

(19) World Intellectual Property
Organization
International Bureau

(43) International Publication Date
9 January 2014 (09.01.2014)



(10) International Publication Number
WO 2014/006149 A9

(51) International Patent Classification:
E21B 33/06 (2006.01)

(21) International Application Number:

PCT/EP2013/064172

(22) International Filing Date:

4 July 2013 (04.07.2013)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1212091.1	6 July 2012 (06.07.2012)	GB
1214898.7	21 August 2012 (21.08.2012)	GB

(71) Applicant: STATOIL PETROLEUM AS [NO/NO]; N-4035 Stavanger (NO).

(72) Inventors: ROLLAND, Nils Lennart; Eikaasneset 42, N-5131 Nyborg (NO). TVERLID, Steinar Wasa; Geitavengen 4, N-5177 Bjørøyhamn (NO).

(74) Agent: LIND, Robert; Marks & Clerk LLP, Fletcher House (2nd Floor), Heatley Road, The Oxford Science Park, Oxford Oxfordshire OX4 4GE (GB).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

[Continued on next page]

(54) Title: DYNAMIC ANNULAR SEALING APPARATUS

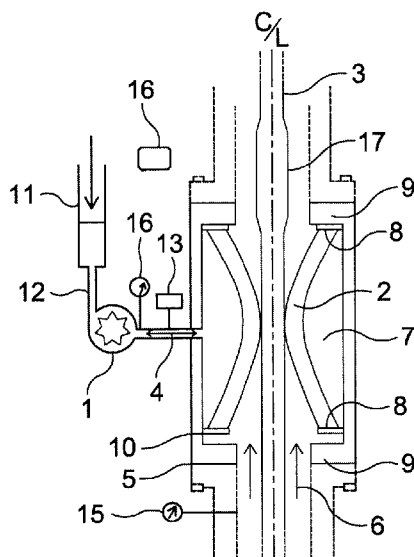


FIG. 1

(57) Abstract: The invention relates to a dynamic annular sealing apparatus comprising a resilient sleeve deformable between a closed sealing configuration and an open non-sealing configuration and a pump controllable to effect such deformation by alteration of pressure exerted on the sleeve. The apparatus is particularly suited to use in wellbore applications.



TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(48) Date of publication of this corrected version:

6 March 2014

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(15) Information about Correction:

see Notice of 6 March 2014

Dynamic Annular Sealing Apparatus

Field of the Invention

5 This invention relates to a dynamic annular sealing apparatus. Particularly, but not exclusively, the invention relates to a dynamic annular sealing apparatus for use in deepwater riserless drilling for the extraction of oil and gas. Aspects of the invention can be considered to provide a dynamic annular sealing apparatus for sealing an annular space between concentrically arranged tubulars.

10 Background to the Invention

When drilling in deep waters, it is advantageous to drill without a drilling riser since the additional construction of the riser adds to the time, effort, cost and complexity of the entire operation. Furthermore, many drilling locations (particularly deepwater locations) have been found to be un-drillable with conventional drilling riser systems. Drilling 15 without a riser can also improve the pressure conditions in a well by reducing the pressure difference at the well head (usually referred to as the riser margin), making riser disconnection less risky.

One of the challenges in achieving riserless drilling is to provide an effective annular 20 seal on the drill string, including the bottom hole assembly with varying outer diameters, while also separating drilling fluid from the sea and surrounding environment. A secondary challenge is to develop a seal that can be used in Managed Pressure Drilling (MPD) systems, where the aim is to better control the annular pressure profile throughout the wellbore, so as to allow MPD to be employed by 25 floating drilling vessels.

There are to-date no solutions developed for this purpose within the offshore drilling industry. Today's sealing solutions (often referred to as rotating control devices, RCDs) are typically not used subsea (i.e. below water level), wear fast and have limited 30 sealing ability when worn.

US7,926,593 B1 is directed towards a method for converting a drilling rig between conventional hydrostatic pressure drilling and managed pressure drilling or underbalanced drilling using a docking station housing, and, along with the prior art 35 referred to therein, describes further background to the present invention.

It is an aim of the present invention to provide a dynamic annular seal which addresses at least some of the afore-mentioned problems.

5 Summary of the Invention

According to a first aspect of the present invention there is provided a dynamic annular sealing apparatus comprising: a resilient sleeve deformable between a closed sealing configuration and an open non-sealing configuration; and a pump controllable to effect such deformation by alteration of pressure exerted on the sleeve.

10

Thus, embodiments of the present invention provide a dynamic annular sealing apparatus (i.e. RCD) which is controllably deformable from a narrow sleeve capable of sealing against an inner tubular to a wide sleeve allowing free-running of tubulars there-within. A particular advantage over known technology is that embodiments of the invention can be configured to allow full, unencumbered, access to a borehole with the seal still in place (i.e. by deforming the sleeve so as to provide an opening equivalent to the full borehole inner diameter).

15

The sealing apparatus may be suited for use in a borehole or drilling riser application, and may be particularly suited to deep water subsea applications. More specifically, the apparatus may be employed in a so-called blow-out preventer (BOP) commonly mounted adjacent the seabed at the top of a wellbore. The apparatus may be configured to maintain a desired annular pressure in the wellbore (below) and/or to prevent seawater or base fluid in a riser (above) from mixing with drilling fluid below. Thus, the apparatus may seal against pressure both downstream and upstream. Advantageously, the apparatus can be used to maintain a desired pressure in the wellbore which is either higher or lower than ambient pressure. This allows drilling through tight pressure margins using either managed pressure drilling or underbalanced drilling.

20

25

30

Another advantage is that embodiments of the present invention can seal against several different diameters of inner tubulars (e.g. drillpipes and tooling) without requiring the sealing element to be changed. By contrast, it should be noted that conventional subsea seals need to be retrieved and replaced multiple times during a

drilling operation since they are not adjustable in the same manner as the present sealing apparatus.

5 The sleeve may be biased towards the closed sealing configuration. Accordingly, with no pressure differential applied to the sleeve, the sleeve may adopt the closed sealing configuration, which will conveniently be such that it will form a sealing contact with a desired minimum diameter inner tubular. The sleeve may be constituted by a waisted annular band (hyperboloid) having a smaller inner diameter at its centre and a larger inner diameter at each end.

10

The sleeve may be formed of polymeric material, more particularly elastomeric material and, in some embodiments may be formed of rubber. The sleeve may contain material to mitigate wear. The material may be embedded in the sleeve. The material may comprise fine grade hard or plastic material, for example, silicate, ceramic or diamond pieces.

15

The pump may be arranged to provide suction (i.e. below ambient pressure) to deform the sleeve into the open non-sealing configuration. The pump may further be arranged to provide increased pressure (i.e. above ambient pressure) to increase the sealing force of the sleeve in the closed configuration. Moreover, the pump may be controlled to adjust the physical force applied by the sleeve to an inner tubular and, in doing so, the sleeve may remain in sealing contact with the inner tubular even when the diameter of the inner tubular changes, for example, when tools are provided along the length of a drill string.

25

The sleeve may be provided within a cylindrical housing having inwardly directed top and bottom flanges, clamps, connectors or the like to contain the sleeve therein. Each end of the sleeve may be in sealing engagement with the housing so as to define a cavity between the outer longitudinal surface of the sleeve and the housing. The pump may be connected to the cavity by a fluid conduit such that operation of the pump may increase or decrease the fluid pressure in the cavity and thereby deform the sleeve.

30

At least one end of the sleeve may be axially moveable within the housing to accommodate deformation of the sleeve. In certain embodiments the at least one end of the sleeve may be fixed (e.g. vulcanised) to a metal (e.g. steel) ring configured for

35

axial movement within the housing. The other end of the sleeve may also be fixed (e.g. vulcanised) to a metal (e.g. steel) ring.

5 The pump may be connected to a hydraulic reservoir via an inlet. The hydraulic reservoir may be balanced to ambient pressure. Thus, if the hydraulic reservoir is provided on the seabed, the pump power will be proportional to the pressure at the seabed, which will be significant in deep water drilling applications.

10 At least one pressure sensor may be provided. The at least one pressure sensor may be in communication with a control system configured to regulate the pump to adjust the pressure in the cavity and thereby adjust the sealing force and/or degree of opening of the sleeve. The at least one pressure sensor may be provided in the fluid conduit and/or borehole.

15 An accumulator may be provided to compensate for variations in the volume of the cavity due to deformation of the sleeve (e.g. such as would result from variations in the outer diameter of a drill string as it passes through the sleeve). The accumulator may be connected to the fluid conduit.

20 In a second embodiment, a retainer pipe may be at least partially inserted into the sleeve so as to hold at least one end of the sleeve open. The sealing apparatus may be configured for sealing an annular space between concentrically arranged tubulars. A tubular net formed by a multiplicity of resiliently deformable segments interconnected by means of flexible joints may be at least partially embedded within the sleeve.

