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(54) **DOWNHOLE PLUG**

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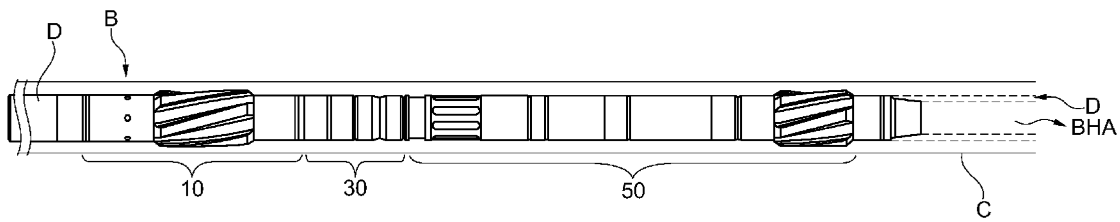
(57) **ABSTRACT**

A downhole plug for plugging and method of controlling fluids within a borehole in an oil and/or gas well. The downhole plug has a body having a throughbore for the passage of fluids. The plug also has a mechanical anchoring device that can radially expand an anchoring member on an outer surface of the body to lock the body in a fixed axial position within the borehole and an annular sealing device that can radially expand a sealing member on the outer surface of the body to seal an annulus formed between the outer surface of the body and an inner surface of the borehole. The plug also has a throughbore plugging device that can change configuration between a first open configuration in which the throughbore of the body permits the passage of fluid, and a second closed configuration in which the throughbore resists the passage of fluid.



