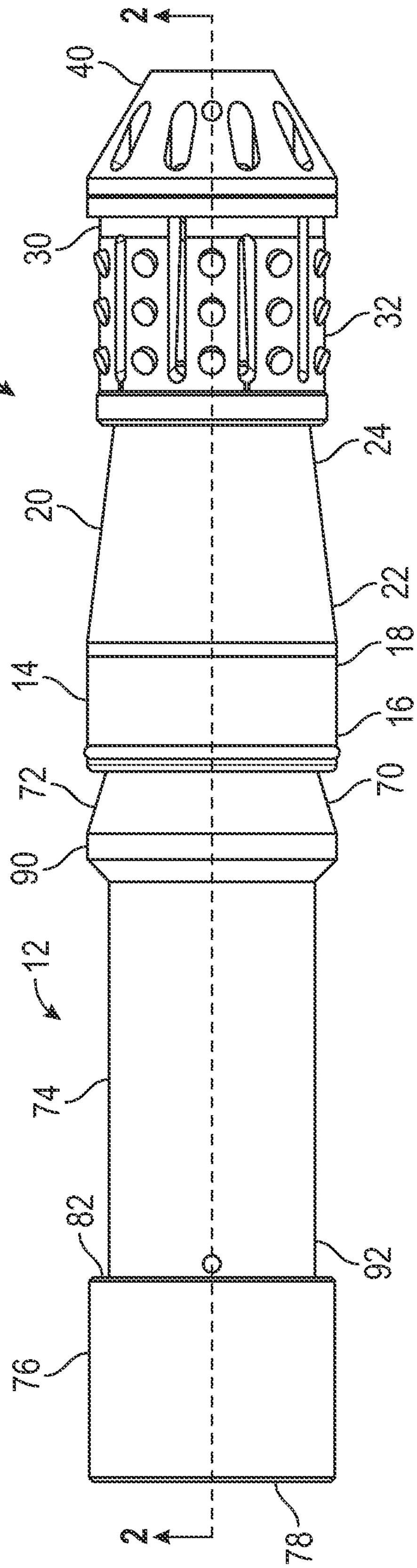
2
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FIG. 1

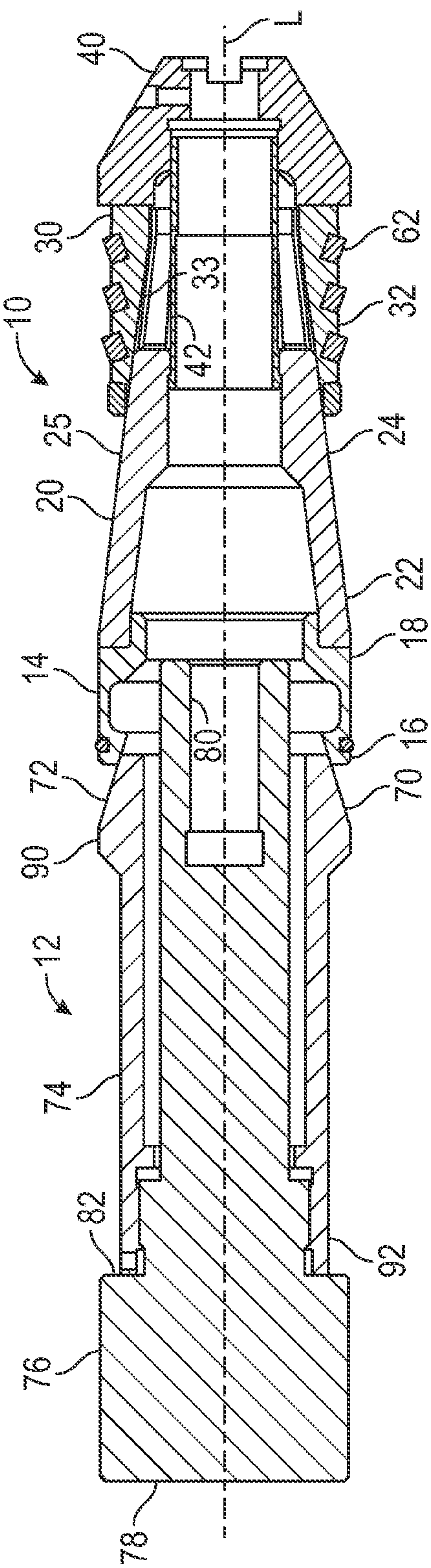
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FIG. 2

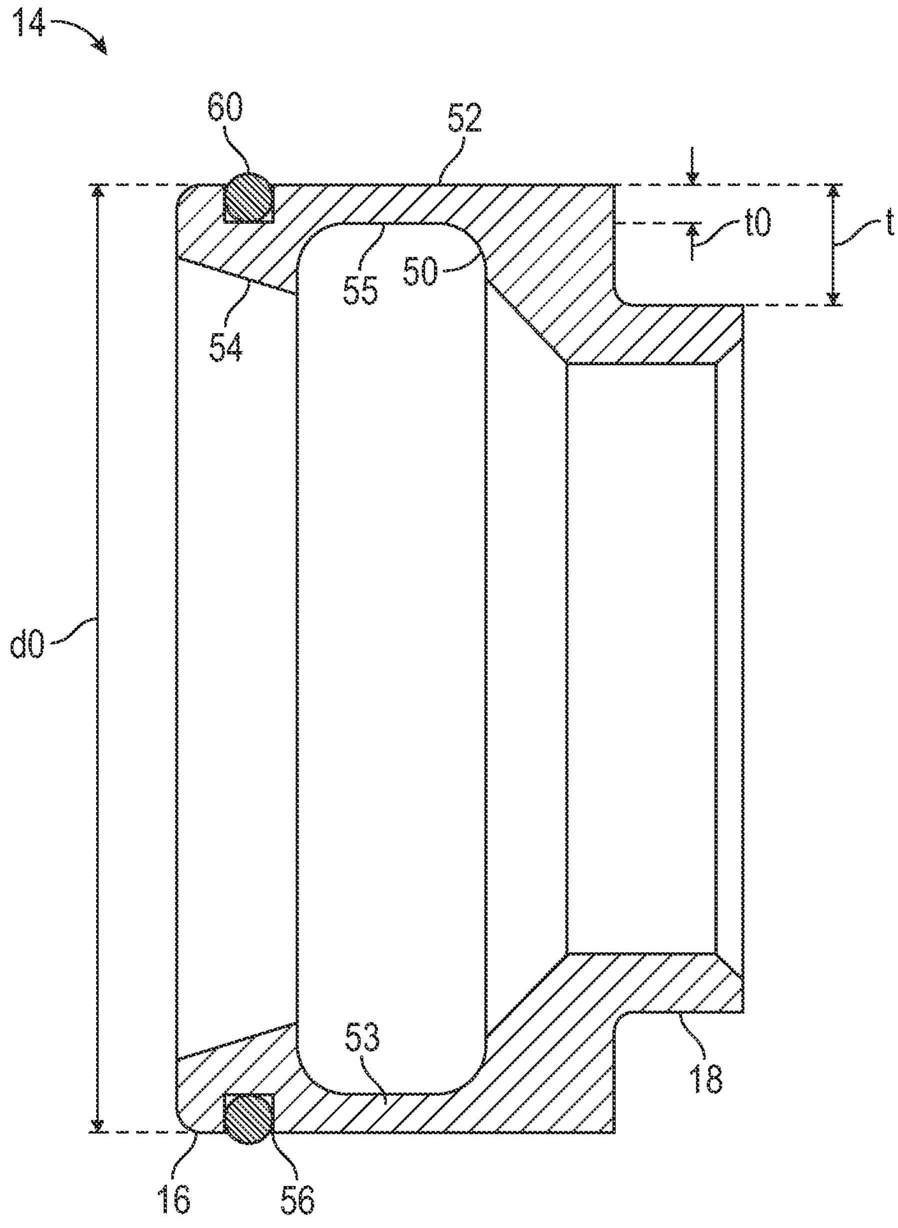
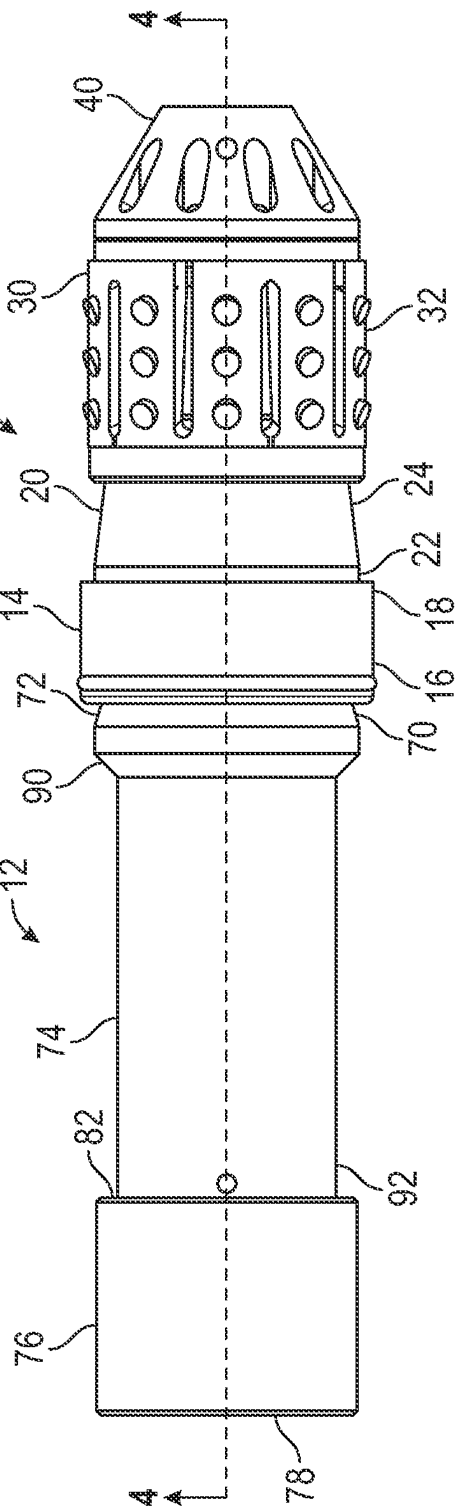