25 Such embodiments of the invention provide a flexible annular sealing apparatus which is deformable from a narrow sleeve to a wide sleeve and which comprises a robust and reliable construction having improved wear and sealing lifespan and no rotating parts. The construction of the apparatus also provides a degree of flexibility ensuring that
30 varying diameters of tubulars (e.g. associated with different tooling) can be securely accommodated, even within a single seal. As the deformation of each segment in the net will generally increase with increasing diameter, the inwardly directed restoring or sealing force of the apparatus will also tend to increase such that the apparatus will be
35 easy to use as it will be biased towards contracting around an inner tubular. Thus, although it will be possible to 'park' the sleeve around a retainer pipe and to remove or

insert the retainer pipe to effectively remotely activate or deactivate the sleeve (as explained below in more detail), it is important to note that, when in use, the sleeve will automatically contract around an inner tubular to seal there-against. Furthermore, the sleeve will continue to provide good, possibly even improved, sealing characteristics in the case of an emergency well event such as a blowout which causes an increase in pressure surrounding the seal, resulting in an increased force being applied to the inner tubular. It should be noted that the pump may be employed to enhance or counteract the inherent biasing force of the sleeve so as to more accurately control the sealing characteristics of the sleeve.

As mentioned previously, the apparatus may be employed in a number of different wellbore applications, for example, between a drill string and a riser (e.g. at the sea bed), as a blowout prevention (BOP) annular seal, as a seal in riserless drilling, and in Managed Pressure Drilling (MPD), Underbalanced Drilling or Dual Gradient Drilling systems. The apparatus may further be suitable for sealing an annular space between non-concentrically arranged tubulars. The apparatus may be used as a single seal or employed to form a series of multiple seals, for example, to enable a lubricator function for a bottom hole assembly (BHA). In certain embodiments, the seal may be configured as a loose mud scraper provided on a rig floor to scrape mud from an inner tubular. Alternatively, the seal may be employed in well interventions such as snubbing operations or in any operation where a wireline, pipe or coiled tubing is required to be run through a stuffing box.

The flexible joints may be configured to allow the segments to fold over each other when the sleeve is in a collapsed configuration and to lever the segments apart when the sleeve is in an expanded configuration.

The segments may be interconnected by way of hinged joints having axes of rotation which are substantially radially aligned with respect to the sleeve.

Each segment of the net may be coupled at each of its ends to a set of neighbouring segments by a bolt having an axis aligned substantially radially with respect to the sleeve. Intermediate segments of the net may be coupled at each end to three neighbouring segments. Thus, the net may comprise a series of flexible quadrilateral elements.

The segments may be of metal (e.g. steel). Each segment may be substantially planar in its undeformed state, such that when the sleeve is expanded the segments are deformed, resulting in a radially inward force being exerted by the sleeve.

5

It is also contemplated that the segments may be formed of metal rope or the like.

The sealing apparatus may be configured for use with a rotating or non-rotating inner tubular such as a drill string.

10

For example, radially inwardly facing surfaces of the segments may be exposed and may project from the sleeve so that, in use, these surfaces of the segments come into contact with an inner tubular, thereby reducing the friction between the apparatus and the inner tubular. The surfaces may be provided with a relatively low friction coating to facilitate insertion and/or rotation of the inner tubular within the sleeve. The coating may comprise a ceramic or polymer coating but is not limited thereto.

15

It will be understood that both friction and wear between the apparatus and the inner tubular can be controlled through selective use of a material having the desired friction/wear and sealing properties at the interface between the segments and the inner tubular. However, the interface material need not be chosen for its elastic properties also, as is the case for traditional BOP annular seals, since in accordance with the present invention, the elastic properties are catered for by the provision of the deformable sleeve and flexible net.

20

25

The sleeve may be configured to have a large operating range, for example, by having an outer diameter which can flex from at least 6.625 inches (approximately 0.19m) to at least 18.75 inches (approximately 0.48m), thus making the sleeve suitable for use with drill pipes and slick drill collars.

30

According to a second aspect of the present invention there is provided a method of installing an apparatus for sealing an annular space between concentrically arranged tubulars, the method comprising:

providing the apparatus according to the second embodiment of the invention within an outer tubular;

35

expanding the sleeve for receipt of a retainer pipe; and
inserting the retainer pipe at least partially into the sleeve so as to hold at least one end of the sleeve open for subsequent receipt of an inner tubular.

- 5 An expansion member may be employed to expand the sleeve for receipt of the retainer pipe.

10 In order to allow insertion of the inner tubular through the sleeve, the retainer pipe may be arranged to hold just one end of the sleeve open or may expand along the entire length of the sleeve. Once the inner tubular is inserted, the retainer pipe may be fully or partially withdrawn from within the sleeve.

15 In certain embodiments, the retainer pipe may be constituted by a full bore pipe section such that the sleeve is pre-tensioned and "parked" around the full bore pipe section and wherein the retainer pipe can be moved axially to expose the sleeve to an inner tubular (e.g. drill pipe), which the sleeve will automatically clamp onto due to the restoring forces in the net. When the use of the sleeve is complete the full bore pipe section may be run back into the sleeve such that the sleeve will again be pre-tensioned and "parked" behind the full bore pipe, ready to be deployed around a
20 subsequent inner tubular as and when required. Notably, the full bore pipe, which energises and offloads the sleeve by sliding up and down, may allow full access to the bore (the same as a BOP stack bore) when the sleeve is not required and is parked.

25 As above, the apparatus is particularly suited to sealing an opening between a subsea riser and a tubular extending through the riser and out of an end of the riser. This tubular may be a drill string. A tubular retainer pipe can be inserted between the inner tubular and the sleeve in order to radially expand at least a portion of the sleeve and force its outer surface into sealing contact with the inner surface of the riser, whilst an unexpanded portion of the sleeve remains tightly sealed against the inner tubular. The
30 apparatus may also be used downhole to seal components other than a riser.

In a particular embodiment, the apparatus may be installed down hole and configured to seal automatically if an external annular pressure reaches a pre-determined level (i.e. becomes too high) relative to an internal string pressure. Such a configuration
35 would stop a so-called kick at its infancy down where the formation can handle the

pressures concerned. The apparatus will also make it easier to work through the kick and regain integrity since one can operate through a bore of the sleeve like normal (as long as the retainer pipe or inner tubular is not pulled out).

5 According to a third aspect of the present invention there is provided a method of manufacturing an apparatus for sealing an annular space between concentrically arranged tubulars, the method comprising:

assembling a tubular net formed by a multiplicity of resiliently deformable segments interconnected by means of flexible joints; and

10 at least partially embedding the net within a sleeve of elastically deformable material.

The elastically deformable material may comprise rubber, more specifically although not limited to, vulcanised rubber.

15

It will be understood that the provision of the flexible net will not only prime the sleeve so that it will try to latch onto an inner tubular but also serve to reinforce the sleeve of deformable material.

20 Brief Description of the Drawings

Specific embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a cross-sectional view of a dynamic annular sealing apparatus in accordance with a first embodiment of the present invention, in a closed configuration;

25 Figure 2 shows a cross-sectional view of the dynamic annular sealing apparatus of Figure 1, in an open configuration;

Figure 3A shows a plan view of a portion of a tubular net in accordance with a second embodiment of the present invention, in both an expanded configuration and a contracted configuration;

30 Figure 3B shows a side perspective view illustrative of one segment of the tubular net illustrated in Figure 3A;

Figure 3C shows a side perspective view illustrative of two segments from the tubular net of Figure 3A, coupled together with a flexible joint;

35 Figure 4A illustrates a tubular net similar to that shown in Figure 3A, provided around an inner tubular;

Figure 4B illustrates the forces causing elastic deformation of a segment of the net shown in Figure 4A, when it is wrapped around an inner tubular;

Figure 4C illustrates the deformed shape of segments of the net as a result of the forces illustrated in Figure 4B;

5 Figure 5 shows a deformed segment in the form it would adopt when in a net wrapped around an inner tubular as per Figure 4C;

Figure 6A shows a side perspective view of a segment of a tubular net in accordance with another embodiment of the invention, comprising a low friction coating on its underside;

10 Figure 6B shows a cross-sectional view taken along the dashed centre line shown in Figure 6A, when the segment is provided on an inner tubular;

Figure 7 illustrates the sealing capacity of a tubular net in accordance with an embodiment of the present invention;

15 Figure 8A illustrates a top and side view of an unexpanded tubular net in accordance with an embodiment of the present invention;

Figure 8B illustrates the tubular net of Figure 8A once incorporated into a sleeve of elastically deformable rubber to form a sealing apparatus in accordance with an embodiment of the invention;

20 Figure 8C shows the sealing apparatus of Figure 8B provided within an outer tubular housing in, for example, a wellbore;

Figure 8D shows a retainer pipe prior to insertion into the sealing apparatus of Figure 8C; and

Figure 8E shows the top of the sealing apparatus being held in an expanded configuration to allow insertion of the retainer pipe into the apparatus;

25 Figure 9A shows the sealing apparatus of Figures 8B to 8E in stand-by mode with the retainer pipe provided through the sealing apparatus such that the sealing apparatus is expanded energized (pressing strongly towards the retainer pipe ready to seal if the retainer pipe is removed) and primed for use;

30 Figure 9B shows the sealing apparatus of Figure 9A in use whereby the retainer pipe is withdrawn to allow the sealing apparatus to contract around a smaller inner tubular – the arrows also illustrate that if the apparatus is exposed to high external pressures, these pressures will contribute to a higher sealing force which is important for a good sealing;

35 Figure 10A shows a transverse cross-sectional view of the apparatus when contracted around an inner tubular;

Figure 10B shows a side view of apparatus of Figure 10A;

Figure 11A shows the apparatus of Figure 10B adapted to seal around an inner tubular having a varying outer diameter;

Figure 11B shows the apparatus of Figure 11A returning to seal the inner tubular as the
5 varying outer diameter portion is extracted from the apparatus; and

Figure 12 shows the apparatus of Figure 10B fitted with an emergency closure pipe from below.

