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DESCRIPTION

Description

Field of the Invention

[0001] The present invention relates to the technical field of downhole operations in oil/gas wellbores, and in particular to remedial operations associated with repairing faults in annular seals, such as annular packers and cement seals, found within oil/gas wellbores.

Background of the Invention

[0002] In order to access oil and gas deposits located in underground formations it is necessary to drill bore holes into these underground formations and deploy production tubing to facilitate the extraction of the oil and gas deposits.

[0003] Additional tubing, in the form of well lining or well casing, may also be deployed in locations where the underground formation is unstable and needs to be held back to maintain the integrity of the oil/gas well.

[0004] During the formation and completion of an oil/gas well it is crucial to seal the annular space created between the casing and the surrounding formation. Also the annular space between the different sizes casings used as the well is completed. Additionally the annular space between the production tubing and said casing needs to be sealed. Further seals may be required between the underground formation and the additional tubing.

[0005] One of the most common approaches to sealing oil/gas wells is to pump cement into the annular spaces around the casing. The cement hardens to provide a seal which helps ensure that the casing provides the only access to the underground oil and gas deposits. This is crucial for both the efficient operation of the well and controlling any undesirable leakage from the well during or after the well is operated.

[0006] However it is not uncommon for crack/gaps (sometimes referred to as micro annuli) to form in these cement seals over time, which lead to unwanted leakage from the well. One location where such cracks/gaps can form is at the interface between the production tubing and the cement seal.

[0007] Another commonly used operation in oil/gas wells is the installation of packers to seal

off zones within an annulus of a wellbore. However, as with cemented annuli, over time annular packers can develop leaks.

[0008] In the case of repairing crack/gaps in the cement seal it is known to deploy eutectic alloy, such as bismuth alloy, into the annular space and then heat the alloy so that it melts and flows into the cracks/gaps. The alloy is then allowed to cool, wherein it expands to form an effective seal. This process is described in International application WO 0194741 A1.

[0009] However there are disadvantages to this approach, not least because it requires at least a partial dismantling of the well so that the alloy can be deployed within the annular space, which can be time consuming and costly in terms of the down time of the well.

[0010] US 2018/0003001 A1 relates to an apparatus and a method for repairing a leaking annular seal located within an annulus that encircles an oil/gas wellbore tubular body.

Summary of the Invention

[0011] The present invention seeks to provide an alternative approach to repairing leaks that may have developed in an existing annular seal that is located in an annular space encircling a tubular body within an oil/gas wellbore. Typical annular seals include cement seals and annular packers. The invention is defined by claims 1 and 9; other aspects of the invention are given in the dependent claims 2 to 8 and 10 to 18.

[0012] In a first aspect of the present invention there is provided a method of repairing a leaking annular seal located within an annulus that encircles an oil/gas wellbore tubular body, said method comprising: deploying a heating tool comprising at least one heater downhole via the tubular body to a downhole target region that is proximal to the annular seal; positioning a deflector in the downhole target region so that the deflector is up-hole of the annular seal and the heating tool and down-hole of a portion of the tubular body wall that comprises one or more openings; delivering alloy beads to the downhole target region via the tubular body such that the deflector redirects the alloy beads radially outwards towards said one or more openings and into the annulus, wherein the alloy beads accumulate on top of the annular seal; and operating said heating tool to increase the temperature within the downhole target region to a temperature that is sufficient to melt the alloy beads accumulated within the annulus before allowing the molten alloy to cool and form an alloy plug that repairs the leaking annular seal.

[0013] Preferably the annular seal being repaired may comprise an annular packer and/or a cement seal.

[0014] It will be appreciated that the terms 'up-hole' and 'down-hole' used herein are intended to denote the relative positioning of the various elements present in the wellbore. That is to say, 'up-hole' denotes that a first element is closer to the surface of the wellbore than a second

element, (i.e. the first element is located between the surface and the second element).

[0015] Conversely, 'down-hole' denotes that the first element is further away from the surface of the wellbore than the second element (i.e. the second element is located between the surface and the first element).

[0016] Rather than deploying the alloy downhole from the surface of the wellbore via the annulus that houses the annular seal that is to be repaired, the method of the present invention utilises the innermost wellbore tubular body to achieve the majority of the alloy's journey to a downhole target region. In this way it is possible to make use of the cleaner internal diameter of the innermost tubular body, which typically has less restrictions than the annulus not least due to the absence of couplings that project into the annulus.