FIG. 3


4
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78
4

FIG. 4

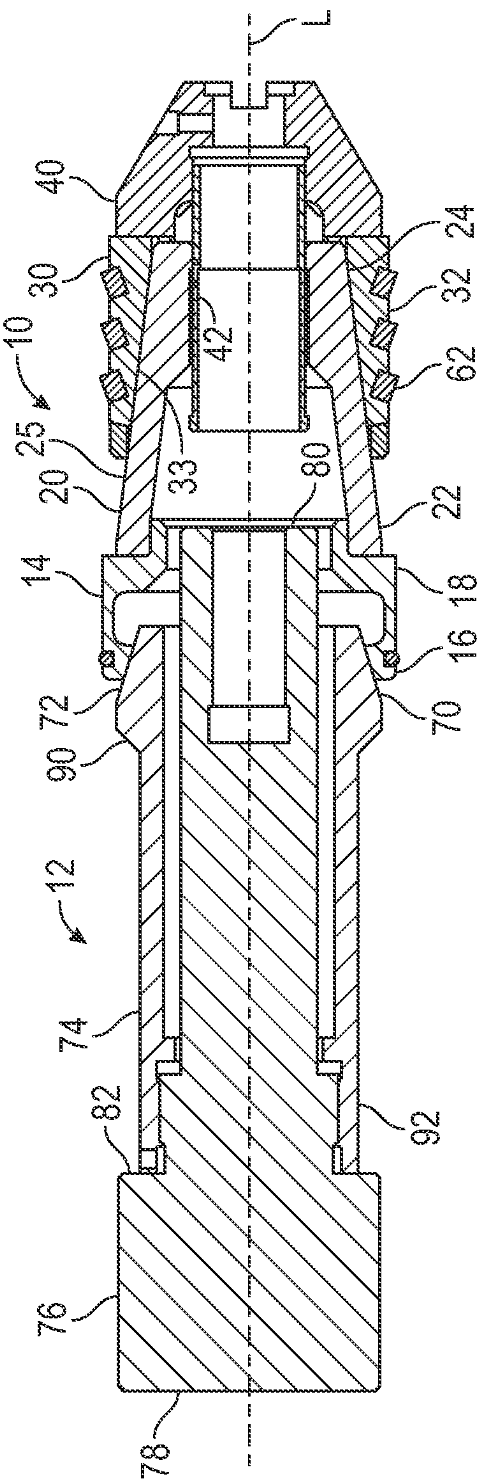
L
40
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FIG. 5

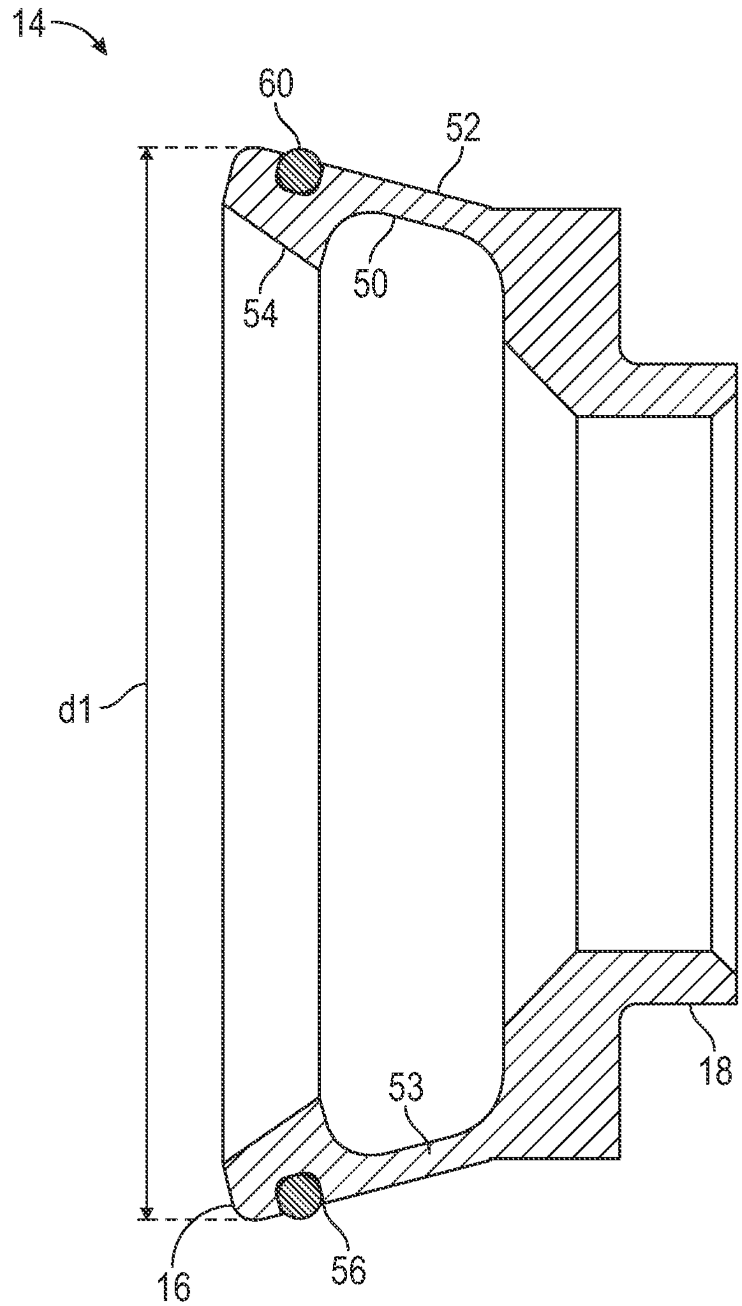
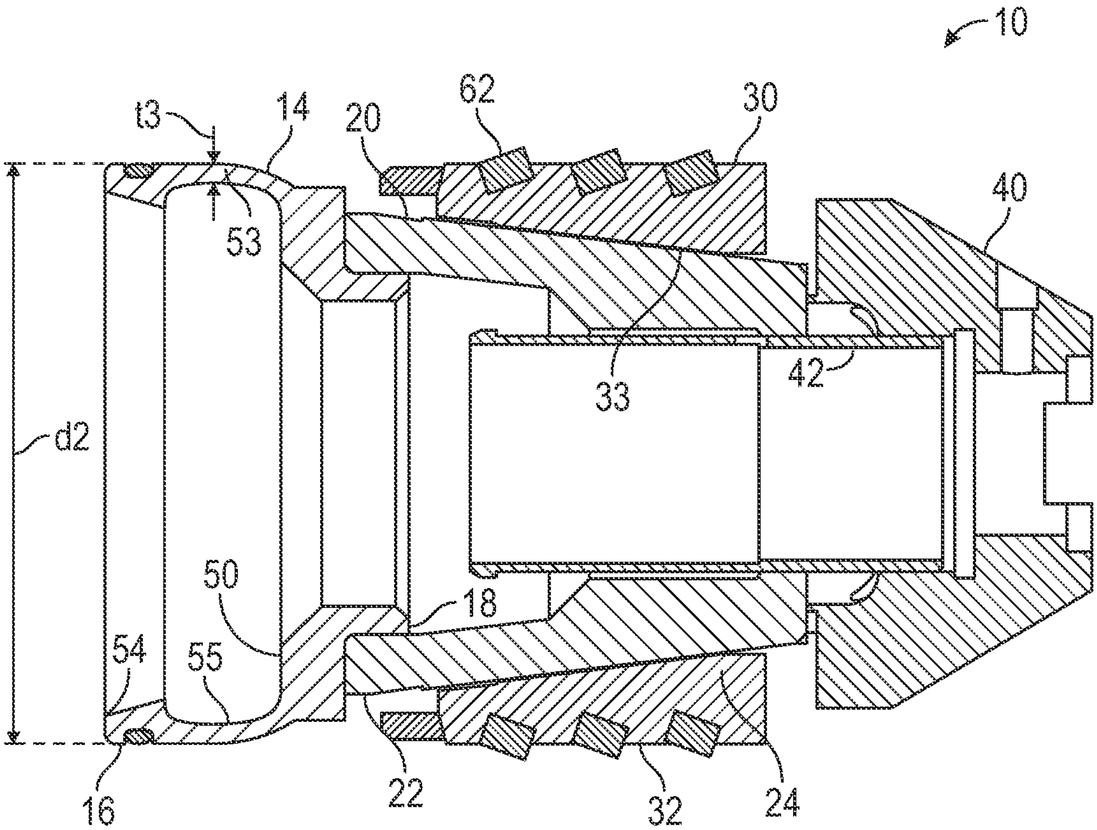


FIG. 6


10
t3
14
20
62
30
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33
42
d2
50
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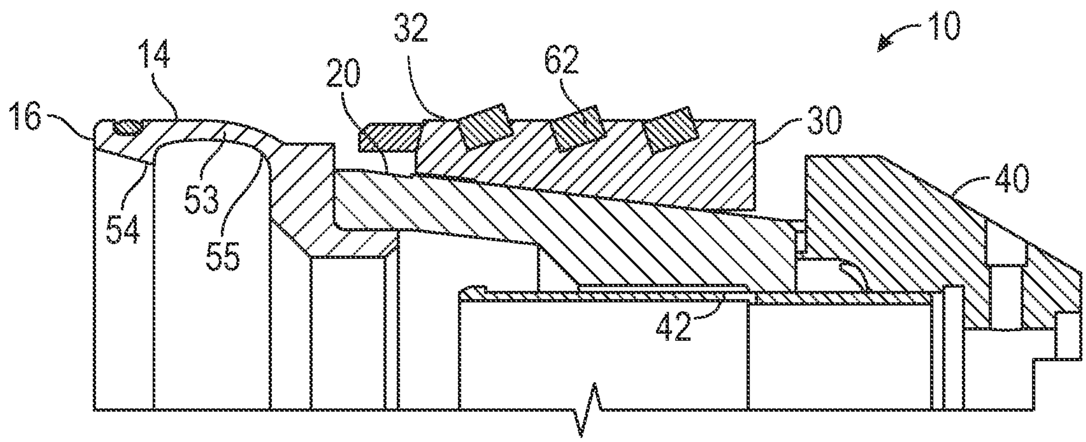
54
55
16
22
32
24

FIG. 7


10
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42

FIG. 7A

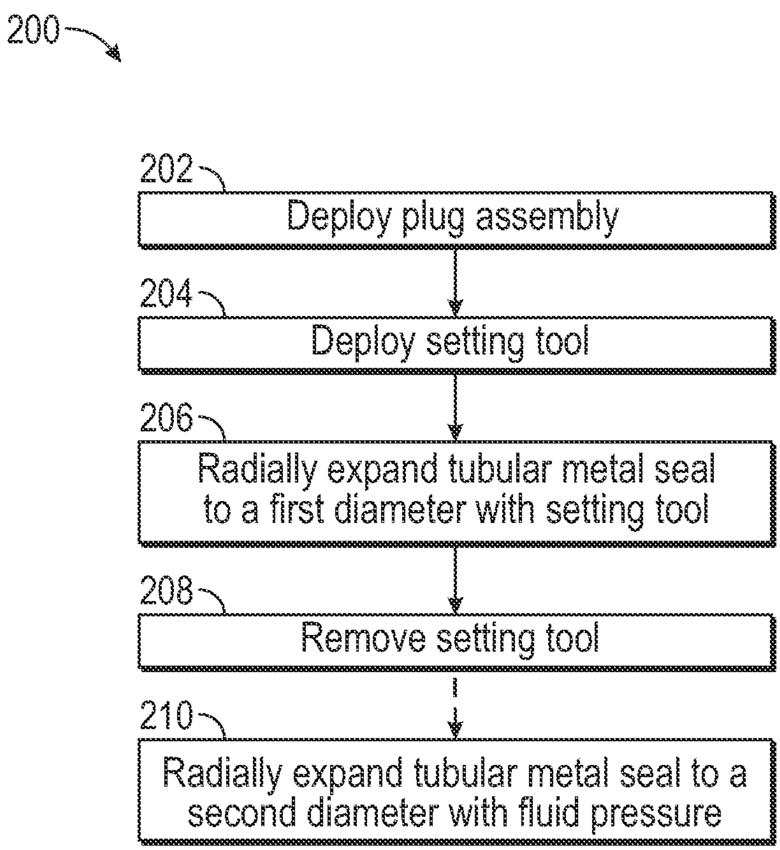
200
202
Deploy plug assembly
204
Deploy setting tool
206
Radially expand tubular metal seal to a first diameter with setting tool
208
Remove setting tool
210
Radially expand tubular metal seal to a second diameter with fluid pressure