Detailed Description of Certain Embodiments

10 With reference to Figures 1 and 2, there is illustrated a dynamic annular sealing apparatus in accordance with a first embodiment of the present invention, in a closed and an open configuration, respectively. The apparatus comprises a hydraulic pump 1 and an annular resiliently deformable sleeve seal 2. The apparatus is shown in operation, with a drill string 3 extending through the opening (i.e. bore) of the seal 2.

15

Figure 1 shows the seal 2 in a neutral position (i.e. without any external pressure differential), which takes the shape of a hyperboloid. In such a position, the centre of the seal 2 is shown in a relaxed state which, in this case, is arranged such that the seal 2 is in sealing contact with a desired minimum diameter drill string 3. However, in other
20 embodiments the seal 2 may be arranged such that in its relaxed states its centre is disposed part-way between the drillstring 3 and a surrounding housing 5, or it may be close to or adjacent the drill string or even providing an inwards force against the drill string 3.

25 The housing 5 in which the seal 2 is provided is cylindrical and, in this case, is provided in an expanded head of a wellbore 6. Each end 8 of the seal 2 is in sealing engagement with the housing 5 so as to define a cavity 7 between the outer longitudinal surface of the seal 2 and the housing 5. The pump 1 is connected to the cavity 7 by a fluid conduit 4 such that operation of the pump 1 may increase or
30 decrease the fluid pressure in the cavity 7 to thereby deform the seal 2.

The housing 5 comprises inwardly directed top and bottom flanges 9 to contain the seal 2 therein. As illustrated, the lower end 8 of the seal 2 is axially moveable within the housing 5 to accommodate deformation of the seal 2 such as when it is retracted to the
35 open configuration shown in Figure 2. In this particular embodiment, the seal 2 is

formed from rubber and the lower end 8 is vulcanised to a steel ring 10 slidably mounted in the housing 5. It should also be noted that in this particular embodiment, the seal 2 comprises embedded diamond pieces to mitigate material wear.

- 5 The pump 1 is connected to an ambient pressure hydraulic reservoir 11 via an inlet 12. Furthermore, an accumulator 13 is connected to the fluid conduit 4 to compensate for variations in the volume of the cavity 7 due to deformation of the seal 2.

10 A first pressure sensor 14 is provided in the fluid conduit and a second pressure sensor 15 is provided in the wellbore 6, downstream of the seal 2. Both pressure sensors 14, 15 are configured to communicate their respective pressure readings to a control system 16 which is provided on a surface rig (not shown). The control system 16 is configured to regulate the pump 1 to adjust the pressure in the cavity 7 and thereby adjust the sealing force and/or degree of opening of the sleeve, for example, to
15 maintain sealing contact with the drillstring 3 even as tools 17 of different diameter are feed through the apparatus. Further pressure sensors may also be also be incorporated, for example, to monitor the pressure upstream of the seal (e.g. in a riser).

20 As shown in Figure 1, the pressure exerted by the seal 2 on the drillstring 3 can be augmented by operating the pump 1 so as to provide above ambient pressure in the cavity 7. In this way, the apparatus can be used to seal the annulus between the housing 5 and the drillstring 3 to thereby retain a desired pressure in the wellbore 6.

25 As shown in Figure 2, operating the pump 1 so as to provide below ambient pressure in the cavity 7 will force the centre of the seal 2 to deform and retract towards the housing 5, allowing full access to the wellbore 6. Typically, 18 $\frac{3}{4}$ inch (approximately 0.48m) blowout preventors are employed and in such cases the inner diameter of the seal 2 in the open position will be configured to be at least 18 $\frac{3}{4}$ inches (approximately 0.48m).

30 It will be noted that the seal 2 illustrated is relatively short and wide in its closed sealing configuration (Figure 1) and becomes relatively tall and narrow in its open non-sealing configuration (Figure 2). However, other shapes of seals and other types of deformation are also contemplated.

35 With reference to Figure 3A, there is illustrated a portion of a tubular net 110 in

accordance with an embodiment of the present invention, in both an expanded configuration 112 and a contracted configuration 114. The net 110 comprises a multiplicity of resiliently deformable steel segments 116 interconnected by means of flexible joints 118. As will be illustrated in later figures, the net 110 will be partially
5 embedded in a rubber sleeve to form a sealing apparatus in accordance with a second embodiment of the present invention.

Each segment 116 of the net 110 is coupled at each of its ends to a set of neighbouring segments 116 by a bolt 120. As shown in Figure 3A, intermediate segments 116 of the
10 net 110 are coupled at each end to three neighbouring segments 116 so as to form a series of flexible quadrilateral elements 122.

In the expanded configuration 112, the segments 116 are each spaced relatively far apart such that the quadrilateral elements 122 are relatively short and wide. However,
15 in the contracted configuration 114, the segments 116 are each spaced relatively close together such that the quadrilateral elements 122 are relatively tall and narrow. Similarly, the net 110 as whole is relatively short and wide in its expanded configuration 112 and becomes relatively tall and narrow in its contracted configuration 114.

As illustrated in Figure 3B, each segment 116 is substantially planar in its undeformed state, with the plane of each segment 116 extending radially with respect to the tubular structure of the net 110. In addition, a first end of the segment 116 is provided with a first coupling 124 and a second end of the segment 116 is provided with a second
20 coupling 126.

25 The first and second couplings 124, 126 are configured to engage with one another so that, as shown in Figure 3C, the second coupling 126 of one segment 116 can engage with the first coupling 124 of another segment 116 and the bolt 120 can pass through the engaged first and second couplings 124, 126 to hingably connect the two segments
30 116 together. Notably, the hinged joints 118 have an axis of rotation which is substantially radially aligned with respect to the tubular structure of the net 110. However, it will be understood that the couplings 124, 126 shown in Figures 3B and 3C are simplified for illustrative purposes since, as drawn, they are only able to connect to one other segment while, in reality, at least one end of each segment 116 must
35 connect to three other segments as shown in Figure 3A. Also, in certain embodiments,

two aligned segments 116 need not be hinged together as shown in Figure 3C. However, in such a case, the two aligned segments must be hinged at their centre to two crossing aligned segments. In other words, each of the two continuous lines forming an "X" in the net 110 may be stiff/not hinged, but the two lines themselves must be hinged to each other allowing the angle between the two lines to change unstrained.

Figure 4A illustrates a tubular net 110 similar to that shown in Figure 3A, provided around an inner tubular 130. Thus, it can be seen that, in use, each of the segments 116 will be deformed so as to allow the net 110 to encircle the inner tubular 130. More specifically, as shown in Figure 4B for a specific segment 116A (which is curving downwardly from left to right in Figure 4A), each segment 116 will be subject to opposed twisting forces. Thus, for segment 116A the top of the first coupling 124 will be forced in a first direction 132, the bottom of the first coupling will be forced in an opposite, second direction 134, the top of the second coupling 126 will be forced in the second direction 132 and the bottom of the second coupling 126 will be forced in the first direction 134. Of course, the segments 116 curving from downwardly from right to the left in Figure 4B would be subject to opposite twisting forces to those illustrated in Figure 4B. Figure 4C shows the resulting deformation of the segment 116A of the net 110, when it is wrapped around the inner tubular 130.

It should be noted that the elastic deformation of each segment 116 of the tubular net 110 will increase as the diameter of the net 110 is increased and this will set up a force that will try to collapse the net 110 and which, in turn, will serve to seal the net 110 against the inner tubular 130.

Figure 5 shows a single deformed segment 116 in the form it would adopt when part of the net 110 is wrapped around the inner (hollow) tubular 130. As illustrated, the first and second couplings 124, 126 (through which the bolts 120 pass) each have an axis 136 which is perpendicular to the surface of the inner tubular 130. Consequently, the forces between each segment 116 will be evenly distributed and each segment 116 will adopt a shape having an underside 138 which follows the surface of the inner tubular 130 tangentially. It should be noted that the length of each segment 116 (or each set of two adjacent stiff segments) will be restricted by the need for each segment 116 to deform sufficiently so that it follows and seals against the circumference of the inner tubular 130.

As shown in Figures 6A and 6B, in a particular embodiment of the present invention the underside 138 is provided with a low friction polymer coating 140 (or a coating of another material) that exhibits low friction and low wear characteristics on the inner tubular 130 (which may comprise steel), and which has the ability to seal one side of the segment 116 from the other - Δp . It will be noted that the cross-sectional configuration of the polymer coating 140 shown in Figure 6B is for illustrative purposes only and other cross-sections may be employed to achieve the desired sealing effect.