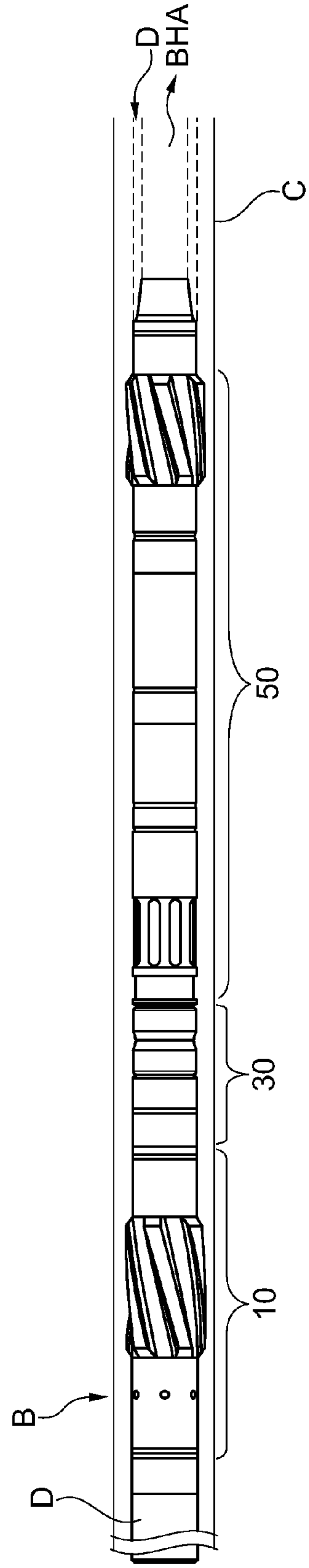


Fig. 1

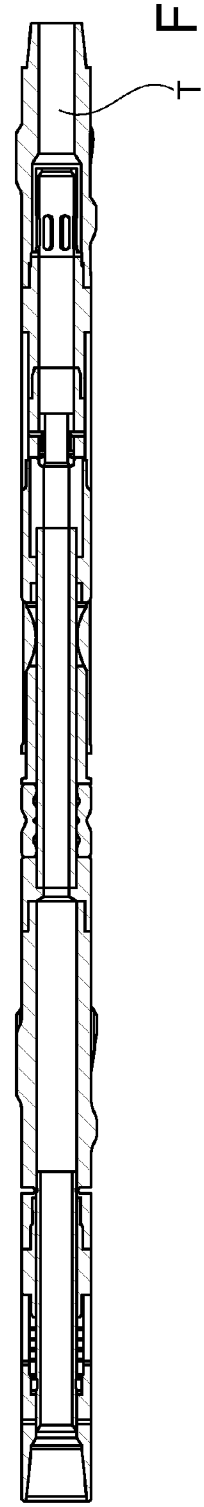


Fig. 2

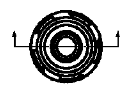


Fig. 3

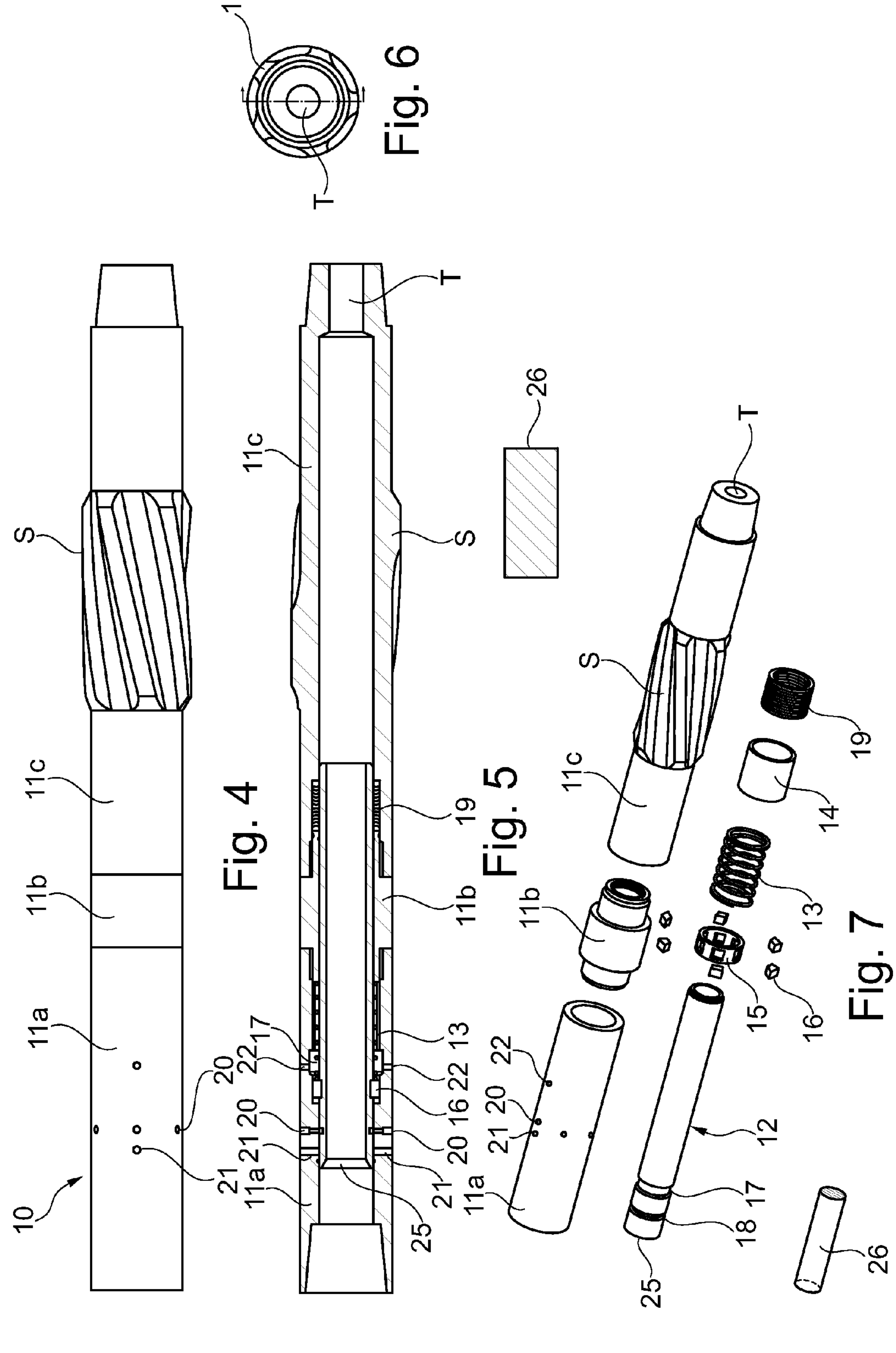


Fig. 4

Fig. 5

Fig. 6

Fig. 7

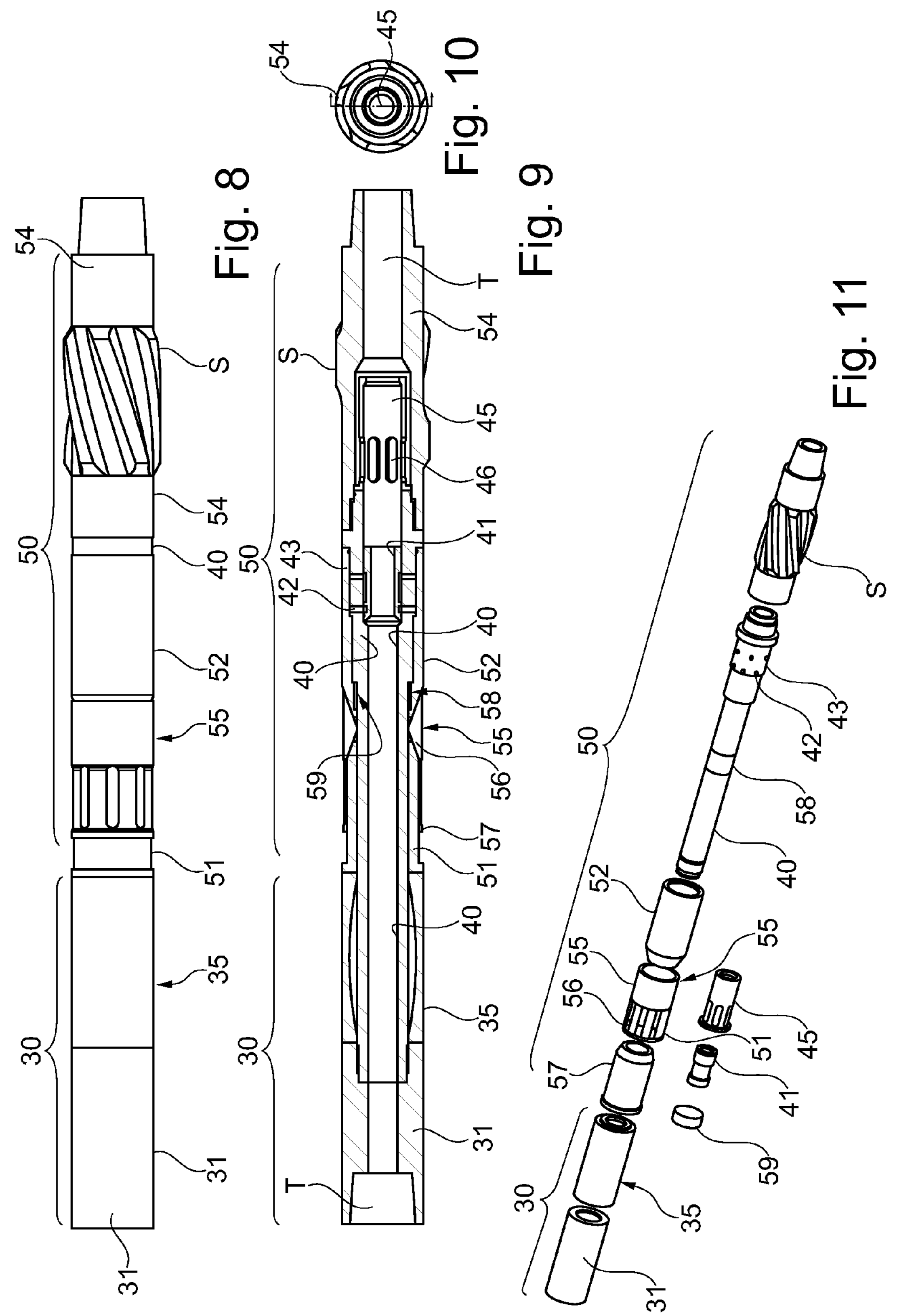


Fig. 8

Fig. 9

Fig. 10

Fig. 11

DOWNHOLE PLUG

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of Great Britain patent application number 1206381.4 filed on 11 Apr. 2012, the disclosure of which is hereby incorporated by reference.

RELATED ART

[0002] 1. Field of Invention

[0003] This invention relates to an apparatus and method for the control of fluids in an oil and/or gas well, typically in the form of a downhole plug used to close the wellbore.