FIG. 8

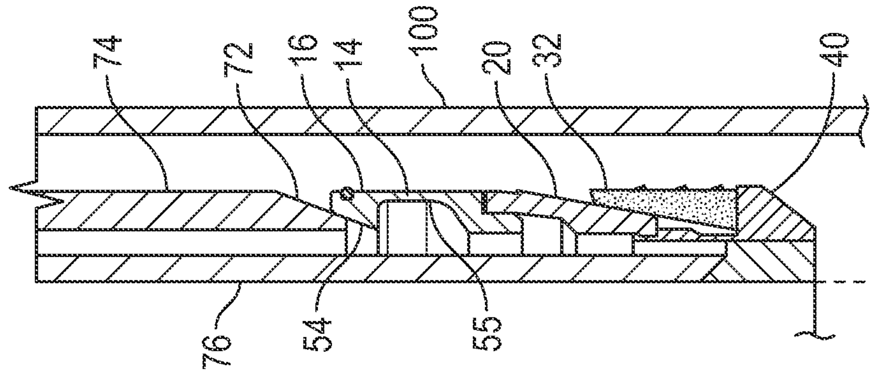

FIG. 9A

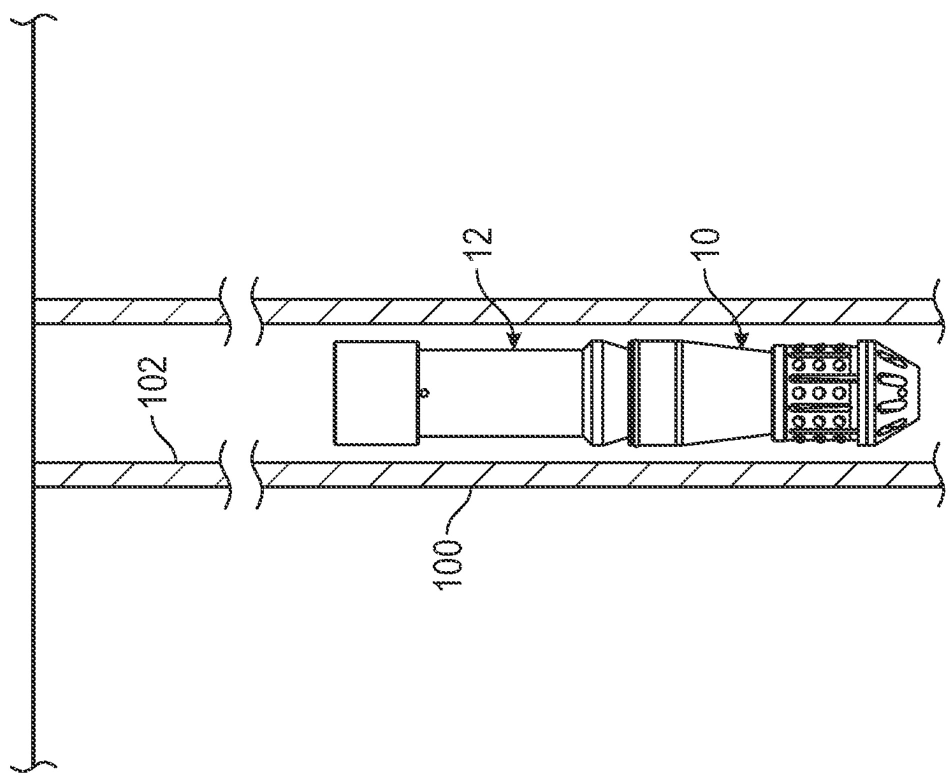

FIG. 9

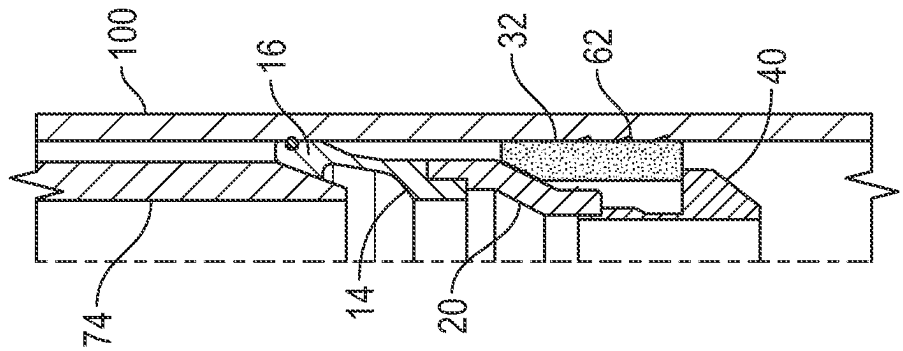

FIG. 10A

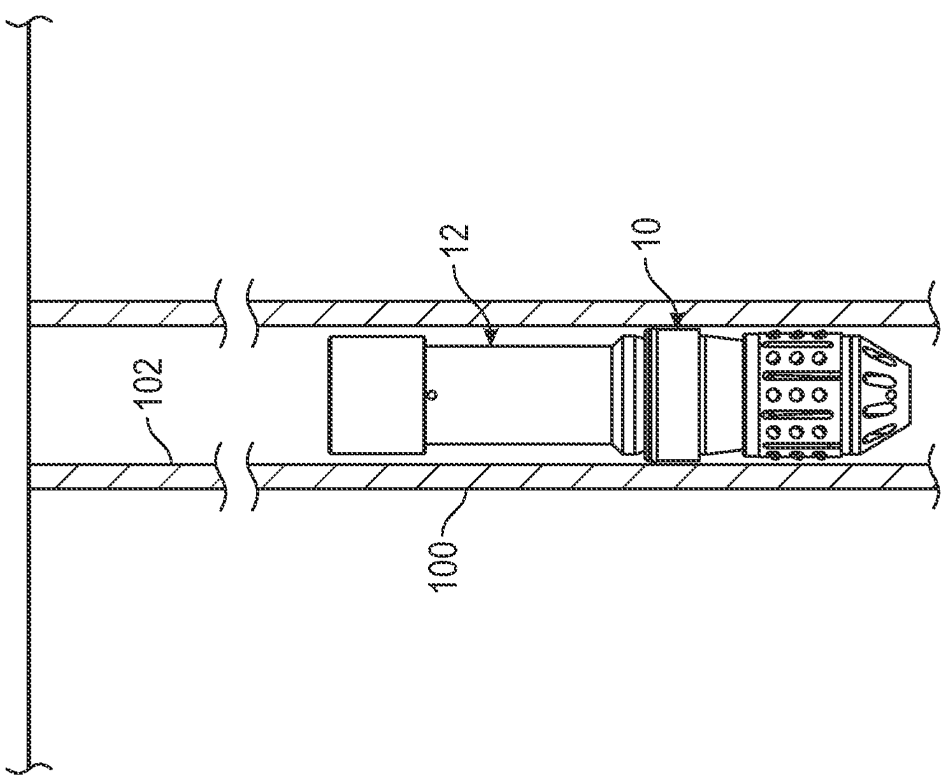

FIG. 10

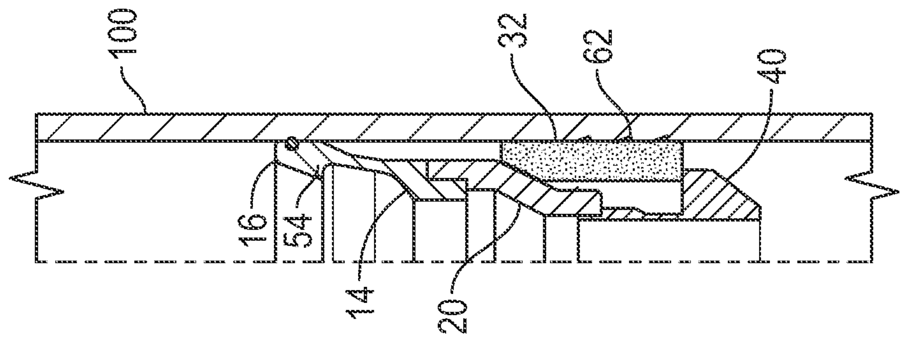

FIG. 11A

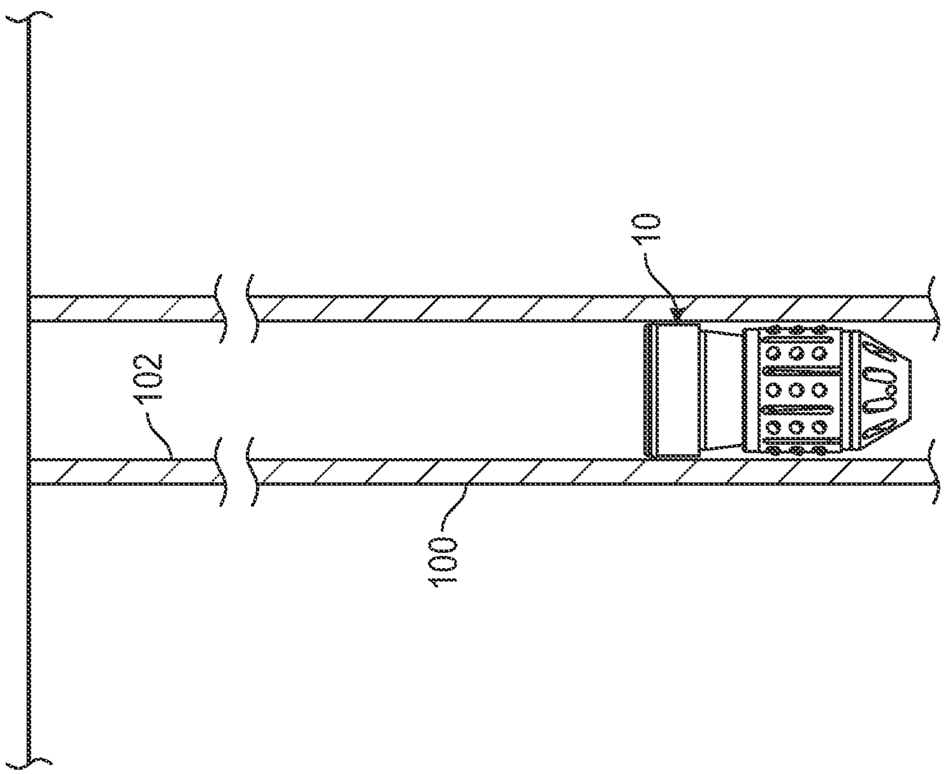

FIG. 11

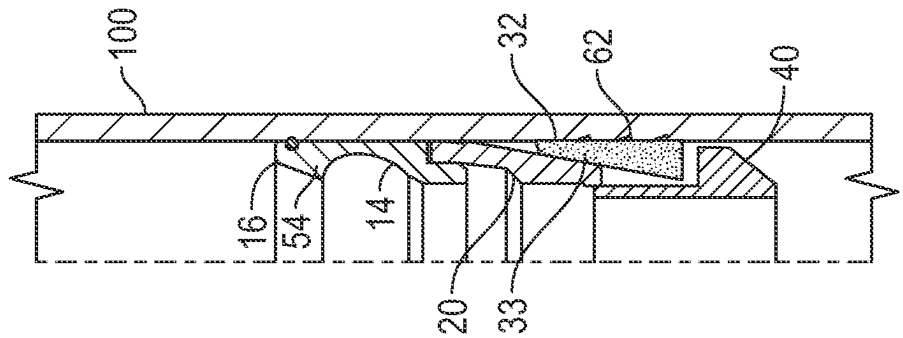

FIG. 12A

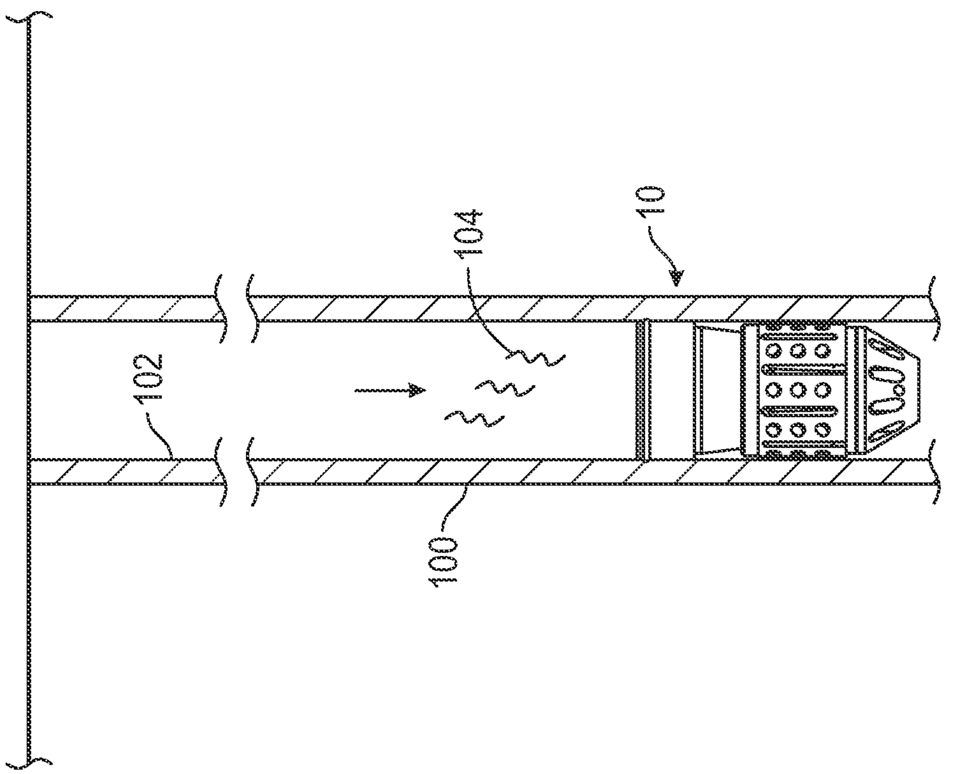

FIG. 12

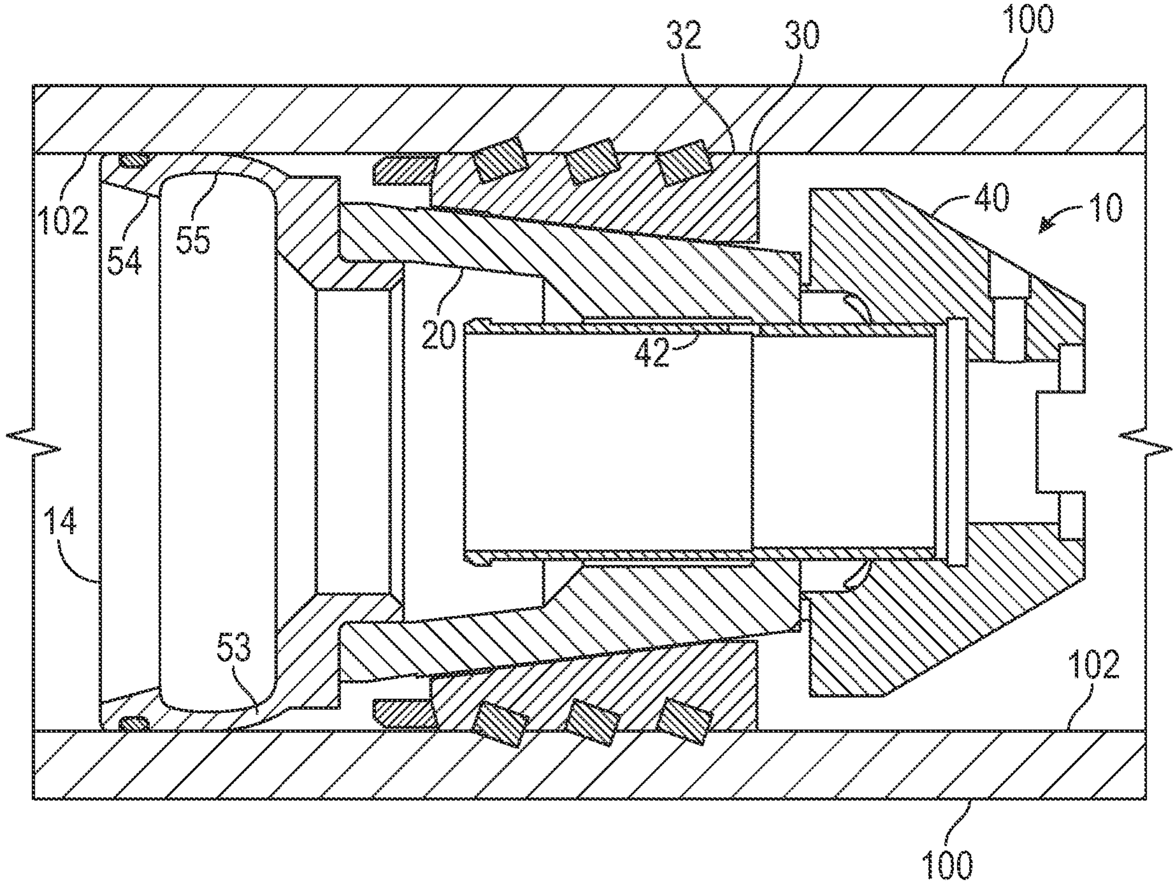

FIG. 13

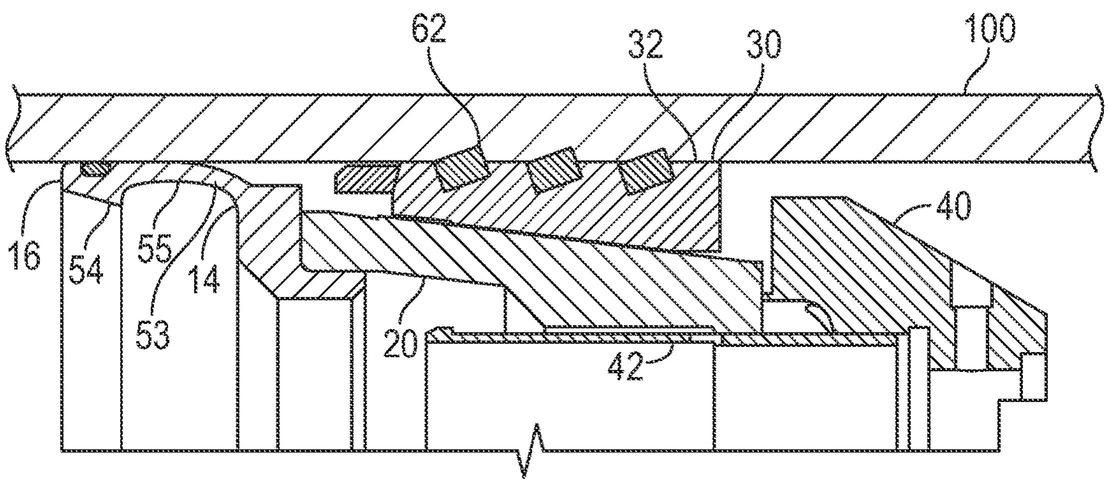

FIG. 13A

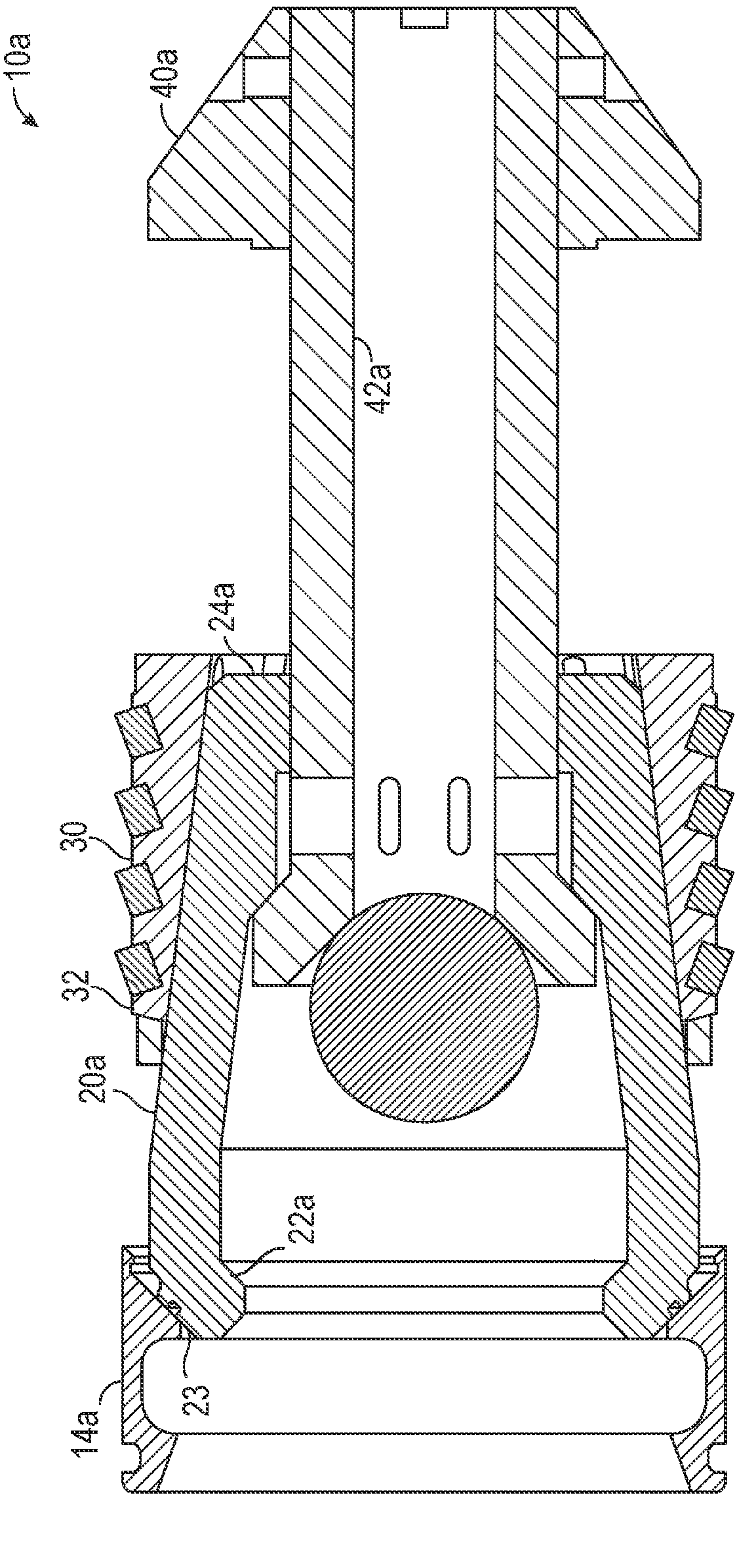

FIG. 14

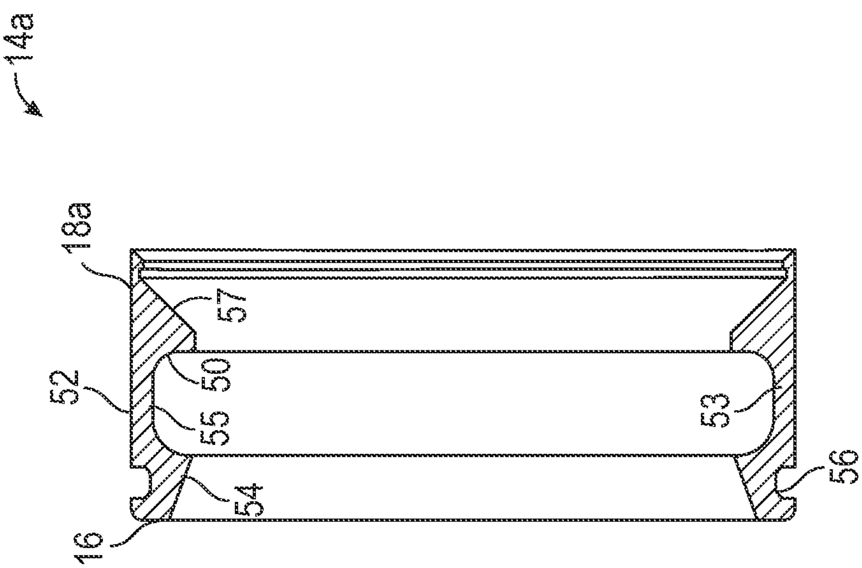

FIG. 15

METHOD FOR SETTING A FRAC PLUG WITH A TUBULAR METAL SEAL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to the provisional patent application identified by U.S. Ser. No. 63/158,475, filed Mar. 9, 2021, titled "Method for Setting a Frac Plug with a Tubular Metal Seal", the entire contents of which are hereby expressly incorporated herein by reference.

FIELD OF THE DISCLOSURE

The disclosure generally relates to methods and apparatuses for setting downhole plugs, such as for oil and gas production. More particularly the disclosure relates to methods and apparatuses utilizing a tubular metal seal (a flare seal) to set and/or seal a plug, such as a frac plug, in a downhole environment, such as within a casing.

BACKGROUND

The extraction of oil and gas from the ground often involves plugging a drilled hole, either partially or completely, during various phases of the extraction. For example, plugs may be used to temporarily block passage of oil, gas, and/or water on one side of the plug and/or fluids pumped down the drilled hole on the other side of the plug. In some implementations, one or more plugs are used in hydraulic fracturing ("fracking") processes. Such plugs may be referred to as "frac plugs."

Traditional frac plugs are secured downhole using slip systems having one or more cones that are longitudinally moved such that the cones slide under slip segments and expand the slip segments radially (outwardly) toward the casing of the drilled hole, until teeth or buttons on the outside of the slip segments engage the inner diameter of the casing. Typically, these traditional plugs also have an elastomer ring that is expanded radially (outwardly) by the cones' movements caused by the longitudinal compression force. Usually, the slip segments hold the frac plug in place against the casing, while the elastomer rings create a fluid seal such that fluid movement past the outside of the frac plug in the casing is limited or stopped.

However, elastomer rings tend to fail, such as through extrusion, causing leakage around the frac plug and possible total failure of the plug. Elastomer rings typically have a tensile strength of up to 2,500 psi, such that higher pressures and temperatures often cause failure of the elastomer rings. Further, elastomer rings that are designed to be dissolvable are costly and dissolve incompletely, leaving elastomer pieces that can interfere with other downhole equipment and/or operations.

In some cases, metal seals have been used that have been set with longitudinal compression force. Metal seals have conventionally been made of materials that kept a circular shape when expanded. Since many downhole casings have irregularly shaped interiors, that is, not perfectly circular interiors, these conventional circular metal seals are ineffective and do not seal the plug to the interior of the casing and fluid leaks past the plug. Such leakage can cause complete failure of the plug and interfere with downhole operations. What is needed are effective metal seals and methods to set metal seals for frac plugs for sealing the frac plug against the interior of the casing, in a cost effective and time effective manner.