Figure 7 illustrates the sealing capacity of the tubular net 110. In this particular embodiment, the sealing capacity of the net 110 is determined by the sum of the force provided by each circumferential band of segments 116 and the sealing capacity of each joint 118 is determined as twice the restoring force associated with a single segment 116. Thus, where the net 110 comprises six bands, each providing a pressure of 100 bar, the net 110 will have a total sealing capacity of 600 bar. Note, this means that each joint 118, as drawn in this illustration, needs to handle a Δp of 200bars (this can be seen by drawing a straight vertical line through the net along one set of nodes/joints 118 since this line will pass three quadrilateral elements 122 and $600/3=200$). As explained previously, the restoring forces experienced by each segment 116 will increase as the diameter of the net 110 is increased and so the sealing capacity will also increase accordingly.

Figures 8A through 8E illustrate the assembly and installation of an apparatus 150 according to an embodiment of the present invention. Thus, a tubular net 110 as described above is first formed from a multiplicity of resiliently deformable segments 116 interconnected by means of flexible joints 118, as shown in Figure 8A. The net 110 is then partially embedded within the inner surface of a sleeve 152 of elastically deformable vulcanised rubber, as shown in Figure 8B, to form the apparatus 150.

The apparatus 150 is then inserted (in a relaxed or collapsed state) into an outer tubular 160 which, in this case, is constituted by an expanded head of a wellbore as shown in Figure 8C. In order to insert a retainer pipe 162, as shown in Figure 8D, into the apparatus 150, it is necessary to expand at least the upper portion of the apparatus 150 as shown in Figure 8E. Although not shown, the apparatus 150 may be expanded by an expansion member in the form of a funnel which can be pulled through the

apparatus 150 allowing the retainer pipe 162 to follow the large end of the funnel such that the retainer pipe 162 is then partially inserted into the apparatus 150 so as to hold at least one end 164 of the apparatus 150 open for subsequent receipt of an inner tubular. The end 164 of the apparatus 150 may then be fixedly secured to the outer tubular 160 for subsequent operation. Alternatively, the retainer pipe 162 may be inserted into the apparatus 150 as a manufacturing step.

Figure 9A shows the apparatus 150 of Figures 8B to 8E in a stand-by mode with the retainer pipe 162 inserted along the entire length of the apparatus 150 such that the apparatus 150 is stretched and expanded against the inner surface of the outer tubular 160 and is thereby provided with potential energy ready for use. Notably, in stand-by mode, the inner surface of the retainer pipe 162 will surround the inner, usable portion of the wellbore at full bore width. Figure 9B shows the apparatus 150 in use whereby the retainer pipe 162 has been partially withdrawn to allow the apparatus 150 to contract around and seal against a smaller inner tubular 166 in the form of a drill string which is provided through the retainer pipe 162. As illustrated, any increase in external pressure due to a wellbore issue will enhance the sealing capacity of the apparatus 150 such that it will more tightly seal against the inner tubular.

It should also be noted that, in the partially expanded configuration of Figure 9B, the upper end of the apparatus 150 is brought into sealing contact with the inner surface of the outer tubular 160 thereby preventing flow from passing around the apparatus 150 in a vertical direction. In certain embodiments, the upper end of the apparatus 150 may be held or fixed in sealing contact with the outer tubular 160. In other embodiments, the sealing contact with the outer tubular 160 may be provided at the lower end of the apparatus 150, or part-way along its length. It will be understood that, as illustrated in Figure 9B, the apparatus 150 is primarily configured to seal against external pressure acting on the apparatus from below. In order to seal against external pressure from above, the apparatus 150 may be inverted such that the sealing contact with the outer tubular 160 is downstream of the high pressure area. Consequently, in order to seal against external pressure from both directions (above and below), two oppositely orientated sets of apparatus 150 may be provided with the sealing contact of each with the outer tubular 160 provided in the centre. Of course, the two sets of apparatus described could also be integrated in a single apparatus configured for external sealing contact at its centre.

As shown in Figures 10A and 10B, when the apparatus 150 is contracted around the inner tubular 166, gaps 168 are provided between the outer surface of the inner tubular 166 and the rubber 152 due to the partially exposed ends of the segments 116, which are provided with the polymer coating 140. Thus, there is low friction between the apparatus 150 and the inner tubular 166 making it much easier to manoeuvre and rotate the inner tubular 166 within the apparatus 150.

Figure 11A shows the apparatus of Figure 10B adapted to seal around an inner tubular 170 having a varying outer diameter. More specifically, the retainer pipe 162 has been partially withdrawn to expose the apparatus 150 to the inner tubular 170 which comprises a radially expanded portion 172 part-way along its length. Notably, the apparatus 150 has adapted to expand around the portion 172 but is still contracted around the remaining narrow regions of the inner tubular 170 to completely seal against the inner tubular 170. Figure 11B shows the apparatus 150 returning to seal a narrow region of the inner tubular 170 as the expanded portion 172 is extracted from the apparatus 150. Accordingly, it will be clear that the apparatus 150 can easily adapt to different outer diameters (such as may be encountered with wellbore tooling) while continuously and firmly tightening around the tool surface and returning to a desired outer diameter when required. Notably, this process is reversible such that Figure 11B can also be interpreted to show how the apparatus 150 would behave when the larger portion 172 of the drill pipe is on its way upwards expanding the lower end of the apparatus 150.

In the event of an emergency situation, the apparatus 150 can be locked in place by providing an emergency closure pipe 180 forced around the apparatus 150 from below, as shown in Figure 12. The emergency closure pipe 180 in this example is constituted by a hollow steel pipe having an inwardly tapering (i.e. funnelled) leading edge 182 which forces the apparatus 150 inwardly such that the apparatus 150 adopts an outer diameter which matches the inner diameter of the emergency closure pipe 180.

As mentioned previously, the net 110 can ensure no contact between the inner tubular 170 and the rubber 152 so that friction is low and, in certain embodiments, a metal-to-metal seal can be provided, in particular, where a metal funnel (e.g. constituted by the emergency closure pipe 180) is used to lock the seal.

It will be appreciated by persons skilled in the art that various modifications may be made to the above embodiments without departing from the scope of the present invention, as defined by the claims.

CLAIMS:

- 5 1. A dynamic annular sealing apparatus comprising: a resilient sleeve deformable between a closed sealing configuration and an open non-sealing configuration; and a pump controllable to effect such deformation by alteration of pressure exerted on the sleeve.
- 10 2. The sealing apparatus according to claim 1 wherein the pump is controllable to provide suction below ambient pressure to deform the sleeve into the open non-sealing configuration.
- 15 3. The sealing apparatus according to either preceding claim configured for use in a borehole or drilling riser application.
- 20 4. The sealing apparatus according to either preceding claim wherein the sleeve is biased towards the closed sealing configuration.
- 25 5. The sealing apparatus according to any preceding claim wherein the sleeve is constituted by a waisted annular band (hyperboloid) having a smaller inner diameter at its centre and a larger inner diameter at each end.
- 30 6. The sealing apparatus according to any preceding claim wherein the pump is arranged to provide above ambient pressure to increase the sealing force of the sleeve in the closed configuration.
7. The sealing apparatus according to any preceding claim wherein the pump is controllable to adjust the physical force applied by the sleeve to an inner tubular and, in doing so, the sleeve may remain in sealing contact with the inner tubular even when the diameter of the inner tubular changes.
8. The sealing apparatus according to any preceding claim wherein the sleeve is provided within a cylindrical housing having inwardly directed top and bottom flanges to contain the sleeve therein.

9. The sealing apparatus according to claim 8 wherein each end of the sleeve is in sealing engagement with the housing so as to define a cavity between the outer longitudinal surface of the sleeve and the housing.
- 5 10. The sealing apparatus according to claim 9 wherein the pump is connected to the cavity by a fluid conduit such that operation of the pump may increase or decrease the fluid pressure in the cavity and thereby deform the sleeve.
- 10 11. The sealing apparatus according to any one of claims 8 to 10 wherein at least one end of the sleeve is axially moveable within the housing to accommodate deformation of the sleeve.
12. The sealing apparatus according to claim 10 wherein the at least one end of the sleeve is fixed to a ring configured for axial movement within the housing.
- 15 13. The sealing apparatus according to any preceding claim wherein the pump is connected to a hydraulic reservoir via an inlet.
- 20 14. The sealing apparatus according to claim 13 wherein the hydraulic reservoir is balanced to ambient pressure.
15. The sealing apparatus according to any preceding claim wherein at least one pressure sensor is provided.
- 25 16. The sealing apparatus according to claim 15 wherein the at least one pressure sensor is in communication with a control system configured to regulate the pump to adjust the pressure exerted on the sleeve and thereby adjust the sealing force and/or degree of opening of the sleeve.
- 30 17. The sealing apparatus according to claim 15 or 16 wherein the at least one pressure sensor is provided in the fluid conduit and/or borehole.
- 35 18. The sealing apparatus according to claim 9 wherein an accumulator is provided to compensate for variations in the volume of the cavity due to deformation of the sleeve.