[0017] In the case of couplings, which occur at the points when consecutive well tubulars are joined, alloy beads that are deployed down the annulus can land on the upper surfaces of the couplings and in so doing be prevented from reaching the downhole target region. The loss of alloy beads in transit due to obstructions within the annulus can be significant over the full distance from the surface to the target region.

[0018] It is only once the alloy reaches the vicinity of the up-hole face of the annular seal (i.e. the downhole target region), that is to say the face of the annular seal that is closest to the surface of the wellbore, that the alloy passes into the annulus.

[0019] The passage of the alloy (which is provided in the form of beads, balls or shot) through the wall of the innermost tubular body into the annulus is achieved via one or more openings provided in the tubular body at a location that is up-hole of the annular seal.

[0020] It is envisioned that in the broadest applications of the method of the invention the passage of the alloy beads through the tubular body is achieved via pre-existing openings. Examples of pre-existing openings include valves, such as: sliding sleeve valves, gas lift mandrel valves, and pressure diverter subs. With that said it is also envisioned that in those situations where there are no suitable pre-existing openings, hole making equipment may be employed to create one or more openings in the tubular body.

[0021] In order to direct the alloy beads from within the tubular body to the annulus via said one or more openings, the method employs a deflector that is also delivered downhole via the tubular body to a location that is down-hole of said one or more openings.

[0022] The positioning and configuration of the deflector is such that when the alloy beads are deployed within the tubular body they contact the deflector and are redirected radially outwards towards said one or more openings and out into the annulus, wherein the alloy beads accumulate on top of the up-hole face of the annular seal.

[0023] A heating tool, which is also deployed downhole via the tubular body, is operated to

increase the temperature within the target region to a level that is sufficient to melt the alloy beads. Following the operation of the heating tool the molten alloy is allowed to cool, wherein the alloy solidifies within the annulus as an alloy plug that effectively repairs any leaks within the annular seal.

[0024] The method of the present invention is considered particularly suitable for use in a single trip annular seal repair. That is to say, the various stages of the repair method can be achieved using a single annular seal repair assembly that is deployed downhole via the tubular body only once.

[0025] Although the heating tool can be deployed to any location that is within heating range of the up-hole face of the annular seal, preferably said heating tool is deployed to a location within the wellbore tubular body that is proximal to and up-hole of the annular seal.

[0026] Preferably the heating tool comprises multiple heaters that are operated independently to provide heat at different times. This use of multiple, independently controllable heaters provides the operator with much greater control of the heating levels within the downhole target region.

[0027] Further preferably, said heaters are independently operated to: a) commence generating heat before the heating tool reaches the downhole target region; b) pre-heat the alloy beads before they are redirected into the annulus by the deflector; c) pre-heat the downhole target region before the alloy beads are accumulated on top of the annular seal; d) provide the alloy melting temperature within the downhole target region after the alloy beads have begun to accumulate on top of the annular seal; and/or e) provide the alloy melting temperature within the downhole target region once the alloy beads have accumulated on top of the annular seal.

[0028] Preferably the heating tool and the deflector are provided as an annular seal repair tool assembly that is deployed downhole via a common delivery support that is connected to delivery means located above-ground at the surface of the wellbore.

[0029] Once again, using an annular seal repair tool assembly that combines all of the main tools required to carry out the main steps of the repair method facilitates the formation of an alloy plug within the annulus in a single trip. Achieving the deployment of an alloy plug using a single combined assembly has the potential to speed up the repair process by avoiding the need for deploying and retrieving a different tool for each step of the method. The single trip approach thereby offers cost efficiencies as a result of the quicker repair times and the need for fewer downhole tool deployments.

[0030] Further preferably the common delivery support used to deploy the annular seal repair tool downhole may be selected from: coiled tubing, pipe, slick line and wireline.

[0031] Preferably the delivery of the alloy beads may be achieved by dumping the alloy beads

into the wellbore tubular body from a location above-ground at the surface of the wellbore. This approach has the benefit of being relatively low cost, because the alloy beads are simply dropped into the innermost tubular body.

[0032] Alternatively, the delivery of the alloy beads may be achieved by a dump bailer deployed downhole via the tubular body, said dump bailer forming part of the annular seal repair tool assembly. This approach has the benefit of providing a more controlled deployment of the alloy beads onto the deflector.