SUMMARY

A method and system for setting a frac plug downhole with a tubular metal seal are disclosed. The problems of ineffective, difficult, and time-consuming setting processes for downhole plugs and of seal failures are addressed through the use of a tubular metal seal that may set and seal a plug in a downhole casing.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate one or more implementations described herein and, together with the description, explain these implementations. The drawings are not intended to be drawn to scale, and certain features and certain views of the figures may be shown exaggerated, to scale, or in schematic in the interest of clarity and conciseness. Not every component may be labeled in every drawing. Like reference numerals in the figures may represent and refer to the same or similar element or function. In the drawings:

FIG. **1** is a side view of an exemplary plug assembly and an exemplary setting tool, in which the plug assembly is in an initial state, in accordance with the present disclosure.

FIG. **2** is a cross-sectional view of the exemplary plug assembly and the exemplary setting tool of FIG. **1**.

FIG. **3** is a cross-sectional view of an exemplary tubular metal seal of the exemplary plug assembly of FIG. **1**.

FIG. **4** is a side view of the exemplary plug assembly and the exemplary setting tool of FIG. **1**, in which the plug assembly is in a first state, in accordance with the present disclosure.

FIG. **5** is a cross-sectional view of the exemplary plug assembly and the exemplary setting tool of FIG. **4**.

FIG. **6** is a cross-sectional view of an exemplary tubular metal seal of the exemplary plug assembly of FIG. **4**.

FIG. **7** is a cross-sectional view of the exemplary plug assembly in a second state in accordance with the present disclosure.

FIG. **7**A is a partial view of the cross-section of FIG. **7**.

FIG. **8** is a process flow diagram of an exemplary method in accordance with the present disclosure.

FIG. **9** is a side view of the exemplary plug assembly and the exemplary setting tool of FIG. **1** deployed in a downhole casing in accordance with the present disclosure.

FIG. **9**A is a partial cross-sectional view of the exemplary plug assembly and the exemplary setting tool deployed in the downhole casing of FIG. **9**.

FIG. **10** is a side view of the exemplary plug assembly and the exemplary setting tool of FIG. **4** deployed in a downhole casing in accordance with the present disclosure.

FIG. **10**A is a partial cross-sectional view of the exemplary plug assembly and the exemplary setting tool deployed in the downhole casing of FIG. **10**.

FIG. **11** is a side view of the exemplary plug assembly in the first state deployed in a downhole casing in accordance with the present disclosure.

FIG. **11**A is a partial cross-sectional view of the exemplary plug assembly deployed in the downhole casing of FIG. **11**.

FIG. **12** is a side view of the exemplary plug assembly in the second state deployed in a downhole casing in accordance with the present disclosure.