19. The sealing apparatus according to any preceding claim wherein the sleeve is formed of polymeric material, elastomeric material or rubber.
- 5 20. The sealing apparatus according to any preceding claim wherein the sleeve comprises material to mitigate wear.
21. The sealing apparatus according to claim 21 wherein the material to mitigate wear is fully or partially embedded in the sleeve.
- 10 22. The sealing apparatus according to claim 21 or claim 22 wherein the material to mitigate wear comprises fine grade hard or plastic material.
23. The sealing apparatus according to claim 1 wherein a retainer pipe is at least partially inserted into the sleeve so as to hold at least one end of the sleeve open.
- 15 24. The sealing apparatus according to any preceding claim configured for sealing an annular space between concentrically arranged tubulars.
- 20 25. The sealing apparatus according to any preceding claim wherein at least partially embedded within the sleeve is a tubular net formed by a multiplicity of resiliently deformable segments interconnected by means of flexible joints.
- 25 26. The sealing apparatus according to claim 25 wherein the flexible joints are configured to allow the segments to fold over each other when the apparatus is in the closed configuration and to lever the segments apart when the apparatus is in the open configuration.
- 30 27. The sealing apparatus according to claim 25 or claim 26 wherein the segments are interconnected by way of hinged joints having axes of rotation which are substantially radially aligned with respect to the sleeve.
- 35 28. The sealing apparatus according to any one of claims 25 to 27 wherein each segment of the net is coupled at each of its ends to a set of neighbouring

segments by a bolt having an axis aligned substantially radially with respect to the sleeve.

5 29. The sealing apparatus according to claim 28 wherein intermediate segments of the net are coupled at each end to three neighbouring segments.

30. The sealing apparatus according to any one of claims 25 to 29 wherein the net comprises a series of flexible quadrilateral elements.

10 31. The sealing apparatus according to any one of claims 25 to 30 wherein the segments comprise metal.

15 32. The sealing apparatus according to any one of claims 25 to 31 wherein each segment is substantially planar in its undeformed state, such that when the apparatus is expanded the segments are deformed, resulting in a radially inward force being exerted by the apparatus.

33. The sealing apparatus according to any one of claims 25 to 32 wherein the segments are formed of metal rope or the like.

20 34. The sealing apparatus according to any one of claims 25 to 33 wherein radially inwardly facing surfaces of the segments are exposed and project from the sleeve so that, in use, these surfaces of the segments come into contact with an inner tubular inserted therein.

25 35. The sealing apparatus according to claim 34 wherein the surfaces are provided with a relatively low friction coating to facilitate insertion and rotation of the inner tubular within the apparatus.

30 36. The sealing apparatus according to claim 35 wherein the coating comprises a ceramic and/or a polymer.

35 37. The sealing apparatus according to any preceding claim configured to have an outer diameter which can flex from at least 6.625 inches (approximately 0.19m) to at least 18.75 inches (approximately 0.48m).

38. The sealing apparatus according to any preceding claim configured for use with a rotating inner tubular.

5 39. The sealing apparatus according to any one of claims 1 to 37 configured for use with a non-rotating inner tubular.

40. A method of installing an apparatus for sealing an annular space between concentrically arranged tubulars, the method comprising:

10 providing the apparatus according to any one of claims 25 to 39 within an outer tubular;

expanding the sleeve for receipt of a retainer pipe; and

inserting the retainer pipe at least partially into the sleeve so as to hold at least one end of the sleeve open for subsequent receipt of an inner tubular.

15

41. The method according to claim 40 wherein an expansion member is employed to expand the sleeve for receipt of the retainer pipe.

20 42. The method according to claim 40 or 41 wherein the retainer pipe is arranged to expand along the entire length of the sleeve.

43. The method according to any one of claims 40 to 42 wherein the retainer pipe is fully or partially withdrawn from within the sleeve once the inner tubular is inserted.

25

44. The method according to any one of claims 40 to 43 wherein the retainer pipe is constituted by a full bore pipe section which allows full access to the bore when the sleeve is not required.

30 45. The method according to any one of claims 40 to 44 wherein the inner tubular comprises a drill string.

46. A method of manufacturing an apparatus for sealing an annular space between concentrically arranged tubulars, the method comprising:

assembling a tubular net formed by a multiplicity of resiliently deformable segments interconnected by means of flexible joints; and

at least partially embedding the net within a sleeve of elastically deformable material.

5

47. The method of claim 46 wherein the elastically deformable material comprises rubber.

10

48. A method of installing an apparatus for sealing an annular space between concentrically arranged tubulars, substantially as hereinbefore described with reference to the accompany drawings.

15

49. A method of manufacturing an apparatus for sealing an annular space between concentrically arranged tubulars, substantially as hereinbefore described with reference to the accompany drawings.

50. A dynamic annular sealing apparatus substantially as hereinbefore described with reference to the accompany drawings.