[0033] In a further alternative, the delivery of the alloy beads may be achieved via the coiled tubing or pipe that is used to deploy the annular seal repair tool assembly downhole. As with the dump bailer approach, this approach provides a more controlled deployment of the alloy beads onto the deflector.

[0034] As noted above, in its broadest application the method of the present invention makes use of pre-existing openings in the well bore tubular body to facilitate the passage of the alloy beads from within the tubular body to the surrounding annulus.

[0035] However, in situations where there are either no pre-existing openings in the wall of the tubular body, or the pre-existing openings are unsuitable to enable the passage of the alloy beads, the method may preferably further comprise forming one or more openings in the portion of the tubular body wall that is located up-hole from the annular seal, wherein said one or more openings are formed prior to the delivery of the alloy beads using a hole making tool that forms part of the annular seal repair tool assembly.

[0036] Preferably the downhole target region may be agitated in order to assist the passage of the alloy beads through said one or more openings into the annulus.

[0037] It will be appreciated that although the suitable openings will be big enough to allow the alloy beads to pass through the wall of the tubular body, when large amounts of alloy beads are deployed at once blockages may occur. Agitating the downhole target region will help to shake the alloy beads through openings so that they can reach the surrounding annulus.

[0038] Preferably the deflector is vibrated to agitate the downhole target region. Additionally, or alternatively, the tubular body is vibrated to agitate the downhole target region. Employing either agitation approach, or indeed both approaches at the same time, helps to prevent the build-up of the alloy beads on the inside of the tubular body.

[0039] It is envisioned that once the heating tool has been activated the deflector will also act to reduce the flow of heating fluids upwards within the tubular body and in so doing reduce the amount of heat being lost from the downhole target region. Reducing heat loss in this way also helps to make more efficient use of the heating tool.

[0040] With that said, preferably the deflector may comprise insulating means configured to

restrict the passage of conducted heat through the deflector. In this way the deflector not only acts to reduce the amount of heat lost as a result of heated fluids rising within the tubular body, but is also prevents heat being transferred across the deflector via a process of conduction.

[0041] Preferably the deflector may be deployed downhole in an unexpanded or partially expanded state and then expanded towards the tubular body wall in the downhole target region so as to increase the extent to which the deflector redirects the alloy beads. It is appreciated that expanding the deflector in this way will also further restrict the upward flow of heating fluids within the wellbore.

[0042] In this way the deflector is easier to deliver downhole in situations of restricted access (e.g. when the tubular body is of smaller diameter and/or the tubular body has one or more obstructions within it).

[0043] Preferably the heating tool comprises one or more chemical reaction heaters. The chemical reaction heaters preferably employ thermite or thermite based mixes for the generation of heat that is suitable to melt the alloy beads.

[0044] Preferably the alloy beads are provided in the form of a low melting alloy that has melting point of less than 300°C. These low melting alloys are sometimes also referred to as fusible alloys. With that said, it will be appreciated that in order for the alloy to be capable of forming a solid alloy plug within the annulus the melting point of the alloy must not be lower than the normal temperature in the downhole target region, which is typically 5 to 50°C.

[0045] Preferably the alloy beads may be provided in the form of bismuth based alloys. It is envisioned that the bismuth based alloys may be eutectic or non-eutectic in nature and may also qualify as low melting alloys.

[0046] In addition to the annular seal repair method of the first aspect of the present invention, there is provided a downhole annular seal repair tool assembly according to a second aspect of the present invention.

[0047] Accordingly, the present invention provides a downhole annular seal repair tool assembly for use in forming an alloy plug on an existing annular seal that substantially encircles an oil/gas wellbore tubular body, said assembly comprising: a delivery support connection point, by which the assembly is connectable to delivery means via a delivery support such that the assembly can be delivered to and retrieved from a downhole target region of the wellbore via the tubular body; a heating tool having at least one heater, said heating tool configured to increase the temperature within the downhole target region to temperature that is sufficient to melt alloy beads accumulated within the annulus so as to enable the formation of the alloy plug on the existing annular seal; and a deflector arranged up-hole of said heating tool, wherein the deflector is configured to obstruct alloy beads delivered downhole and redirect them radially outwards towards the walls of the wellbore tubular body.