FIG. **12**A is a partial cross-sectional view of the exemplary plug assembly deployed in the downhole casing of FIG. **12**.

FIG. **13** is a cross-sectional view of the exemplary plug assembly in the second state deployed in a downhole casing in accordance with the present disclosure.

FIG. **13**A is a partial cross-sectional view of the exemplary plug assembly deployed in the downhole casing of FIG. **13**.

FIG. **14** is a cross-sectional view of another exemplary plug assembly, in accordance with the present disclosure.

FIG. **15** is a cross-sectional view of an exemplary tubular metal seal of the plug assembly of FIG. **14**.

DETAILED DESCRIPTION

The following detailed description refers to the accompanying drawings. The same reference numbers in different drawings may identify the same or similar elements.

The mechanisms proposed in this disclosure circumvent the problems described above. The present disclosure describes a method for setting and sealing a plug, such as a frac plug, in a casing within a bore. An exemplary embodiment includes a method comprising deploying a plug assembly into a casing within a drilled hole, the plug assembly comprising a tubular metal seal having an interior, an exterior, a sidewall extending between the interior and the exterior, a proximal end, a distal end, and a length extending between the proximal end and the distal end, the interior at the proximal end having a tapered interior portion extending inwardly toward the distal end along the length; deploying a setting tool into the casing within the drilled hole, the setting tool having a first end having a tapered exterior portion; expanding the tubular metal seal radially to a first radial diameter with the setting tool by moving the setting tool longitudinally such that the tapered exterior portion of the first end of the setting tool engages the tapered interior portion of the proximal end of the tubular metal seal; and removing the setting tool from the casing.

In some implementations, the method may further comprise expanding the tubular metal seal radially to a second radial diameter, such that the exterior of the tubular metal seal engages an interior of the casing, by pumping fluid into the casing, the fluid providing radial pressure against the interior of the tubular metal seal, thereby preventing fluid flow past the exterior of the tubular metal seal in the casing.

In some implementations, expanding the tubular metal seal radially to the first radial diameter and/or the second radially diameter may comprise plastically deforming at least the proximal end of the tubular metal seal with the setting tool and thereby conforming at least the proximal end of the tubular metal seal to the interior of the casing. In some implementations, expanding the tubular metal seal radially to the first radial diameter and/or the second radially diameter may comprise plastically deforming the tubular metal seal and conforming the exterior of the tubular metal seal to the interior of the casing.

In some implementations, the interior of the casing has an irregular shape, and expanding the tubular metal seal radially to the first radial diameter and/or the second radially diameter may comprise expanding the tubular metal seal radially such that the exterior of the tubular metal seal has an irregularly shaped circumference conforming to the irregular shape of the interior of the casing.