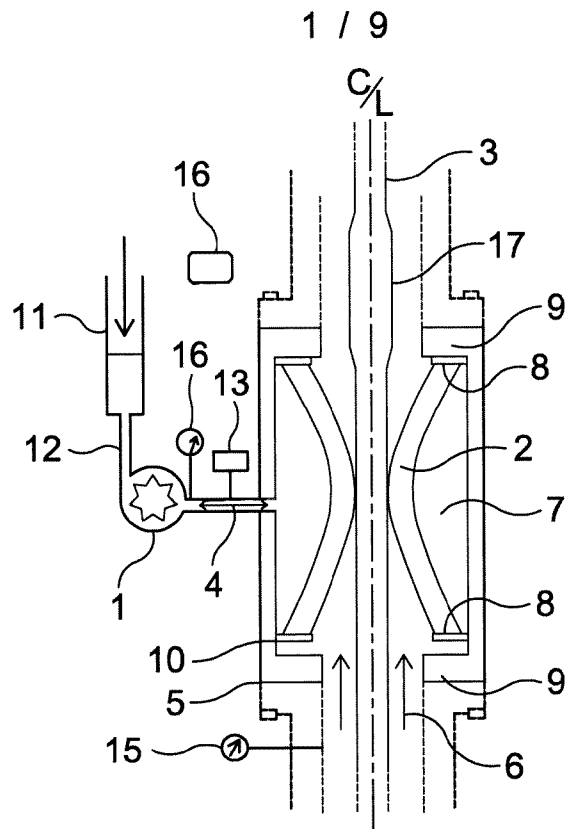


FIG. 1

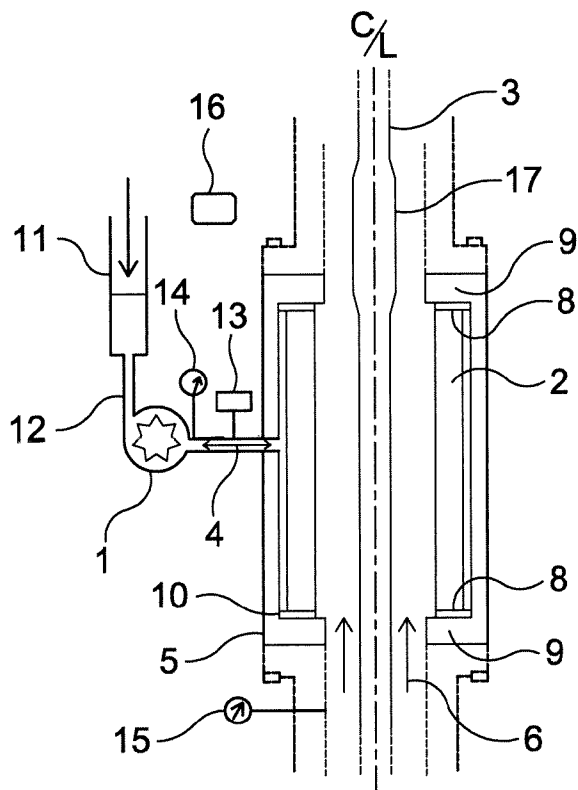
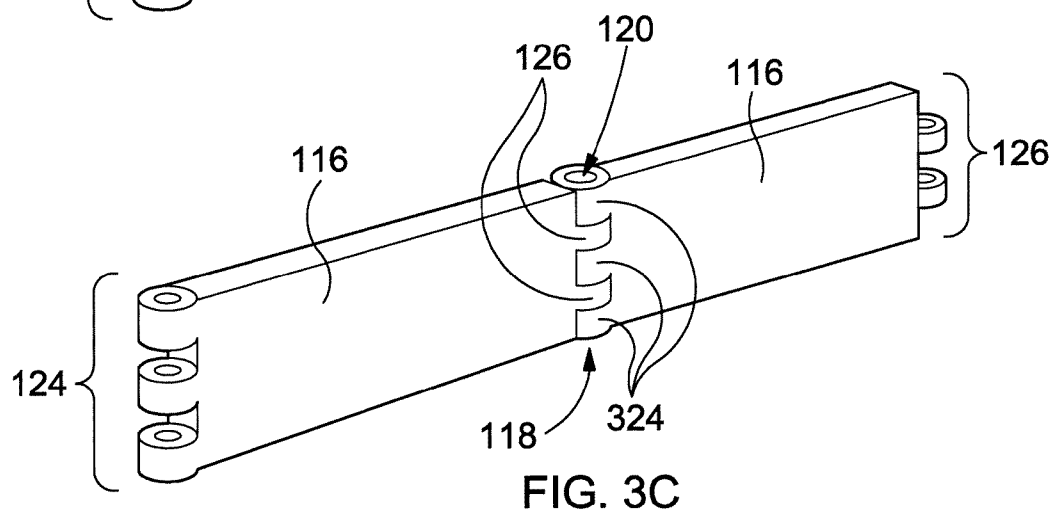
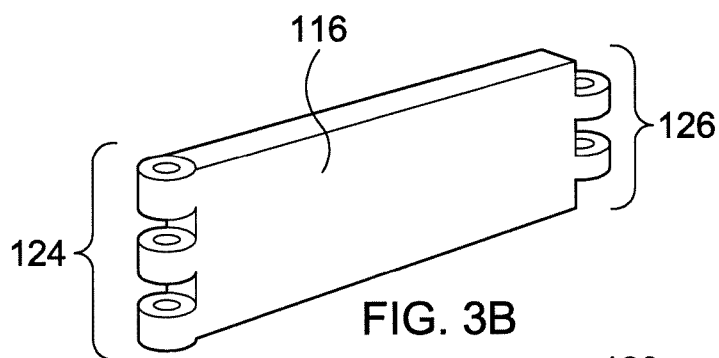
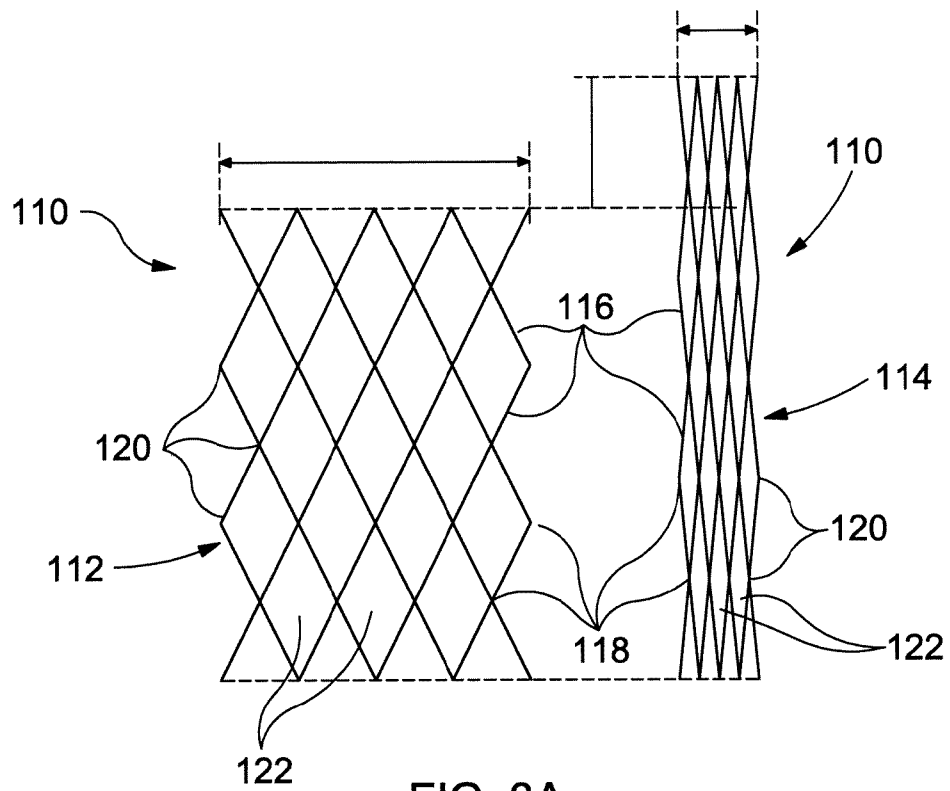