[0048] It is envisioned that the assembly can be used to deliver the annular seal repair method of the present invention in a single trip. That is to say, all of the components needed to carry out the steps of the described repair method are either provided by the assembly or otherwise present without the need to retrieve the assembly and deploy a second tool downhole. As noted above, the present invention is considered particularly suitable for repairing leaks in annular cement seals and annular packers.

[0049] Preferably the heating tool may comprise multiple heaters that are independently controlled. In this way each of the heaters can be operated in unison at the same time or separately according to a predetermined sequence.

[0050] Preferably the deflector comprises an up-hole facing surface that comprises at least one sloped region. In this way, when the alloy beads hit the deflector they are re-directed radially outwards towards the wall of the tubular body in which said one or more openings are located.

[0051] Further preferably the up-hole facing surface of the deflector is cone-shaped or domed. Further, the apex of the cone or the dome is preferably located on a central axis running through the deflector.

[0052] Additionally or alternatively the assembly may further comprise an agitation mechanism configured to agitate and/or vibrate the downhole target region of the wellbore. As detailed above, agitating the downhole target region helps to prevent the alloy beads from becoming jammed in said one or more openings in the tubular body wall, which would otherwise prevent the alloy beads from passing through into the annulus.

[0053] Preferably the agitation mechanism is configured to vibrate the deflector. Alternatively or additionally the agitation mechanism is configured to vibrate the tubular body within the downhole target region of the wellbore.

[0054] Preferably the deflector may be configured to be expandable radially outwards towards the tubular body wall. In this way the deflector can be delivered downhole in a smaller form and then, once in position, increased in size to make it more effective at re-directing the alloy beads.

[0055] Further preferably the mechanism by which the expansion of the deflector is achieved is selected from hydraulic means, pneumatic means, mechanical means and combinations thereof.

[0056] In particular, in the case of a mechanical expansion means, the deflector may preferably be urged to expand and/or contract by way of one or more resilient biasing means. Further preferably the deflector may comprise a canopy of flexible material connected to an umbrella spring mechanism.

[0057] Preferably the deflector may comprise insulating means configured to restrict the passage of conducted heat through the deflector. As detailed above, providing the deflector with insulating properties helps to reduce the amount of heat lost from the downhole target region. This in turn helps to make more efficient use of the heat generated by the heating tool.

[0058] Preferably the assembly may further comprise a delivery support selected from: coiled tubing, pipe, slick line and wireline.

[0059] In situations where the delivery support is either coiled tubing or pipe, preferably such delivery supports are configured to deliver alloy beads to the downhole target region of the wellbore. In this way the alloy beads can be delivered onto the deflector via the same coiled tubing/pipe that is used to deploy the deflector and the heating tool.

[0060] Alternatively, the assembly may further comprise alloy bead delivery means in the form of a dump bailer arranged up-hole of the deflector and said heating tool. In this way the alloy beads can be delivered downhole on-board the assembly and then, once the deflector is in position adjacent to said one or more openings in the wall of the tubular body, released onto the deflector.

[0061] As noted above, it is envisioned that the alloy beads may also be simply dumped onto the deflector from a location at the surface of the wellbore. In such situations neither the dump bailer nor the specific delivery supports are essential.

[0062] In those situations where the tubular body wall does not include suitable openings to facilitate the passage of the alloy beads out of the tubular body into the annulus, it is envisioned that it will be necessary to form openings in the wall of the tubular body before the alloy beads are deployed.

[0063] With this aim in mind the assembly of the present invention preferably further comprises hole making equipment configured to form one or more opening in the walls of the wellbore tubular body.

[0064] In this regard, the hole making equipment is preferably selected from: a drill, a mechanical punch, a perforating gun, a saw or any other suitable cutting tools such as chemical cutters and fluid jet cutters.

[0065] Preferably the assembly may further comprise a junk basket positioned at a leading end of the assembly. In this way, any material that may fall down hole from the downhole target region can be caught. The junk basket is considered particularly useful for catching any alloy beads that are not re-directed into the annulus by the deflector. With that said, another material that might be caught is the swarf created by the operation of the hole making equipment.

[0066] Preferably the heating tool may comprise one or more chemical reaction heaters. The

chemical reaction heaters preferably employ thermite or thermite based mixes for the generation of heat that is suitable to melt the alloy beads.