In some implementations, the tubular metal seal may have a radial interior groove in the sidewall extending about the interior. In some implementations, the method may comprise expanding the tubular metal seal radially to a first radial diameter and/or a second radial diameter and plastically deforming the sidewall at the radial interior groove of the tubular metal seal, such that the exterior of the tubular metal seal engages an interior of the casing, through use of the setting tool and/or by pumping fluid into the casing to provide radial pressure against the interior of the tubular metal seal, thereby preventing fluid flow past the exterior of the tubular metal seal in the casing.

In some implementations, the first end of the frustoconical tube has a first diameter and the frustoconical tube has a second end having a second diameter smaller than the first diameter, and the plug assembly may further comprise a slip member having one or more slip segments positioned at least partially around the second end of the frustoconical tube; and the method may further comprise moving the frustoconical tube longitudinally within the one or more slip segments by moving the setting tool longitudinally, thereby expanding the one or more slip segments outwardly.

Further, in some implementations, an exemplary plug assembly may comprise a tubular metal seal having an interior, an exterior, a proximal end, a distal end, a length extending between the proximal end and the distal end, and a sidewall extending between the interior and the exterior, the interior having a tapered portion extending inwardly along the length toward the distal end, the interior having a radial interior groove located between the tapered portion and the distal end; and wherein the tubular metal seal is radially expandable to a first radial diameter by moving a setting tool longitudinally such that a tapered exterior portion of a first end of the setting tool engages the tapered portion of the interior of the proximal end of the tubular metal seal, thereby radially deforming the tubular metal seal.

In some implementations of the plug assembly, the tubular metal seal may be radially expandable to a second radial diameter larger than the first radial diameter by pumping fluid into the casing, the fluid providing radial pressure against the interior of the tubular metal seal, thereby further outwardly radially deforming the tubular metal seal, such that the exterior of the tubular metal seal engages an interior of the casing, preventing fluid flow past the exterior of the tubular metal seal in the casing.

In some implementations of the plug assembly, the tubular metal seal may have a radial interior groove extending about the interior, and deforming the tubular metal seal may include deforming at least the tapered portion of the interior of the proximal end and the sidewall at the radial interior groove of the tubular metal seal to conform to the interior of the casing.

As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by anyone of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

In addition, use of the "a" or "an" are employed to describe elements and components of the embodiments herein. This is done merely for convenience and to give a general sense of the inventive concept. This description should be read to include one or more and the singular also includes the plural unless it is obvious that it is meant otherwise.

Further, use of the term "plurality" is meant to convey "more than one" unless expressly stated to the contrary.

As used herein, qualifiers like "substantially," "about," "approximately," and combinations and variations thereof, are intended to include not only the exact amount or value that they qualify, but also some slight deviations therefrom, which may be due to manufacturing tolerances, measurement error, wear and tear, stresses exerted on various parts, and combinations thereof, for example.

The use of the term "at least one" or "one or more" will be understood to include one as well as any quantity more than one. In addition, the use of the phrase "at least one of X, V, and Z" will be understood to include X alone, V alone, and Z alone, as well as any combination of X, V, and Z.

The use of ordinal number terminology (i.e., "first", "second", "third", "fourth", etc.) is solely for the purpose of differentiating between two or more items and, unless explicitly stated otherwise, is not meant to imply any sequence or order or importance to one item over another or any order of addition.

Finally, as used herein any reference to "one embodiment" or "an embodiment" or "implementation" means that a particular element, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment. Element, feature, structure, or characteristic described in connection with one implementation may be combined with other implementations, unless expressly described otherwise.

As discussed above, current systems for sealing around plugs, such as frac plugs, in downhole casings are not dependable and are costly. The present disclosure addresses these deficiencies with a methodology for setting a plug in a casing including expanding a tubular metal seal within the casing.

Referring now to the drawings, and in particular to FIGS. **1** and **2**, an exemplary plug assembly **10**, such as for use as a frac plug when deployed into a casing **100** within a drilled hole, is shown in conjunction with a setting tool **12**, in which the plug assembly **10** is in an initial state. In some implementations, the plug assembly **10** may comprise a tubular metal seal **14** having a proximal end **16** and a distal end **18**. The plug assembly **10** may further comprise a frustoconical tube **20** having a first end **22** and a second end **24**. The first end **22** of the frustoconical tube **20** may be in contact with the distal end **18** of the tubular metal seal **14**. The plug assembly **10** may have a longitudinal axis L.

The plug assembly **10** may further comprise a slip member **30** having one or more slip segments **32**. The slip member **30** may be positioned at least partially around the second end **24** of the frustoconical tube **20**, such that the slip segments **32** are pushed outwardly when the second end **24** of the frustoconical tube **20** moves longitudinally. The slip member **30** may have a sloped interior surface **33** configured to engage the second end **24** of the frustoconical tube **20**.

The plug assembly **10** may further comprise a tubular mandrel **42** positioned longitudinally through the frustoconical tube **20**.

The plug assembly **10** may further comprise an end cap **40** in contact with the slip member **30** and/or the second end **24** of the frustoconical tube **20** and/or the distal end **18** of the tubular metal seal **14** and/or the tubular mandrel **42**.

The plug assembly **10** has an initial set of dimensions in an initial state, as illustrated in FIGS. **1**, **2**, **9**, and **9**A; a first set of dimensions in a first state, as illustrated in FIGS. **4**, **5**, **10**, **10**A, **11**, and **11**A; and a second set of dimensions in a second state, as illustrated in FIGS. **7**, **7**A, **12**A, **13**, and **13**A.

The tubular metal seal **14** has an initial radial diameter d**0** when the plug assembly **10** is in the initial state (FIG. **3**), a first radial diameter d**1** when the plug assembly **10** is in the first state (FIG. **6**), and a second radial diameter d**2** when the plug assembly **10** is in the second state (FIG. **7**). The first radial diameter d**1** is larger than the initial radial diameter d**0**. The second radial diameter d**2** is larger than the first radial diameter d**1**. The tubular metal seal **14** may be deformed plastically to expand to the first radial diameter d**1** and/or the second radial diameter d**2**. In some implementations, the tubular metal seal **14** may be deformed plastically to expand to the first radial diameter d**1** and to a first external circumference, the first external circumference conformed to the interior of the casing **100**. If the interior of the casing **100** has an irregular shape, the first external circumference may be an irregularly shaped circumference, formed by plastic deformation of the tubular metal seal in contact with the interior of the casing **100**. In some implementations, the tubular metal seal **14** may be deformed plastically to expand to the second radial diameter d**2** and to a second external circumference, the second external circumference conformed to the interior of the casing **100**. If the interior of the casing **100** has an irregular shape, the second external circumference may be an irregularly shaped circumference, formed by plastic deformation of the tubular metal seal in contact with the interior of the casing **100**.

The tubular metal seal **14** may be referred to as a flare seal. In some implementations, the tubular metal seal **14** has an interior **50** and an exterior **52** and a sidewall **53** extending between the interior **50** and the exterior **52**. The interior **50** at the proximal end **16** may have a tapered interior portion **54** extending inwardly toward the distal end **18**. In some implementations, the tapered interior portion **54** may have an angle of approximately fifteen degrees to approximately twenty degrees. In some implementations, the tapered interior portion **54** may have an angle of approximately seventeen degrees.

In some implementations, the tubular metal seal **14** may have an interior groove **55** in the interior **50** of the metal seal **14**, or may have a cavity in the sidewall **53** or other narrowing of the sidewall **53**. In some implementations, the interior groove **55** may be a radial groove in the interior **50** of the metal seal **14**, having a radial diameter that is greater than the diameter of the remainder of the interior **50** of the metal seal **14**, such that the sidewall **53** at the interior groove **55** has an initial thickness t**0** less than the thickness(s) of other portions of the sidewall **53** of the metal seal **14**. In some implementations, the interior groove **55** may be a radial groove in the interior **50** of the metal seal **14**, having a diameter that is greater than the diameter of the tapered interior portion **54** of the metal seal **14**, such that the sidewall **53** at the interior groove **55** has an initial thickness t**0** less than the thickness(s) of the sidewall **53** of the tapered interior portion **54** of the metal seal **14**. The interior groove **55** may be a radial groove extending about the diameter of the interior **50**, or the cavity or other narrowing of the sidewall **53**, may be configured such that the sidewall **53** expands radially and/or is deformed at the interior groove **55** when radial pressure is applied, such that the tubular metal seal **14** reaches the second radial diameter d**2** (FIG. **7**).

The tubular metal seal **14** may be partially or completely formed of a metal having a low modulus of elasticity such that the metal stretches, expands, and/or conforms to the casing **100** when the plug assembly **10** is in the second state and/or the third state, such that the sidewall **53** has an expanded thickness that is less that the initial thickness, for example, the sidewall **53** at the interior groove **55** may have an expanded thickness t**3** that is less than the initial thickness t**0** (FIG. **7**). In some implementations, the tubular metal seal **14** may be formed of a metal having a ductility of approximately 12% maximum elongation to approximately 35% maximum elongation. In some implementations, the tubular metal seal **14** may be formed of a metal having a ductility of approximately 30% maximum elongation. In some implementations, the tubular metal seal **14** may be formed of a metal having a yield strength of approximately 30,000 psi. In some implementations, the tubular metal seal **14** may be formed of a metal having a yield strength of approximately 10,000 psi to approximately 30,000 psi. In some implementations, the tubular metal seal **14** may be formed of a metal having a yield strength of at least approximately 10,000 psi.

The tubular metal seal **14** may be partially or completely formed of a metal that expands when under a fluid pressure of less than approximately 4,000 psi. In some implementations, the tubular metal seal **14** may be partially or completely formed of a metal that expands when under a fluid pressure of less than approximately 3,000 psi. In some implementations, the tubular metal seal **14** may be partially or completely formed of a metal that expands when under to a fluid pressure of between approximately 3,000 psi and approximately 4,000 psi.

The tubular metal seal **14** may be partially or completely formed of a metal or metal alloy that is disintegrable in a downhole environment. In some implementations, the tubular metal seal **14** is partially or completely formed of a metal alloy having a composition that includes magnesium. In some implementations, the tubular metal seal **14** is formed of magnesium.

In some implementations, the plug assembly **10** may further comprise an elastomer seal **60** positioned radially on the exterior of the tubular metal seal **14**. The elastomer seal **60** may be an O-ring or other gasket, for example. In some implementations, the exterior **52** of the tubular metal seal **14** may include a radial groove **56** around the exterior **52** of the plug assembly **10** and the elastomer seal **60** may be seated at least partially in the radial groove **56**.

As illustrated in FIGS. **2** and **5**, for example, in some implementations, the first end **22** of the frustoconical tube **20** of the plug assembly **10** may have a first outer diameter and the second end **24** of the frustoconical tube **20** may have a second outer diameter smaller than the first outer diameter. The frustoconical tube **20** may have a sloped exterior **25** at the second end **24**. The sloped exterior **25** of the frustoconical tube **20** may be engageable with the sloped interior surface **33** of the slip member **30**, such that when the sloped exterior **25** moves longitudinally along the sloped interior surface **33** of the slip member **30**, the slip segments **32** are radially expanded outward by the frustoconical tube **20**.