[0004] 2. Brief Discussion of Related Art

[0005] The production of oil and/or gas from a downhole well involves drilling of a borehole through a formation containing production fluids, typically oil or gas, to be recovered through the borehole. As is known in the art, the upper lengths of borehole are drilled and then typically cased with a tubular casing cemented in place to prevent inward collapse of the walls of the borehole. Drilling operations then resume using a narrower diameter drill bit deployed through the casing, which drills a further length of the borehole into the formation below the casing. Sequential radial steps in the inner diameter of the borehole can be formed in this manner, until the production zone of the reservoir is reached, and the production fluids can be recovered using a production string of tubulars deployed through the radially stepped central bore of the casing.

[0006] Reservoir fluids to be produced from the well are normally pressurised, and it is known to use drilling fluid to control sudden pressure changes in the borehole during drilling. Drilling fluid (also sometimes called drilling mud) usually comprises a dense liquid, which helps to contain the reservoir fluids within the borehole, and has many other functions, such as lubricating the bit, and washing entrained cuttings back to surface. Typical simple drilling fluids can include water, but often drilling fluids are highly engineered fluids with a high density designed to resist blowouts and other undesirable pressure changes as the drillbit cuts through the formation.

[0007] Sometimes the drillbit cutting through the formation to create a new borehole encounters cavities in the formation. These cavities can present significant challenges for well control, particularly affecting the practice of pumping well control fluids such as drilling fluid through the drillstring in order to control wellbore pressures. Certain large cavities have such a high volume that the drilling fluid pumped into them simply flows away from the borehole through the cavity or is otherwise lost from the borehole, and is then ineffective to control the wellbore pressure changes, and to perform its other functions. Without reliable pressure control, such a well often has to be plugged and abandoned, and an alternative path must be drilled, typically by side-tracking out of the existing borehole above the cavity.

[0008] Embodiments of the present invention typically provide a wellbore plugging tool and a method for plugging a wellbore.

INTRODUCTION TO THE INVENTION

[0009] According to the present invention, there is provided a downhole plug for plugging a borehole in an oil or gas well, the downhole plug comprising:

[0010] a body having a throughbore adapted to permit the passage of fluids through the throughbore;

[0011] a mechanical anchoring device adapted to radially expand an anchoring member on the outer surface of the body, to lock the body in a fixed axial position within the borehole;

[0012] an annular sealing device adapted to radially expand a sealing member on the outer surface of the body, to seal an annulus formed between the outer surface of the body and the inner surface of the borehole; and

[0013] a throughbore plugging device adapted to change configuration between a first open configuration, in which the throughbore of the body of the tool permits the passage of fluid, and a second configuration in which the throughbore resists passage of fluid.

[0014] Typically the body has a central axial throughbore, and has upper and lower connections at opposite ends of the body, communicating with the throughbore, and adapted to connect the body to a string of tubulars within the well. Typically the downhole plug is run within a drillstring, above a bottom hole assembly, and typically within a cased borehole. Typically the body is adapted to operate within conventional sizes of casing, for example casing with an outer diameter (OD) of 9⅝ inch, 7 inch and 5-5½ inch.

[0015] The downhole plug may be referred to as a tool.

[0016] Typically the mechanical anchoring device is provided on the outer surface of the body of the tool, and is adapted to expand the anchoring member radially into contact with the inner surface of the casing in which the tool is being run. Typically the outer surface of the mechanical anchoring device has gripping formations adapted to grip the inner surface of the casing and resist axial movement of the body of the tool when the mechanical anchoring device is engaged. Typically the gripping formations can comprise teeth, or other abrasive or high friction formations or materials, which bite into the inner surface of the borehole, typically into the inner surface of the casing.

[0017] Typically the mechanical anchoring device comprises one or more wedge devices typically in the form of slips or the like having tapered surfaces adapted to expand the radial dimensions of the anchoring member as a result of relative axial movement of the slips. Typically the slips are moved axially by an actuator of the mechanical anchoring device that moves axially relative to the body of the tool, and which typically takes the form of a piston. Typically the mechanical anchoring device comprises pairs of opposed slips, typically having opposed tapers on upper and lower axial facing surfaces of the anchoring member. The anchoring member is typically in the form of a grapple device having collet fingers attached to the mechanical anchoring device in a cantilever manner, allowing the free ends of the fingers to move radially outwards from the axis of the body into contact with the inner surface of the borehole. Typically the other ends of the fingers are connected by a ring. Typically the mechanical anchoring device resists axial movement of the body of the tool in both axial directions across the device. Typically the mechanical anchoring device is adapted to expand as a result of axial force in either direction.

[0018] Typically the annular sealing device comprises a resilient sleeve adapted to radially expand on an outer surface of the body, typically as a result of axial movement of an actuator relative to the resilient sleeve. Typically the resilient sleeve seals against the inner surface of the casing, substantially preventing fluid flow through the annulus between the inner surface of the casing and the outer surface of the body.

[0019] Typically the annular sealing device is actuated by an actuating mechanism which changes the configuration of the annular sealing device between a first configuration, in which the resilient sleeve is radially unexpanded and does not engage the walls of the borehole, and a second configuration, in which the resilient sleeve has radially expanded to seal between the inner surface of the borehole (e.g. the casing) and the outer surface of the body. Typically the actuator mechanism causes axial sliding of different body parts relative to one another between the first and second configurations, typically compressing the ends of the resilient sleeve together, and causing the outward radial expansion of the resilient sleeve. Typically the annular sealing device is activated by setting weight down on the body from the surface, and can be de-activated by picking up weight on the body. Typically the annular sealing device resists fluid passage within the annulus in both directions across the device. Typically the annular sealing device is adapted to expand as a result of axial force in either direction.

[0020] Typically the annular sealing device is moved from the radially unexpanded configuration to its radially expanded sealing configuration by setting weight down on the tool after the mechanical anchoring device has been activated and the body is locked in a fixed axial position within the borehole.

[0021] Typically the throughbore plugging device comprises a plugging member adapted to engage on a seat within the throughbore in the body. Typically, the throughbore plugging device has a sealing arrangement, typically in the form of an annular seal set in the inner surface of the throughbore adjacent to the seat, typically above the seat, and typically arranged such that when the throughbore plugging member is engaged with the seat, it is sealed against the annular sealing member in order to close the throughbore, and resist fluid passage through the throughbore. Typically the throughbore plugging device substantially prevents fluid passage through the throughbore of the body. Typically the throughbore plugging device resists fluid passage through the throughbore in both axial directions across the device.