Brief Description of the Drawings

[0067] The various aspects of the present invention will now be described with reference to the preferred embodiments shown in the drawings, wherein:

Figure 1 shows a diagrammatic representation of the key stages of an annular seal repair method according to a first preferred embodiment of the present invention;

Figure 2 shows a diagrammatic representation of the key stages of an annular seal repair method according to a second preferred embodiment of the present invention;

Figure 3 shows a diagrammatic representation of the key stages of an annular seal repair method according to a third preferred embodiment of the present invention; and

Figure 4 shows a preferred embodiment of the deflector used in the annular seal repair tool assembly of the present invention.

Detailed Description of the Preferred Embodiments

[0068] The annular seal repair method of the present invention will now be described with reference to the various preferred embodiments shown in the figures. Each embodiment employs an annular seal repair tool assembly that comprises the core components of a heating tool and a deflector, wherein the deflector is located up-hole of the heating tool. In addition, the annular seal repair tool assembly shown in each embodiment comprises certain other preferable components.

[0069] It should be appreciated from the outset that assemblies shown in the figures are not intended to be limiting, but rather to demonstrate examples of how certain preferred components work in combination with the core components to help repair an annular seal, such as an annular packer, in a single trip.

[0070] It is envisioned that the preferred components described below can be used in a range of combinations, and not in just those shown, provided the heating tool and the deflector are present in the assembly.

[0071] Figure 1 shows the application of the annular seal repair method of the present invention in a wellbore target region where only a single annulus is present. The annulus 3 is defined by the outer casing 1 and the inner tubular body 2. Within the annulus 3 is provided an

annular packer 4. The annular packer 4 shown in Figure 1 has a fault line which is causing the packer 4 to leak, hence the application of the annular seal repair method.

[0072] In the downhole situation shown in Figure 1, the wellbore tubular body 2 has pre-openings 5 in the tubing wall of the inner tubular body. It is envisioned that the pre-existing holes may be the result of a previous downhole operation or could be provided by components already present on the tubular body 2; such as valves (e.g. sliding sleeve valves, gas lift mandrel valves, and pressure diverter subs).

[0073] In the first stage of the method shown in Figure 1, the annular seal repair tool assembly 6 is delivered downhole and brought into close proximity with the pre-existing openings 5.

[0074] The annular seal repair tool assembly 6 comprises a heating tool 7 that is located at the leading end of the assembly 6 at a position down-hole of a deflector 8.

[0075] The annular seal repair tool assembly 6 is deployed downhole using a common delivery support that is connected to delivery means located above-ground at the surface of the wellbore.

[0076] The delivery means are not shown in Figure 1, but it will be appreciated by the skilled person that standard delivery means can be utilised to achieve the deployment of the assembly 6 to the downhole target region in which the openings 5 are located.

[0077] Also, although the delivery support is not shown in any detail, it will be appreciated that suitable types of delivery support include coiled tubing, pipe, slick line and wireline. It is appreciated that any combination of delivery support and delivery means can be employed provided it facilitates the controlled deployment of the annular seal repair tool assembly 6 to the downhole target region via the interior of the tubular body 2.

[0078] Once in position within the downhole target region, the deflector 8, which is located down-hole of the openings 5, is expanded so that it extends radially outwards towards the surrounding wall of the tubular body 2.

[0079] It is envisioned that the expansion of the deflector 8 can be achieved by way of hydraulic means, pneumatic means, mechanical means and combinations thereof.

[0080] It is appreciated that deploying the assembly 6 downhole with the deflector 8 in an unexpanded or partially expanded state helps to make the assembly's passage easier, particularly in wellbore tubular bodies of limited diameter and/or which contain obstructions. Reducing the size of deflector during transit also reduces the resistance due to the existing wellbore fluids by allowing some flow area for the fluid to pass the deflector.

[0081] In addition, deploying the deflector in this way would also help prevent swabbing of the wellbore tubular body.

[0082] Further, the expansion of the deflector 8 towards the wall of the tubular body 2 greatly reduces the possibility that alloy beads 9 will fall past the assembly 6 without coming into contact with the deflector 8.

[0083] Once the assembly 6 is in place, and the deflector 8 has been expanded, alloy beads 9 are delivered to the downhole target region. In the preferred embodiment shown in Figure 1 the alloy beads are delivered by a process of dumping the alloy beads into the wellbore tubular body 2 at the surface of the wellbore above ground (not shown).