In some implementations, the slip member **30** may be plastic, metal, or a combination thereof. In some implementations, the slip segments **32** of the slip member **30** may optionally have one or more grips **62** protruding externally from and/or through the slip segments **32**. Nonexclusive examples of the grips **62** include, teeth, buttons, and ridges. In some implementations, the grips **62** may be cylindrical and may have longitudinal axes set at an angle to the longitudinal axis L of the plug assembly **10**.

The setting tool **12** may have a first end **70** having a tapered exterior portion **72**. The tapered exterior portion **72** of the first end **70** of the setting tool **12** may be engageable with the tapered interior portion **54** of the proximal end **16** of the tubular metal seal **14**, such that longitudinally advancing the setting tool **12** radially expands the proximal end **16** of the tubular metal seal **14** outwardly from an initial set of dimensions (FIG. **3**) having the initial diameter d**0** to the first set of dimensions (FIG. **6**) having the first diameter d**1** larger than the initial diameter d**0**. In some implementations, the angle of the tapered interior portion **54** may be determined so as to engage with the tapered exterior portion **72** of the first end **70** of the setting tool **12**.

In some implementations, longitudinally advancing the setting tool **12** radially expands the tubular metal seal **14** outwardly from an initial set of dimensions (FIG. **3**) having the initial diameter d**0** to the second set of dimensions (FIG. **7**) having the second diameter d**2** larger than the initial diameter d**0**.

In some implementations, the setting tool **12** may comprise a setting sleeve **74** and a tension mandrel **76**. The tension mandrel **76** may have a proximal end **78** having a first diameter, a distal end **80** having a second diameter smaller than the first diameter, and a step **82** between the proximal end **78** and the distal end **80**. The setting sleeve **74** may be positioned about the distal end **80** of the tension mandrel **76**. The setting sleeve **74** may have a first end **90**, including the tapered exterior portion **72** of the first end **70** of the setting tool **12**, and may have a second end **92** in contact with the step **82** of the tension mandrel **76**.

In some implementations, the second end **92** of the setting sleeve **74** may have a maximum wall thickness that is greater than a maximum thickness of the sidewall **53** of the proximal end **16** of the metal seal **14**. In other words, the maximum thickness of the sidewall **53** of the proximal end **16** of the metal seal **14** may be less than the maximum wall thickness of the second end **92** of the setting sleeve **74**.

As illustrated in FIG. **8**, in use, a method **200** of setting the plug assembly **10** within a casing **100** in a drilled hole may comprise deploying the plug assembly **10** into the casing **100** (step **202**); deploying the setting tool **12** into the casing (step **204**); expanding the tubular metal seal **14** radially from the initial radial diameter d**0** to the first radial diameter d**1** with the setting tool **12** by moving the setting tool **12** longitudinally such that the tapered exterior portion **72** of the first end **70** of the setting tool **12** engages and expands the tapered interior portion **54** of the proximal end **16** of the tubular metal seal **14** (step **206**); and removing the setting tool **12** from the casing **100** (step **208**). In some implementations, expanding the tubular metal seal **14** radially from the initial radial diameter d**0** comprises moving the setting tool **12** longitudinally such that the tapered exterior portion **72** of the first end **70** of the setting tool **12** engages the tapered interior portion **54** of the proximal end **16** of the tubular metal seal **14** and radially outwardly expands the sidewall **53** of the tubular metal seal **14**.

In some implementations, the method **200** comprises expanding the tubular metal seal **14** radially to the second radial diameter d**2** by pumping fluid **104** into the casing **100**, the fluid **104** providing radial pressure against the interior **50** of the tubular metal seal **14**, such that the exterior **52** of the tubular metal seal **14** engages (and/or sealingly conforms to) an interior **102** of the casing **100**, thereby preventing fluid flow between the plug assembly **10** and the interior **102** of the casing **100** (step **210**).

In some implementations, the method **200** further comprises moving the frustoconical tube **20** longitudinally with the setting tool **12**, such as by transferred force through the tubular metal seal **14** and/or by direct contact of the setting tool **12** with the frustoconical tube **20**. In some implementations, for example, the distal end **80** of the tension mandrel **76** of the setting tool **12** may be in contact with the first end

22 of the frustoconical tube 20 and may transfer longitudinal force to the frustoconical tube 20. The method 200 may further comprise moving the frustoconical tube 20 longitudinally within the one or more slip segments 32 of the slip member 30 by moving the setting tool 12 longitudinally, thereby expanding the one or more slip segments 32 outwardly. In some implementations, expanding the one or more slip segments 32 outwardly comprises expanding the one or more slip segments 32 outwardly until the grips 62 on the one or more slip segments 32 contact the interior 102 of the casing 100, causing a gripping force between the slip segments 32 and the interior 102 of the casing 100.

In some implementations, in step 206, expanding the tubular metal seal 14 radially from the initial radial diameter d0 to the first radial diameter d1 with the setting tool 12 by moving the setting tool 12 longitudinally such that the tapered exterior portion 72 of the first end 70 of the setting tool 12 engages the tapered interior portion 54 of the proximal end 16 of the tubular metal seal 14, may further comprise expanding the tubular metal seal 14 radially to the first radial diameter d1 with the setting tool 12 by moving the setting tool 12 longitudinally such that the tapered exterior portion 72 of the first end of the setting sleeve 74 of the setting tool 12 engages the tapered interior portion 54 of the proximal end 16 of the tubular metal seal 14, thereby radially expanding the proximal end 16 of the metal seal 14.

In some implementations, the method 200 may further comprise expanding the optional elastomer seal 60 on the exterior 52 of the tubular metal seal 14 as the tubular metal seal 14 radially expands, such that the elastomer seal 60 is in contact with the interior 102 of the casing 100.

In some implementations, in step 210, since the initial thickness t0 of the sidewall 53 of the metal seal 14 at the interior groove 55 (and/or other thin portion of the sidewall 53) is less than the thickness of the sidewall 53 elsewhere in the metal seal 14, then the sidewall 53 at the interior groove 55 deforms and/or expands first when fluid pressure is introduced, as it requires less pressure to expand the thinner part of the sidewall 53. The thickness t0 of the sidewall 53 and the material of the sidewall 53 of the metal seal 14 are configured to deform outwardly, like a balloon, and to conform to the interior 102 of the casing 100. In some implementations, the sidewall 53 at the interior groove 55 expands when under to a fluid pressure of less than approximately 4,000 psi. In some implementations, the sidewall 53 at the interior groove 55 expands when under a fluid pressure of less than approximately 3,000 psi. In some implementations, the sidewall 53 at the interior groove 55 expands when under to a fluid pressure of between approximately 3,000 psi and approximately 4,000 psi.

The exterior 52 of the expanded tubular metal seal 14 may provide a seal against the interior 102 of the casing 100 preventing fluid from moving between the interior 102 of the casing 100 and the plug assembly 10. The expanded tubular metal seal 14 may further provide a setting force which may hold (or assist in holding) the plug assembly 10 in place within the casing 100.

In some implementations, the method 200 may not include step 206. Instead, the metal seal 14 may be expanded by fluid pressure from the initial radial diameter d0 until the metal seal 14 is radially expanded to the second radial diameter d2, thereby sealing the plug assembly 10 against the interior 102 of the casing 100.

In some implementations, the method 200 may include another step after step 210, in which, once the metal seal 14 is radially expanded to the second radial diameter d2, the fluid pressure acts on the metal seal 14 to transmit longitudinal force to the frustoconical tube 20 which moves the frustoconical tube 20 longitudinally, thereby transmitting further radial forces into the slip segments 32, increasing the force of the slip segments 32 and/or the grips 62 against the interior 102 of the casing, and further securing the plug assembly 10 in the casing 100.

An example of the method 200 in use will now be described in relation to FIGS. 9-13A. It will be understood that FIGS. 9-13A have been drawn to illustrate the method 200, but that gaps shown between the interior 102 of the casing 100 and the plug assembly 10 and schematic illustrations in the cross-sectional drawings are for explanatory purposes and may or may not exist and may not be drawn to scale.

FIG. 9 illustrates the plug assembly 10 and the setting tool 12 being deployed in the casing 100 as in steps 202 and 204 of the method 200. The plug assembly 10 and/or the setting tool 12 may be moved through the casing hydraulically, mechanically, electrically, and/or magnetically. The plug assembly 10 and/or the setting tool 12 may be disposed on, or with, a drill string. As shown in FIGS. 9 and 9A, during deployment (and, in some implementations, until completion of step 206), the plug assembly 10 may be in the initial state with the initial set of dimensions, including the tubular metal seal 14 having the initial radial diameter d0 and the sidewall 53 (such as at the interior groove 55) having the initial thickness to.

FIGS. 10 and 10A illustrate the plug assembly 10 in the first state having the first dimensions within the casing 100, after the setting tool 12 has radially expanded the tubular metal seal 14 to the first diameter d1 in step 206. In the first state, at least the proximal end 16 of the metal seal 14 may be radially expanded by the force of the setting sleeve 74 as it moves longitudinally and engages the tapered interior portion 54 of the proximal end 16 of the metal seal 14.

In the first state, the slip segments 32 of the slip member 30 may be expanded outwardly such that the slip segments 32 (and/or the grips 62, when present) are in contact with the interior 102 of the casing 100 and/or the optional elastomer seal 60 may be radially expanded and in contact with the interior 102 of the casing 100. At least while the plug assembly 10 is in the first state, the slip segments 32 and/or the grips 62 contact with the interior 102 of the casing 100 may maintain the position of the plug assembly 10 in the casing 100. Additionally, in the first state, the elastomer seal 60 may temporarily slow or stop fluid flow between the plug assembly 10 and the interior 102 of the casing 100. However, it will be understood that the slip member 30 and/or the elastomer seal 60 may be eliminated and the tubular metal seal 14 may hold the plug assembly 10 in place in the casing 100 and/or create a fluid-impervious seal between the plug assembly 10 and the interior 102 of the casing 100, such as when the plug assembly 10 is in the second state.

FIGS. 11 and 11A illustrate the plug assembly 10 positioned in the casing 100 in the first state, with the tubular metal seal 14 expanded to the first diameter d1, after the setting tool 12 has been removed in step 208.

FIGS. 12-13A illustrate the plug assembly 10 in the casing 100 in the second state, after step 210, in which the tubular metal seal 14 is radially expanded to the second radial diameter d2, such as by pumping fluid 104 into the casing 100, the fluid 104 providing radial pressure against the interior 50 of the tubular metal seal 14, such that the exterior 52 of the tubular metal seal 14 engages (and/or sealingly conforms to) the interior 102 of the casing 100, thereby preventing fluid flow past the exterior 52 of the tubular metal seal 14 and the interior 102 of the casing 100. The expanded tubular metal seal **14** may further provide a setting force which may hold (or assist in holding) the plug assembly **10** in place within the casing **100**.