FIG. 2

2 / 9



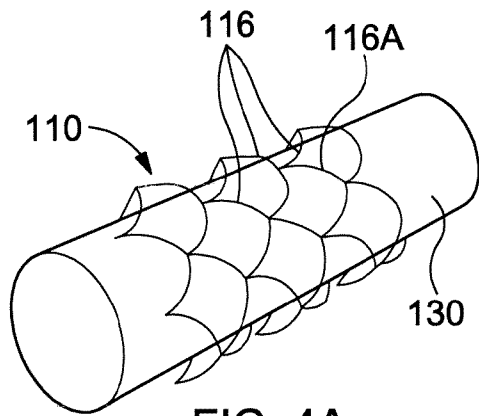


FIG. 4A

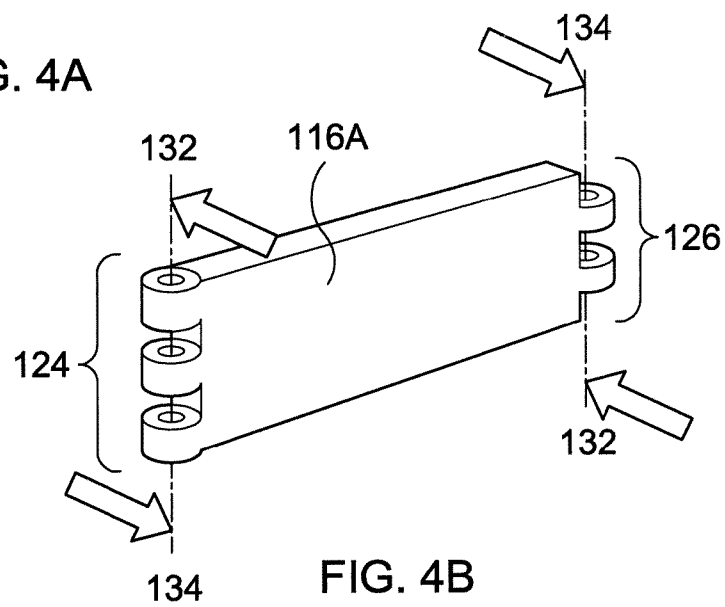


FIG. 4B

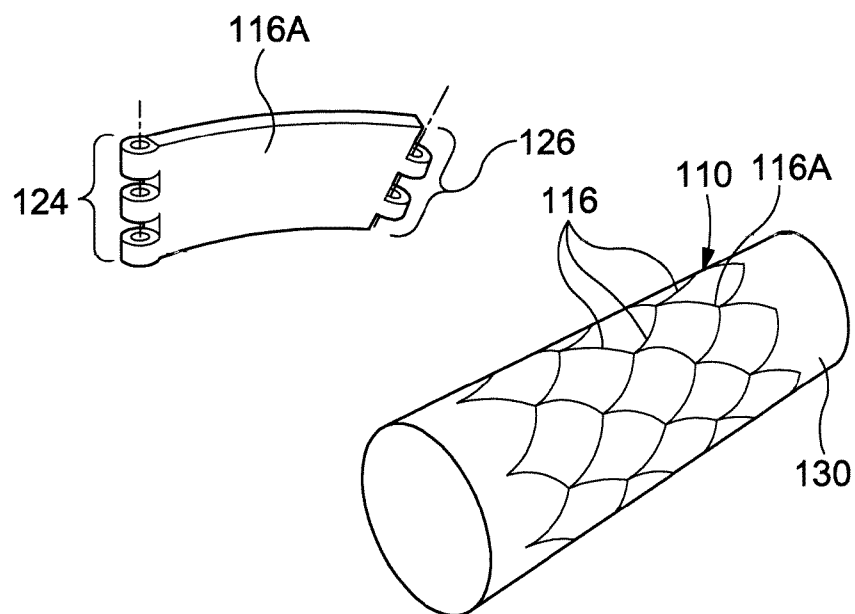


FIG. 4C

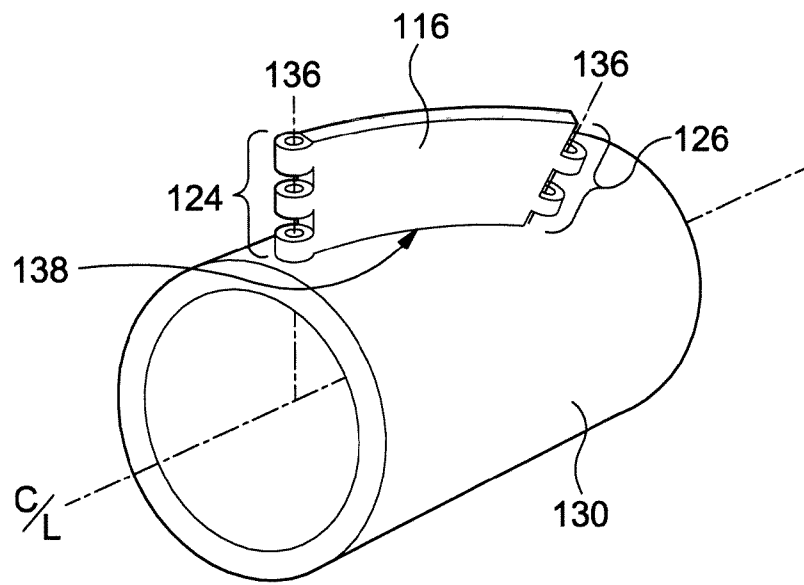


FIG. 5

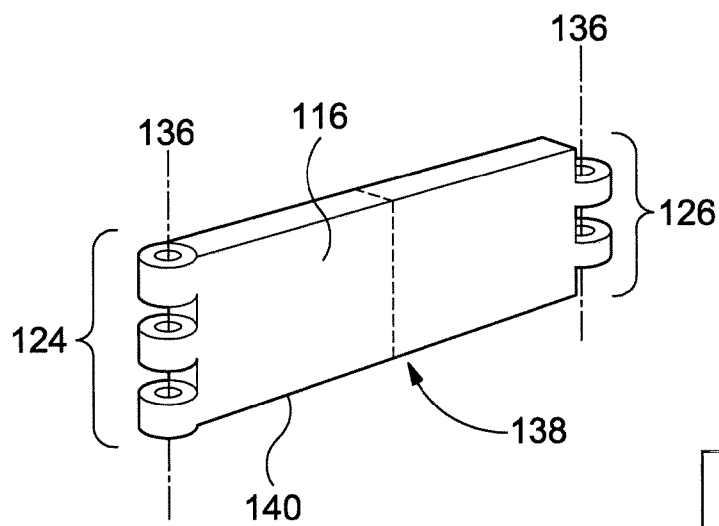


FIG. 6A

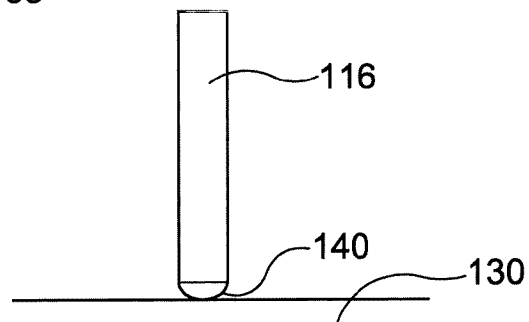


FIG. 6B

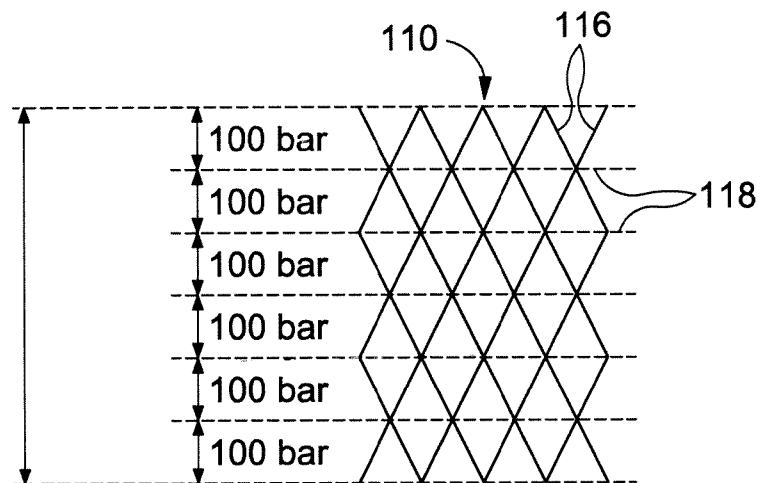