[0022] The invention also provides a method of controlling fluids within a borehole of an oil or gas well, the method comprising:

[0023] providing a well control device having a body with a throughbore for fluid passage through the body, a mechanical anchoring device for anchoring the body in a fixed axial position within the borehole, an annular sealing device for sealing the annulus between the body and the borehole and a bore plugging device for closing the fluid pathway through the body, wherein the method comprises:

[0024] running the body into the borehole;

[0025] activating the mechanical anchoring device in order to fix the body in the borehole and resist axial movement of the body within the borehole;

[0026] activating the annular sealing device to seal the annulus between the outer surface of the body and the inner surface of the borehole, thereby substantially resisting passage of fluid within the annulus passed the annular sealing device; and

[0027] plugging the bore through the body to resist fluid passage through the bore.

[0028] The mechanical anchoring device may comprise an anchoring member on an outer surface of the body and the borehole may have an inner surface. The step of activating the annular sealing device may include sealing the annulus between the outer surface of the body and the inner surface of the borehole.

[0029] The annular sealing device may be moved from a radially unexpanded configuration to a radially expanded sealing configuration by setting weight down on the well control device after the mechanical anchoring device has been activated and the body is locked in a fixed axial position within the borehole.

[0030] The step of activating the mechanical anchoring device includes expanding the mechanical anchoring device.

[0031] The various aspects of the present invention can be practiced alone or in combination with one or more of the other aspects, as will be appreciated by those skilled in the relevant arts. The various aspects of the invention can optionally be provided in combination with one or more of the optional features of the other aspects of the invention. Also, optional features described in relation to one embodiment can typically be combined alone or together with other features in different embodiments of the invention.

[0032] Various embodiments and aspects of the invention will now be described in detail with reference to the accompanying figures. Still other aspects, features, and advantages of the present invention are readily apparent from the entire description thereof, including the figures, which illustrates a number of exemplary embodiments and aspects and implementations. The invention is also capable of other and different embodiments and aspects, and its several details can be modified in various respects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. Furthermore, the terminology and phraseology used herein is solely used for descriptive purposes and should not be construed as limiting in scope. Language such as "including," "comprising," "having," "containing," or "involving," and variations thereof, is intended to be broad and encompass the subject matter listed thereafter, equivalents, and additional subject matter not recited, and is not intended to exclude other additives, components, integers or steps. Likewise, the term "comprising" is considered synonymous with the terms "including" or "containing" for applicable legal purposes.

[0033] Any discussion of documents, acts, materials, devices, articles and the like is included in the specification solely for the purpose of providing a context for the present invention. It is not suggested or represented that any or all of these matters formed part of the prior art base or were common general knowledge in the field relevant to the present invention.

[0034] In this disclosure, whenever a composition, an element or a group of elements is preceded with the transitional phrase "comprising", it is understood that we also contemplate the same composition, element or group of elements with transitional phrases "consisting essentially of", "consisting", "selected from the group of consisting of", "including", or "is" preceding the recitation of the composition, element or group of elements and vice versa.

[0035] All numerical values in this disclosure are understood as being modified by "about". All singular forms of elements, or any other components described herein are understood to include plural forms thereof and vice versa.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] An embodiment of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

[0037] FIG. **1** shows a side view of a downhole plug in accordance with one embodiment;

[0038] FIG. **2** shows a side section view of the device of FIG. **1**;

[0039] FIG. **3** shows an end view of the FIG. **1** device;

[0040] FIG. **4** shows a side view of an upper part of the FIG. **1** device showing a throughbore plugging device for closing a bore of the FIG. **1** device;

[0041] FIG. **5** shows a sectional view of FIG. **4**;

[0042] FIG. **6** shows an end view of the FIG. **4** arrangement;

[0043] FIG. **7** shows an exploded view of the FIG. **4** arrangement;

[0044] FIG. **8** shows a side view of the lower part of the FIG. **1** device, comprising a mechanical anchoring device and annular sealing device;

[0045] FIG. **9** shows a side sectional view of FIG. **8**;

[0046] FIG. **10** shows an end view of FIG. **8**; and

[0047] FIG. **11** shows an exploded view of FIG. **8**.

DETAILED DESCRIPTION

[0048] Referring now to the drawings, apparatus for controlling the flow of fluid in a borehole in the form of a downhole plug has a body B, provided with a throughbore T extending between opposite ends of the body B, the two ends of the body B having box and pin connectors as are known in the art for connecting the body B into a string of tubulars in an oil or gas well. Typically, the body B is connected within a drill string D, typically above a bottom hole assembly and drill bit, and is typically run into a wellbore within a casing string C, terminating at the lower end of the casing string with a casing shoe through which the drill string D is deployed. Typically the body B can have stabilisers and/or centralisers on its outer surface in order to space the body B away from the walls of the casing C. In the drawings, the upper end of the plug nearest the well head and the surface is shown on the left, and the lower end is shown on the right, closest to the bottom of the well, although the skilled person will understand that in deviated wells, the “upper” end can be at the same depth or physically deeper than the “lower” end as a result of deviation of the borehole, so the terms “up”, “down”, “upper” and “lower” refer the depth of penetration in the borehole, rather than the actual depth below the wellhead and similar terms should be interpreted accordingly.

[0049] The body B comprises a plug sub **10** comprising a throughbore plugging device, a seal sub **30** comprising an annular sealing device, and an anchor sub **50** comprising a mechanical anchoring device, all of which are sequentially arranged from an upper part of the body B to a lower part but, in other embodiments, the order of the subs **10**, **30**, **50** can be changed. At the upper end of the body B, the plug sub **10** has an outer housing **11** formed in three sections **11***a*, **11***b* and **11***c*, having screw thread connections between the end housing portions **11***a* and **11***c* and the central housing portion **11***b*, typically also allowing metal to metal seals to be formed between the housing portions. The assembled housing **11** has a throughbore T which houses a sliding sleeve **12** which is biased upwardly within the bore T by a spring **13** held in compression between an upwardly facing end of the central portion **11***b*, and the downwardly facing surface of a dog collar **15** disposed in the annulus between the outer surface of the sleeve **12** and the inner surface of the upper portion of housing **11***a*. The dog collar **15** has a series of circumferentially spaced recesses typically spaced substantially equidistantly around the circumference, and typically passing radially through the wall of the collar **15**, to receive dogs **16**, which are typically adapted to move radially outward from the collar to locate within an annular dog recess **17** in the outer surface of the sleeve **12**. Above the dog recess **17**, the sleeve **12** has a shear pin recess **18** adapted to receive the inner end of at least one shear pin **20** passing through the body of the upper portion **11***a* of the housing, which serves to keep the sleeve **12** fixed axially in the configuration shown in FIG. **5**, with the spring **13** held in compression between the dog collar **15** and the central portion **11***b* of the housing. Typically the shear pins **20** are arranged in pairs around the circumference.