In some implementations, portions or all of the plug assembly **10** may be structured to disintegrate after a predetermined amount of time exposed to the fluid **104** in the casing **100**. Portions or all of the plug assembly **10** may be manufactured from metal, metal alloys, or other materials that disintegrate after a predetermined amount of time exposed to the fluid **104** in the casing **100**.

FIGS. **14** and **15** illustrate another embodiment of a plug assembly **10***a* constructed in accordance with the inventive concepts disclosed herein. The plug assembly **10***a* is substantially similar to the plug assembly **10**, except as described herein below, and may be used in the method **200**.

The plug assembly **10***a* may comprise a tubular metal seal **14***a* having a proximal end **16** and a distal end **18***a*. In the implementation shown in FIGS. **14** and **15**, the tapered interior portion **54** is a first tapered interior portion **54**, and the distal end **18***a* of the tubular metal seal **14***a* has a second tapered interior portion **57** extending inwardly from the distal end **18***a* toward the proximal end **16**. The second tapered interior portion **57** may have an angle that is equal to, more than, or less than the angle of the first tapered interior portion **54**. In the example shown, the second tapered interior portion **57** has a more acute angle than the angle of the first tapered interior portion **54**.

The plug assembly **10***a* may further comprise a frustoconical tube **20***a* having a first end **22***a* and a second end **24***a*. The first end **22***a* of the frustoconical tube **20***a* may be in contact with the distal end **18***a* of the tubular metal seal **14***a*, such as with the interior of the distal end **18***a*. The first end **22***a* of the frustoconical tube **20***a* may have an exterior tapered portion **23** having an angle that is substantially complimentary to the angle of the second tapered portion **57**, while allowing the second tapered portion **57** of the tubular metal seal **14***a* and the exterior tapered portion **23** of the frustoconical tube **20***a* to moveably engage one another.

The second tapered portion **57** of the tubular metal seal **14***a* may engage with the exterior tapered portion **23**, radially expanding the tubular metal seal **14***a*, when force from the setting sleeve **74**, as it moves longitudinally and engages the tapered interior portion **54** of the proximal end **16** of the tubular metal seal **14***a*, is transferred through the tubular metal seal **14***a*. And/or the second tapered portion **57** of the tubular metal seal **14***a* may engage with the exterior tapered portion **23**, radially expanding the tubular metal seal **14***a*, when fluid pressure is applied. The tubular metal seal **14** may be deformed plastically to expand to the first radial diameter d**1** and/or the second radial diameter d**2** and/or to conform to the interior **102** of the casing **100**.

The plug assembly **10** may further comprise the slip member **30** having the one or more slip segments **32**. The slip member **30** may be positioned at least partially around the second end **24***a* of the frustoconical tube **20***a*, such that the slip segments **32** are pushed outwardly when the second end **24** of the frustoconical tube **20***a* moves longitudinally. The slip member **30** may have a sloped interior surface **33** configured to engage the second end **24***a* of the frustoconical tube **20**.

The plug assembly **10** may further comprise a tubular mandrel **42***a* positioned longitudinally through the frustoconical tube **20***a*. Though a particular tubular mandrel **42***a* is shown in this implementation in FIG. **14**, it will be understood that other tubular mandrels may be utilized.

The plug assembly **10***a* may further comprise an end cap **40***a* in contact with the slip member **30** and/or the second end **24***a* of the frustoconical tube **20***a* and/or the distal end **18***a* of the tubular metal seal **14***a* and/or the tubular mandrel **42***a*.

In some implementations, the plug assembly **10**, **10***a* and/or the tubular metal seal **14**, **14***a* may be used in conjunction with and/or combined with elements of the systems and methods describe in the U.S. patent application entitled "Systems and Methods for Flow-Activated Initiation of Plug Assembly Flow Seats," having Ser. No. 17/405,690, filed Aug. 18, 2021, the entire contents of which are hereby incorporated herein.

CONCLUSION

Conventionally, setting plugs, such as frac plugs, in downhole applications has been time consuming and costly and the resulting seals were undependable. In accordance with the present disclosure, a plug assembly is set and sealed in a casing using a tubular metal seal. The tubular metal seal may be deformed using radial force from pressurized fluid and/or longitudinal force from a setting tool to set and seal the plug assembly within the casing.

The foregoing description provides illustration and description, but is not intended to be exhaustive or to limit the inventive concepts to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of the methodologies set forth in the present disclosure.

Even though particular combinations of features are recited in the claims and/or disclosed in the specification, these combinations are not intended to limit the disclosure. In fact, many of these features may be combined in ways not specifically recited in the claims and/or disclosed in the specification. Although each dependent claim listed below may directly depend on only one other claim, the disclosure includes each dependent claim in combination with every other claim in the claim set.

No element, act, or instruction used in the present application should be construed as critical or essential to the invention unless explicitly described as such outside of the preferred embodiment. Further, the phrase "based on" is intended to mean "based, at least in part, on" unless explicitly stated otherwise.

What is claimed is:

1. A method, comprising:

deploying a plug assembly into a casing within a drilled hole, the plug assembly comprising a tubular metal seal having an interior, an exterior, a sidewall extending between the interior and the exterior, a proximal end, a distal end, and a length extending between the proximal end and the distal end, the interior at the proximal end having a tapered interior portion extending inwardly toward the distal end along the length;

deploying a setting tool into the casing within the drilled hole, the setting tool having a first end having a tapered exterior portion;

expanding the tubular metal seal radially to a first radial diameter with the setting tool by moving the setting tool longitudinally such that the tapered exterior portion of the first end of the setting tool engages the tapered interior portion of the proximal end of the tubular metal seal;

expanding the tubular metal seal radially to a second radial diameter, such that the exterior of the tubular metal seal engages an interior of the casing, by pumping fluid into the casing, the fluid providing radial pressure against the interior of the tubular metal seal, thereby preventing fluid flow past the exterior of the tubular metal seal in the casing; and

removing the setting tool from the casing.

2. The method of claim 1, wherein expanding the tubular metal seal radially to the first radial diameter comprises plastically deforming at least the proximal end of the tubular metal seal with the setting tool and thereby conforming at least the proximal end of the tubular metal seal to the interior of the casing.

3. The method of claim 1, wherein the interior of the casing has an irregular shape, and wherein expanding the tubular metal seal radially to the first radial diameter, comprises expanding the tubular metal seal radially such that the tubular metal seal has an irregularly shaped circumference conforming to the irregular shape of the interior of the casing.

4. The method of claim 1, wherein the tubular metal seal has a radial interior groove in the sidewall extending about the interior.

5. The method of claim 4, further comprising:

expanding the tubular metal seal radially to a second radial diameter and plastically deforming the sidewall at the radial interior groove of the tubular metal seal, such that the exterior of the tubular metal seal engages an interior of the casing, by pumping fluid into the casing, the fluid providing radial pressure against the interior of the tubular metal seal, thereby preventing fluid flow past the exterior of the tubular metal seal in the casing.

6. The method of claim 4, wherein the interior of the casing has an irregular shape, and wherein expanding the tubular metal seal radially to the second radial diameter comprises expanding the tubular metal seal radially such that the tubular metal seal has an irregularly shaped circumference conforming to the irregular shape of the interior of the casing.

7. The method of claim 4, wherein expanding the tubular metal seal radially to the second radial diameter comprises conforming the tubular metal seal to the interior of the casing.

8. The method of claim 1, wherein the plug assembly further comprises an elastomer seal positioned on the exterior of the tubular metal seal.

9. The method of claim 8, wherein expanding the tubular metal seal radially to the first radial diameter further comprises expanding the elastomer seal on the exterior of the tubular metal seal as the tubular metal seal radially expands such that the elastomer seal is in contact with the casing.

10. The method of claim 1, wherein the plug assembly further comprises a frustoconical tube having a first end in contact with the distal end of the tubular metal seal, wherein the first end of the frustoconical tube has a first diameter and the frustoconical tube has a second end having a second diameter smaller than the first diameter.

11. The method of claim 10, wherein the plug assembly further comprises a slip member having one or more slip segments positioned at least partially around the second end of the frustoconical tube; and the method further comprises:

increasing an outward radial force on the one or more slip segments by applying fluid pressure until after the tubular metal seal is fully expanded, such that the fluid pressure creates a longitudinal force between the tubular metal seal which is transmitted via an engagement between the frustoconical tube and the slip member into the outward radial force on the one or more slip segments.

12. The method of claim 10, wherein the plug assembly further comprises a slip member having one or more slip segments positioned at least partially around the second end of the frustoconical tube; and wherein the method further comprises:

moving the frustoconical tube longitudinally within the one or more slip segments by moving the setting tool longitudinally, thereby expanding the one or more slip segments outwardly.

13. The method of claim 12, wherein moving the frustoconical tube longitudinally by moving the setting tool longitudinally further comprises moving the frustoconical tube longitudinally with the setting tool via transferred force through the tubular metal seal.

14. The method of claim 12, wherein expanding the one or more slip segments outwardly comprises expanding the one or more slip segments outwardly until grips on the one or more slip segments contact the casing.

15. The method of claim 10, wherein the plug assembly further comprises:

a slip member having one or more slip segments positioned at least partially around the second end of the frustoconical tube; and

an end cap in contact with the slip member.

16. The method of claim 1, wherein the setting tool further comprises:

a tension mandrel having a proximal end having a first diameter, a distal end having a second

diameter smaller than the first diameter, and a step between the proximal end and the distal end, wherein the distal end is initially in contact with the tubular metal seal; and a setting sleeve positioned around the distal end of the tension mandrel, the setting sleeve having a first end including the tapered exterior portion of the setting tool and having a second end in contact with the step of the tension mandrel.

17. A plug assembly deployable into a casing in a drilled hole, comprising:

a tubular metal seal having an interior, an exterior, a proximal end, a distal end, a length extending between the proximal end and the distal end, and a sidewall extending between the interior and the exterior, the interior having a tapered portion extending inwardly along the length toward the distal end, the interior having a radial interior groove located between the tapered portion and the distal end;

wherein the tubular metal seal is radially expandable to a first radial diameter by moving a setting tool longitudinally such that a tapered exterior portion of a first end of the setting tool engages the tapered portion of the interior of the proximal end of the tubular metal seal, thereby radially deforming the tubular metal seal; and

wherein the tubular metal seal is radially expandable to a second radial diameter larger than the first radial diameter by pumping fluid into the casing, the fluid providing radial pressure against the interior of the tubular metal seal, thereby further outwardly radially deforming the tubular metal seal, such that the exterior of the tubular metal seal engages an interior of the casing, preventing fluid flow past the exterior of the tubular metal seal in the casing.

18. The plug assembly of claim 17, the tubular metal seal having a radial interior groove extending about the interior, and wherein deforming the tubular metal seal includes deforming at least the tapered portion of the interior of the

proximal end and the sidewall at the radial interior groove of the tubular metal seal to conform to the interior of the casing.

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