FIG. 7

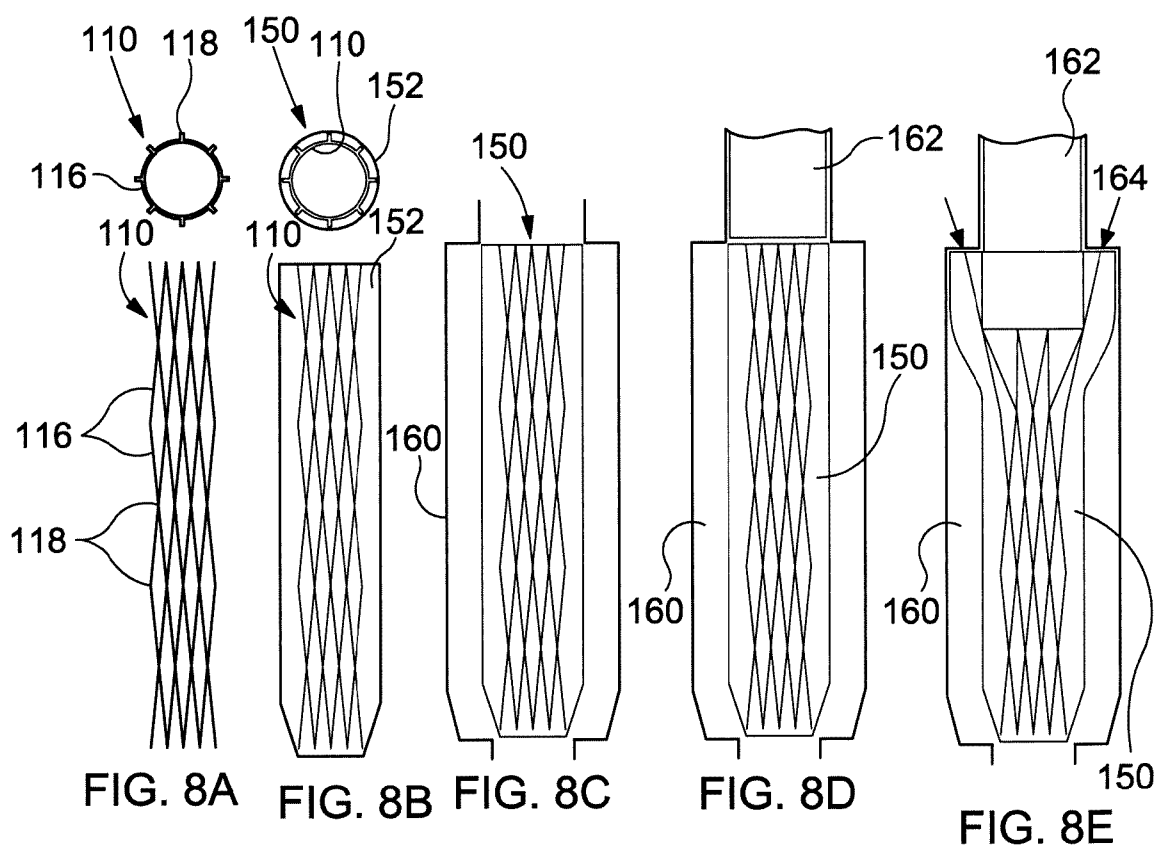


FIG. 8A

FIG. 8B

FIG. 8C

FIG. 8D

FIG. 8E

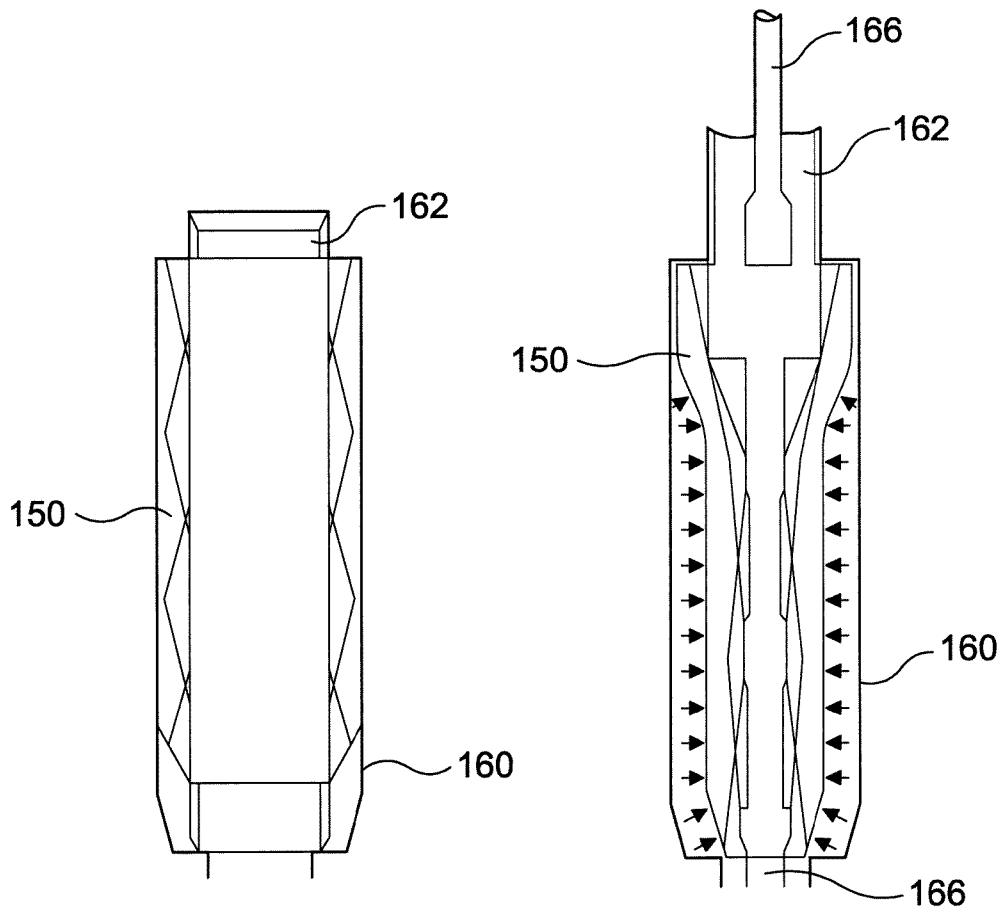
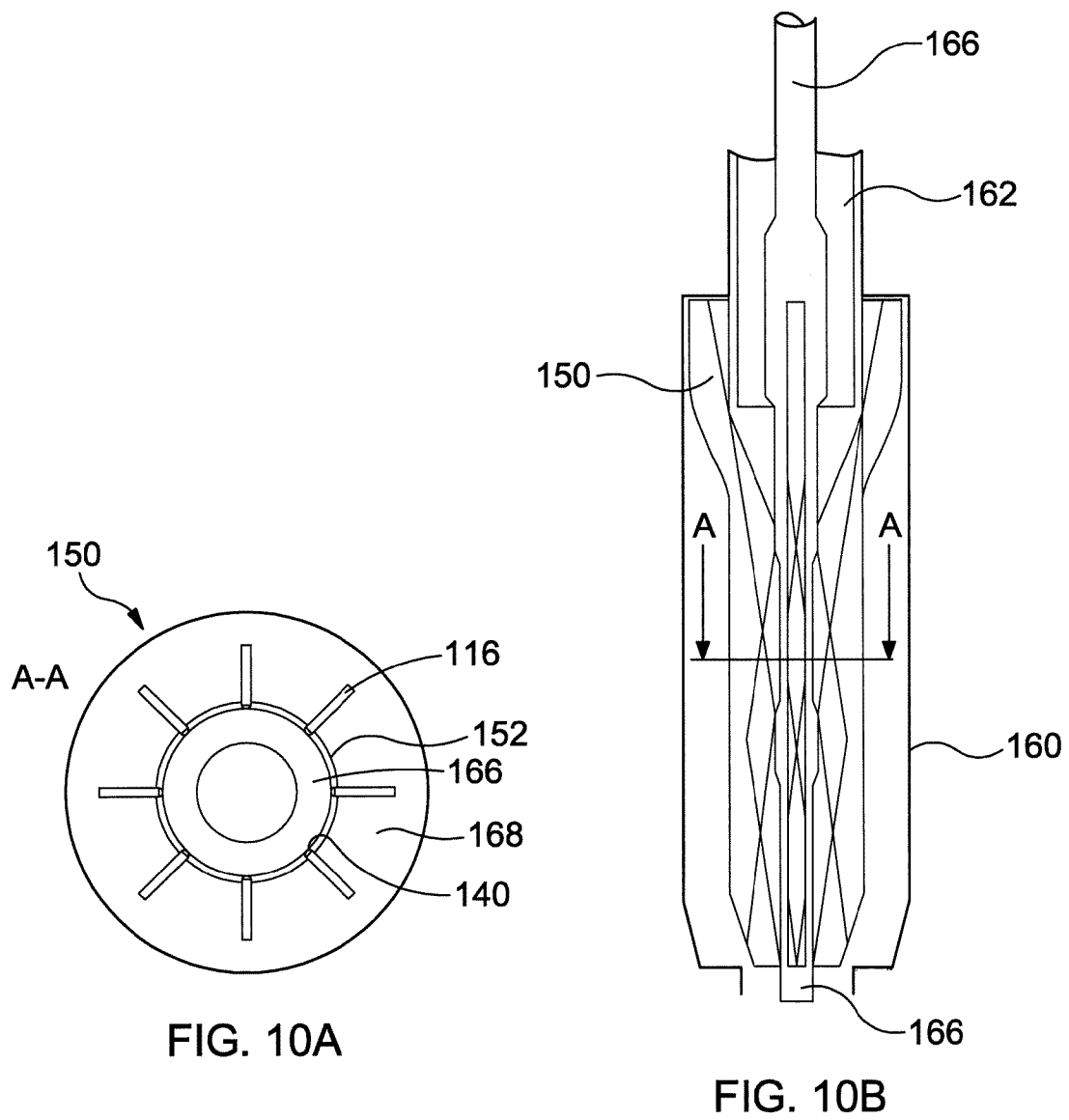


FIG. 9A

FIG. 9B



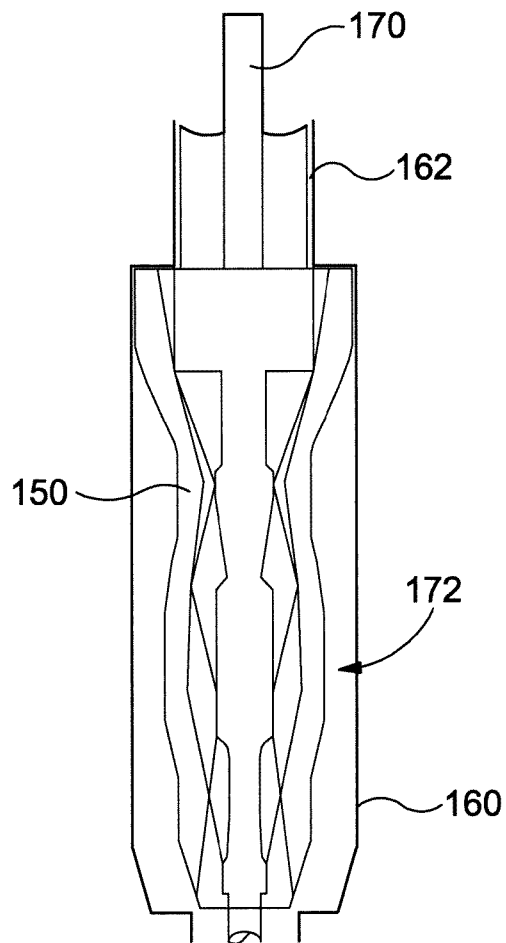


FIG. 11A

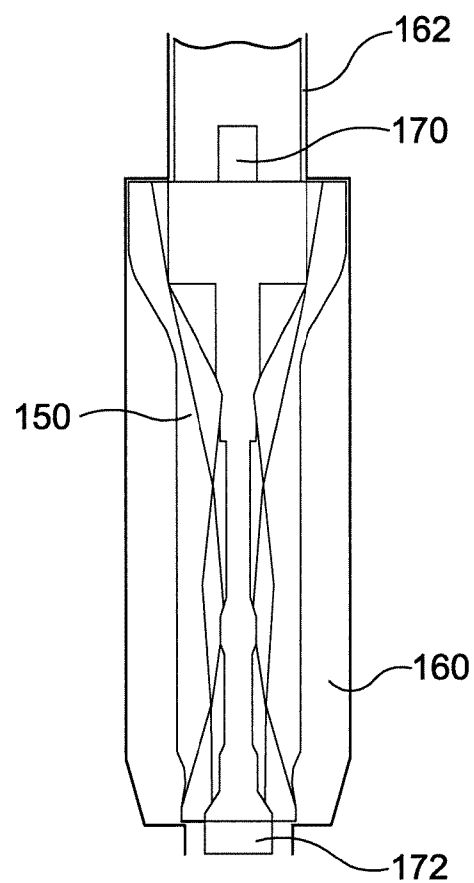


FIG. 11B

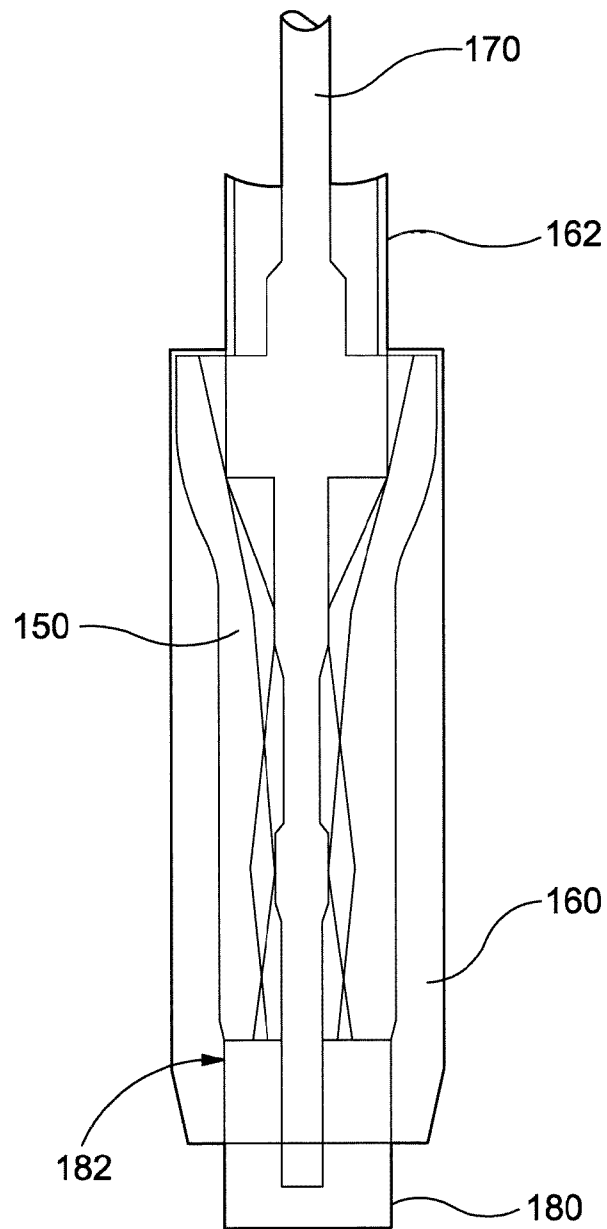


FIG. 12