[0050] At the other end of the central portion **11***b*, the lower portion **11***c* has a seal recess to house a chevron type seal **19** which is disposed (optionally in radial compression) between the inner surface of the housing portion **11***c*, and the outer surface of the sleeve **12**. Other types of seal can be used in other embodiments. Typically the seal **19** is radially compressed between the sleeve **12** and the housing portion **11***c*, and denies fluid passage within the annular space between the housing **11** and the sleeve **12**.

[0051] The lower portion **11***c* of the housing typically has a stabiliser S which is typically adapted to space the body of the plug B radially from the walls of the tubular casing.

[0052] The upper portion of the housing **11***a* has at least one radial port **21** passing through the wall of the housing **11***a* above the shear pins **20** connecting the throughbore T with the exterior of the plug body B. When the inner ends of the shear pins **20** are located within the shear pin recess **18**, the sleeve **12** is held in the position shown in FIG. **5**, in which the upper end of the sleeve **12** covers the ports **21**. Typically the annulus between the sleeve **12** and the housing **11** is sealed, for example by O-ring seals, located above the ports **21**, and by the seals **19** below them, in order to prevent fluid passing from the throughbore T through the ports **21** and reaching the exterior of the body B when the sleeve **12** is in the FIG. **5** position. The ports **21** can be circumferentially spaced around the body B, typically at a 180° spacing as shown in FIG. **5**.

[0053] The shear pins **20** can be typically circumferentially spaced around the body B, typically at substantially equidistant spacing around the circumference, or alternatively, in some configurations, some of the bores in axial alignment with the shear pin **20** can be formed as simple ports, to permit additional fluid communication between the throughbore T and the exterior of the tool.

[0054] Below the shear pins **20**, the wall of the upper portion **11***a* has an additional radial port **22** connecting the throughbore T with the exterior of the tool in the same way as the port **21**, and typically terminating on the inner surface of the housing portion **11***a* within a recess on the inner surface of the housing **11**.

[0055] The spring **13** typically has a spring sleeve **14** which surrounds the outer surface of the spring **13** within the annulus between the sleeve **12** and the upper housing portion **11***a*, in order to restrict the maximum compression of the spring **13**. In the FIG. **5** configuration, the upper housing portion **11***a* connects the sleeve **12** and the housing **11** by means of the shear pins **20**, so that the dogs **16** are pressed radially inwards into the recess **17** in the housing, thereby locking the collar **15** to the sleeve **12** in the FIG. **5** configuration. When the shear pins **20** are sheared as will be described below, the sleeve **12** is free to move axially downwards within the throughbore T, until the collar **15** abuts the upper edge of the spring sleeve **14**, and the dogs **16** are axially aligned with the recess on the inner surface of the housing, at which point the dogs **16** are free to move radially outwardly into the recess, and typically have ramped inner surfaces adapted to facilitate that radial movement, so that they move radially clear of the sleeve **12**, allowing continued downward axial movement of the sleeve **12** independently of the collar **15** within the throughbore T. Thus, upon shearing of the pins **20**, the sleeve **12** can move axially down the throughbore T to bottom out at the upwardly facing shoulder at the lower end of the lower portion **11***c*.

[0056] The upper end of the sleeve **12** has a seat **25** to receive and seat a throughbore sealing device such as a dart or cylinder which has a solid structure with no throughbore and is adapted to close of fluid communication within the throughbore T. The throughbore sealing device may be referred to as a plugging member. The dart **26** is adapted to engage on the seat **25** as will be described below and has an outer surface adapted to seal against the seal **19** when the sleeve **12** has bottomed out on the upwardly facing shoulder at the lower end of the lower portion **11***c*. The seal **19** may be an annular seal and may be set in an inner surface of the throughbore T, adjacent to the seat **25**.

[0057] Referring now to FIGS. **8** to **11**, a seal sub **30** and anchor sub **50** are connected below the lower portion **11***c* of the housing **11** of the plug sub **10**. The seal sub **30** and anchor sub **50** are shown in this embodiment as an interdependent assembly, but can typically also be provided as separate subs within the plug. The seal sub **30** comprises a housing **31** having an outer diameter that is continuous with that of the housing **11**, and having a throughbore T communicating with the throughbore T in the housing **11**. The lower end of the housing **31** has a flat shoulder abutted against a sealing member in the form of a resilient sleeve **35**. The resilient sleeve **35** is slid over the outer surface of an inner tubular mandrel that is connected to the lower surface of the housing **31** by means of a screw thread connection and typically by seals so that the housing **31** and the mandrel **40** essentially move as a single unit. The resilient sleeve **35** is optionally adapted to slide axially and to rotate relative to the inner tubular mandrel **40**, and is adapted to be deformed as will be described below from its radially un-extended configuration shown in FIGS. **8** to **11**, in which the outer diameter of the resilient sleeve **35** is essentially the same as the outer diameter of the housing **31** and housing **11**, to a radially expanded configuration in which the outer diameter of the resilient sleeve **35** has been radially expanded away from the axis of the throughbore T, to press against the inner surface of the casing wall surrounding the body B, thereby sealing the annulus between the body B and the casing C.

[0058] The inner tubular mandrel **40** also supports certain components of the anchor sub **50**, which are mounted on the outer surface of the inner tubular mandrel **40** in the same way as the resilient sleeve **35**.

[0059] In particular, the anchor sub **50** comprises an anchoring member having upper and lower slips **52**, **53** and a grapple sleeve **55**. The slips **52** and **53** are typically in the form of sleeves that are slid over the inner tubular mandrel **40**, and which are rotationally and axially movable relative to the inner tubular mandrel **40** so that they slide on its outer surface. The inwardly facing opposed faces of the slips **51** and **52** have tapered edges. The grapple sleeve **55** is disposed on the outer surface of the upper slip **51**. The grapple sleeve **55** is typically in the form of a circumferential arrangement of collet fingers **56** which are attached together only at their upper ends by means of a grapple ring **57**, leaving their lower ends unattached, in a cantilever arrangement, and free to move radially relative to the axis of the throughbore T. As best shown in FIG. **9**, the inner faces of the fingers **56** have a tapered profile at their lower ends, which is typically tapered in at least one direction, but optionally, as shown in the current example, the section profile of the lower end of the fingers **56** can have a taper in two directions, typically at an angle matching the tapered opposing ends of the slips **51** and **52**. As is shown in FIG. **9** when the slips **51** and **52** are spaced axially apart from one another, the tapered profile at the inner ends of the fingers **56** rests within the V shaped recess provided by the opposing tapered ends of the slips **51** and **52**. Axial sliding movement of the slips **51** and **52** towards one another (or the sliding movement of one slip towards the other) closes the gap, and pushes the lower ends of the fingers **56** radially outwards away from the axis of the throughbore T as a result of the taper. Likewise, when the slips **51** and **52** move apart from one another, the recess between them deepens, allowing the cantilevered lower ends of the fingers **56** to move back into the recess, thereby adopting the radially unexpanded configuration shown in FIG. **9** once more.

[0060] At the lower end of the inner tubular mandrel **40**, a piston sleeve **41** which is received within a larger diameter portion of the lower end of the inner tubular mandrel **40**, and is typically connected to the inner tubular mandrel **40** by means of shear pins **42** passing through the wall of the enlarged portion of the inner tubular mandrel **40**, and locating in an annular recess at the top of the piston **41**. The piston **41** is typically sealed to the inner surface of the bore of the inner tubular mandrel **40**, and has a throughbore allowing fluid communication with the throughbore T. The shear pins **42** are typically arranged in pairs around the circumference of piston, and between adjacent pins **42**, there are typically provided ports (not shown in FIG. **9**) at the same axial position, permitting fluid communication between the throughbore T and the annulus between the piston **41** and the mandrel **40**.

[0061] Beneath the shear pins **42**, the piston sleeve **41** includes at least one additional shear pin **43**, but typically, as is shown in this arrangement, there can be several pins **43**, typically arranged in a circumferentially spaced pairs, passing radially through the wall of the inner tubular mandrel **40**, and terminating in slots on the outer surface of the piston **41**. Seals above and below the ports in line with the pins **42** prevent fluid passage between the throughbore T and the outside of the plug while the piston **41** is held by the shear pins **42** in the upper configuration shown in FIG. **9**.

[0062] The upper face of the piston **41** has a seat for a ball or dart etc., adapted to be dropped from surface. The diameter of the seat on the piston **41** is smaller than the diameter of the seat **25** on the sleeve **12**, so a smaller ball adapted to seat on the piston **41** and cause its axial movement within the large lower portion of the inner tubular mandrel **40** can pass through the seat **25** in the sleeve **12** without activating it.

[0063] The lower end of the inner tubular mandrel **40** has a catcher device **45** adapted to catch the piston **41** and its activating device such as a ball etc. and prevent its onward travel axially within the body B. The catcher device **45** has slots extending radially through its outer walls, allowing passage of fluid through the slots **46** into the annulus between the catcher device **45** and the lower housing **54** of the anchor sub **50**.

[0064] The outer surface of the lower housing **54** typically has a stabiliser S.

[0065] Dropping a ball on the seat of the piston sleeve **41** prevents fluid passage through the bore of the piston sleeve **41** and builds up pressure above it. The pressure differential shears the pins **42**, freeing the piston sleeve **41** to move axially down the bore T towards the catcher device **45**. However, the piston is held by the shear pins **42** above the catcher **45**. As will be described later, the catcher **45** prevents onward axial travel of objects through the bore T but allows fluid passage past it via the slots **46** and annulus between the catcher device **45** and the lower housing **54**. Axial downward movement of the piston sleeve **41** uncovers the ports in line with the pins **42**, allowing fluid communication between the throughbore T and an annulus formed and sealed between the outer surface of the radially enlarged lower portion of the inner tubular mandrel **40**, and the inner surface of the lower slip **52**. Seals (for example O-ring seals) are typically provided above and below the outer opening of the ports and pins **42**, so the communication of pressurised fluid from the throughbore T to the annulus between the inner tubular mandrel **40** and the lower slip **52** creates a piston effect on the lower slip resulting from the difference in the sealed diameters on the lower slip **52**, causing it to move axially upwards, closing the gap between the slips **51** and **52**, and thereby causing the free ends of the fingers **56** on the grapple sleeve **55** to move radially outwards, expanding until they contact and grip the inner wall of the casing C surrounding the body B.

[0066] The outer surfaces of the fingers **56** typically have gripping formation such as teeth, abrasive surfaces such as tungsten carbide, or resilient devices etc. adapted to increase friction between the grapple sleeve **55** and the inner surface of the casing C. The angle of the taper can be adjusted to increase or decrease the extent of radial expansion of the grapple sleeve **55** in accordance with the desired annular spacing between the body B and the inner surface of the casing C.

[0067] Therefore, dropping the ball on the piston **41** causes actuation of the grapple sleeve **55** to grip the inner surface of the casing C and resist (typically substantially prevent) axial movement of the grapple sleeve **55** within the borehole.

[0068] Typically the inner surface of the lower slip **52** has a ratchet surface **58** and the inner surface of the lower slip **52** has a cooperating ratchet device **59** abutting against a downward facing shoulder on the inside of the lower slip **52**, which restricts axial movement to a single direction, i.e. upwards movement of the lower slip **52** relative to the inner tubular mandrel **40**. Therefore, once the lower slip **52** moves up a notch in the ratchet surface **58**, it cannot move down even if the pressure that caused the initial upward movement reduces. Therefore, the anchoring device can typically be actuated by pressuring up within the throughbore to a significantly higher pressure than would be encountered normally, causing upward movement of the lower slip **52** in a single direction by virtue of the ratchet mechanism **58**, **59** until the anchoring member comprising the grapple sleeve **55** is securely set preventing further axial movement of the portion of the string below the grapple sleeve **55**.

[0069] After the mechanical anchoring device has been set by expanding the anchoring member comprising the grapple sleeve **55** radially outwards to contact and grip the inner surface of the casing C, the string below the set anchoring device is essentially immovably anchored by the grapple sleeve **55**, but the string above the set grapple sleeve **55** is still axially moveable within the borehole. Accordingly, setting weight down from the surface on the set grapple sleeve **55** slides the housing **31** and the inner tubular mandrel **40** to which it is attached axially down relative to the set grapple sleeve **55**, causing the resilient sleeve **35** to be compressed between the movable housing **31** and the upper end of the immovable upper slip **51**. This results in radial expansion of the resilient sleeve **35** from the radially unexpanded configuration shown in FIG. **9**, to a radially expanded configuration, in which it engages against the inner surface of the casing C, and forms an annular seal thereby resisting passage of fluid past the seal.

[0070] Setting weight down in this manner typically further energises the expansion of the grapple sleeve **55** as a result of the interaction between the tapered surface at the lower end of the upper slip **51**, urging the tapered inner surfaces of the fingers **56** to push them further radially outwards against the inner surface of the casing C. At the same time, the weight of the string from surface is transferred through the housing **31** to the inner tubular mandrel **40**, causing the ratchet mechanism **58**, **59** to retain the plug in the radially expanded configuration with the resilient sleeve **35** radially expanded when the weight from surface is removed. Therefore, the action of setting down weight from surface typically activates the annular sealing device causing the sealing member provided by the resilient sleeve **35** to seal off the annulus, typically in both directions, thereby substantially preventing fluid from passing the expanded seal provided by the resilient sleeve **35**, even when the weight is removed.

[0071] Once the mechanical anchoring device and the annular sealing device have been set as described above, the throughbore T is typically sealed by dropping a dart from surface, to land on the seat **25** of the sleeve **12**, causing the shear pins **20** to shear, and allowing the downward travel of the sleeve **12** such that the dogs **16** move into the recess on the inner surface of the upper portion **11** a of the housing, and free the sleeve **12** to travel all the way down to the bottom of the plug sub **10**. When the sleeve **12** is bottomed out on the upwardly facing shoulder at the lower end of the lower portion housing **11***c*, the dart **26** is typically engaged against the chevron seal **19**, thereby preventing fluid passage within the throughbore T.

[0072] Thus, the plug sub is typically activated by a subsequent action performed from surface once the mechanical anchoring device and the annular sealing device have been set.

[0073] Accordingly each step of the procedure, mechanical anchoring, annular sealing, and plugging of the throughbore, can typically be independently actuated, and testing of each step can be performed before subsequent actuations of the other components.

[0074] Thus the plug **10** described permits mechanical anchoring within the borehole, annular sealing between the string and the borehole, and plugging of the throughbore that had previously allowed fluid transfer through the string, in order to plug the well.

[0075] Optionally, the plug sub **10** can be provided with a disconnect device further up the string, which can optionally be of conventional design, and can typically be provided immediately above the plug sub **10**, allowing disconnect of the string above the plug after its activation and testing. Typically the plug can be simply left in its activated state for many years, allowing possibility to revisit the plug for reversal of the abandonment procedures if desired, or for testing and monitoring of the efficacy of the seal. Alternatively, the well can be permanently abandoned by cementing above the set plug after setting and testing procedures have been concluded and the casing string above the plug has been recovered if desired.

[0076] A typical sequence of operation of the above described embodiment will now be described.

[0077] In a typical operational sequence, during normal drilling operations, one sign of the drillbit encountering a large cavity is an increase in losses of drilling fluid, typically accompanied by a reduction or absence of returns of fluid to the surface, and sometimes by a reduction in resistance on the bit. When this occurs, it is generally ineffective to continue to pump drilling fluid through the drillstring, because as it egresses from the drillbit, it simply flows away into the cavity, rather than washing back up the annulus between the drill-string and the borehole. In this situation, one option is to use Loss Circulation Materials (LCMs) such as wood fibre, calcium carbonate, ground nut shells, ground cellulose, shredded cedar fibre. Other LCMs can optionally be used.

[0078] Loss Circulation Materials (LCM) are typically pumped through a PBL tool or similar by-pass to try to stem the loss of drilling fluid, and pumping of LCM through the drillstring and into the borehole normally constitutes the first attempt at resolution of borehole problems exhibiting unusually high losses of drilling fluid. Typically a PBL tool is mounted on the drillstring below the plug described above and above the Bottom Hole Assembly (BHA). Sometimes pumping LCM is successful and in that situation normal drilling can resume. However, in the event that pumping LCM through the PBL tool does not cure the drilling fluid losses the string is typically pulled back until the plug sub is above the casing shoe, and located within the casing string C. At this point, a small diameter ball is dropped from surface to seat on the piston sleeve **41**, and to activate the mechanical anchoring device. Typically, the axial movement of the sleeve **41** in response to the ball seating on the top of the sleeve **41** can be limited by shear pins **43**, which have their radially inner ends captive in the slot formed on the outer surface of the piston sleeve **41**. Shear pins **43** can be provided as a single pin, or as pairs of pins, typically spaced at 180° of circumferential spacing around the piston sleeve **41** as shown in FIG. **9**, but multiple pairs of shear pins can optionally be provided as shown in FIG. **11**. Typically the shear pins **43** can have a higher rating than pins **42**, so can retain the sleeve **41** against further axial movement at a pressure threshold that shears the weaker upper pins **42**. Therefore, dropping the ball typically moves the sleeve **41** axially downwards within the bore of the anchor sub **50**, until the pins **43** have reached the tops of the slots on the outer surface of the piston sleeve **41**, and the ports in between the shear pins **42** have been exposed, allowing the upward movement of the lower slip **52** as a result of the differential piston area between the different diameters of seal. However, further increase in pressure on the fluid in the throughbore T above the seated ball can shear the pins **43**, driving the piston sleeve **41** into the catcher device **45**, and permitting fluid bypass in the throughbore T as a result of the slots **46** in the catcher **45**.

[0079] When the first ball is dropped to activate the anchor by uncovering the ports in axial alignment with the pins **42**, the throughbore T is effectively occluded, and it is no longer possible to drop further balls past the plug **10** in order to activate tools below it.

[0080] Once the mechanical anchoring device has been set, the weight is set down in the string above the plug **10** to activate the annular sealing device to seal off the annulus between the drillstring and the casing. At this point, the fluid pressure can optionally be increased within the throughbore in order to shear the shear pins **43**, and drive the piston sleeve **41** into the catcher device **45**, in order to regain pumping ability across the plug sub **10**, by virtue of the slots **46** in the catcher device **45** allowing fluid passage in the throughbore past the catcher **45**. This permits continued pumping if required, and retains some ability to operate parts of the string below the activated annular sealing device and mechanical anchor. If remedial operations are unsuccessful, a decision may be taken at this time to seal the well and side track above it. At this point, the dart **26** is typically dropped from surface and lands on the seat **25** on the sleeve **12**, causing it to move axially down to seal off the bore by means of the chevron seals **19** interacting with the outer surface of the solid dart **26**. This opens the circulation ports **21** above the annular sealing device **30** to allow circulation of fluids in the string and into the annulus above the packer. If required, the disconnect above the plug **10** can be operated, typically by dropping a further ball onto a seat in the disconnect device as is known in the art, leaving the plug sub **10** and BHA anchored in place downhole. The strings above the anchored plug sub **10** can then be pulled out of hole, and optionally cement can be pumped through the drill pipe to set a permanent plug above the packer assembly.

[0081] In certain embodiments, the plug sub **10** can incorporate a fishing neck facing upwards, to facilitate fishing, unlatching and retrieval of the plug sub **10** and BHA if required, on a separate fishing trip, if cement is not pumped.

[0082] Modifications and improvements can be incorporated without departing from the scope of the invention.

What is claimed is:

1. A downhole plug for plugging a borehole in an oil and/or gas well, the downhole plug comprising:

a body having a throughbore adapted to permit the passage of fluids through the throughbore;

a mechanical anchoring device adapted to radially expand an anchoring member on an outer surface of the body to lock the body in a fixed axial position within the borehole;

an annular sealing device adapted to radially expand a sealing member on the outer surface of the body to seal an annulus formed between the outer surface of the body and an inner surface of the borehole; and

a throughbore plugging device adapted to change configuration between a first open configuration in which the throughbore of the body permits the passage of fluid, and a second closed configuration in which the throughbore resists the passage of fluid.

2. A downhole plug according to claim **1**, wherein the mechanical anchoring device has gripping formations for locking the body in a fixed axial position within the borehole.

3. A downhole plug according to claim **2**, wherein the gripping formations comprise teeth or abrasive material.

4. A downhole plug according to claim **1**, wherein the mechanical anchoring device comprises one or more wedge devices in the form of slips having tapered surfaces adapted to expand the radial dimensions of the anchoring member due to relative axial movement of the slips.

5. A downhole plug according to claim **4**, wherein the slips are moveable axially by an actuator of the mechanical anchoring device, the anchoring device being moveable axially relative to the body.

6. A downhole plug according to claim **4**, wherein the slips are moveable axially by a piston of the mechanical anchoring device, the anchoring device being moveable axially relative to the body.

7. A downhole plug according to claim **1**, wherein the anchoring member is a grapple device having collet fingers attached to the mechanical anchoring device in a cantilever manner, free ends of the fingers are movable radially outwards from an axis of the body into contact with the inner surface of the borehole.

8. A downhole plug according to claim **7**, wherein the other ends of the fingers are connected by a ring.

9. A downhole plug according to claim **1**, wherein the throughbore plugging device comprises a plugging member adapted to engage on a seat within the throughbore of the body.

10. A downhole plug according to claim **9**, wherein the throughbore plugging device has a sealing arrangement in the form of an annular seal set in an inner surface of the throughbore adjacent to the seat.

11. A downhole plug according to claim **1**, wherein the inner surface of the borehole is the inner surface of casing located in the borehole.

12. A downhole plug for plugging a borehole in an oil and/or gas well, the downhole plug comprising:

a body having a throughbore adapted to permit the passage of fluids through the throughbore;

a mechanical anchoring device adapted to radially expand an anchoring member on an outer surface of the body to lock the body in a fixed axial position within the borehole;

an annular sealing device adapted to radially expand a sealing member on the outer surface of the body to seal an annulus formed between the outer surface of the body and an inner surface of the borehole;

a throughbore plugging device adapted to change configuration between a first open configuration in which the throughbore of the body permits the passage of fluid, and a second closed configuration in which the throughbore resists the passage of fluid; and

wherein the mechanical anchoring device comprises one or more wedge devices in the form of slips having tapered surfaces adapted to expand the radial dimensions of the anchoring member due to relative axial movement of the slips.

13. A downhole plug according to claim **12**, wherein the anchoring device comprises an upper slip, a lower slip and a grapple sleeve.

14. A downhole plug according to claim **12**, wherein the slips have inwardly facing opposed faces.

15. A downhole plug according to claim **14**, wherein the inwardly facing opposed faces have tapered edges.

16. A method of controlling fluids within a borehole of an oil and/or gas well, the method comprising providing a well control device having a body with a throughbore for fluid passage through the body, a mechanical anchoring device for anchoring the body in a fixed axial position within the borehole, an annular sealing device for sealing the annulus between the body and the borehole and a bore plugging device for closing the fluid pathway through the body, wherein the method comprises the steps of:

running the body into the borehole;

activating the mechanical anchoring device in order to fix the body in the borehole and resist axial movement of the body within the borehole;

activating the annular sealing device to seal the annulus between the body and the borehole, thereby substantially resisting passage of fluid within the annulus past the annular sealing device; and

plugging the throughbore in the body to resist fluid passage through the throughbore.

17. A method of controlling fluids according to claim **16**, wherein the mechanical anchoring device comprises an anchoring member on an outer surface of the body and the borehole has an inner surface, the step of activating the annular sealing device includes sealing the annulus between the outer surface of the body and the inner surface of the borehole.

18. A method of controlling fluids according to claim **16**, wherein the annular sealing device is moved from a radially unexpanded configuration to a radially expanded sealing configuration by setting weight down on the well control device after the mechanical anchoring device has been activated and the body is locked in a fixed axial position within the borehole.

19. A method of controlling fluids according to claim **16**, wherein the step of activating the mechanical anchoring device includes expanding the mechanical anchoring device.

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