[0084] The dumped alloy beads 9 fall down the wellbore via the inner tubular body until they come into contact with the deflector 8, at which point they are re-directed radially outward towards the openings 5 in the wellbore tubular body 2 and out into the annulus 3. The alloy beads 9 then accumulate on the up-hole surface of the annular packer 4.

[0085] In the broadest sense of the present invention the alloy beads can be formed from any alloy, provided the alloy melts at a temperature above that found within the downhole environment (e.g. around 5 to 50°C). This is important because it enables the alloy to form a stable solid plug within the annulus.

[0086] Preferably, however, the alloy beads 9 are formed from a low melting alloy that has a melting point that is no more than about 300°C and which further preferably comprises bismuth. Bismuth is preferred component because its alloys tend to contract upon melting and expand upon re-solidification, which is considered beneficial when forming alloy plugs.

[0087] Typically the alloy beads will have a diameter in the range of 0.76 to 127mm (about 0.030 to 0.5 inches). However, ultimately the size of the beads will be determined by the openings in the tubular body wall and any other restrictions that might exist because the alloy beads must be able to pass downhole and through the openings into the annulus with relative freedom.

[0088] In the embodiment shown in Figure 1 it can be seen that the deflector 8 has an upper face that is dome-shaped such that alloy beads striking the deflector are re-directed radially outward. It is appreciated that the upper surface of the deflector may comprise different shapes, ranging from cone-shaped to single flat sloped faces, and that any face shapes that help re-direct the alloy beads towards the tubular body wall are preferable.

[0089] With that said, it is not considered essential for the upper face of the deflector to be sloped because the process of redirecting the alloy beads towards the wall of the tubular body could also be achieved by agitating the downhole target region to help shake the alloy beads through the openings and into the annulus (see Figure 3).

[0090] Once the alloy beads 9 have been delivered downhole and re-directed into the annulus 3 through the openings 5 by the deflector 8, heat generated by the heating tool 7 causes the

alloy beads to melt.

[0091] Although the heating tool 7 shown in Figure 1 comprises only a single heater, it is envisaged that the heating tool 7 may comprise multiple individually operable heaters. Employing multiple heaters in this way provides the option to operate the heaters sequentially or in unison to achieve different heating programs.

[0092] For example, one possible heating program might employ a first heater to preheat but not necessarily melt the alloy beads before they are deployed onto the deflector. Once the pre-heated alloy beads have been delivered to the annulus via the deflector a second heater could be operated to ensure complete melting of the alloy. This is considered particularly beneficial in the downhole environments where there is a significant difference between the ambient temperature in the target region and the melting point of the alloy.

[0093] However, in the embodiment shown the heating tool 7 comprises a single heater that is operated once the whole load of alloy beads has been delivered to the annulus 3. Preferably the heating tool comprises at least one chemical heater that generates heat from a thermite based reaction. With that said, alternative heat sources will be appreciated by the skilled person.

[0094] Once the alloy beads have been heated for a suitable length of time (for example 2 hours) the molten alloy is allowed to cool and as it does the alloy resolidifies on top of the existing annular packer 4 to form a plug 10 which acts to seal any fissures/cracks in the packer.

[0095] Once the alloy beads have been sufficiently melted the annular seal repair tool assembly 6 can be retrieved from the wellbore using the common delivery support and the above-ground delivery means.

[0096] Turning now to Figure 2, a second preferred embodiment of the method of the present invention will now be described. The downhole target region shown in Figure 2 comprises two annuli. The first annulus is defined by the outer casing 1 and the intermediate well tubing 2a and the second annulus 3 is defined by the intermediate well tubing 2a and the wellbore tubular body 2. In this shown example the failing annular packer 4 is provided in the second annulus.

[0097] In further contrast to the situation shown in Figure 1, there are no pre-existing openings in the tubular body 2 wall. As a result, this embodiment of the annular seal repair method requires that openings are formed in the tubular body 2 before the alloy beads can be delivered into the annulus.

[0098] To this end, the annular seal repair tool assembly 11 employed in this embodiment of the repair method is provided with an alternative construction to that shown in Figure 1. With that said, the heating tool 7 and the deflector (albeit in a different form 12) are maintained in

the assembly 11.

[0099] In particular the annular seal repair tool assembly 11 comprises a heating tool 7 with a deflector mounted above it in an up-hole location. In addition, hole making equipment 13 is provided up-hole of both the heating tool and the deflector.

[0100] It is appreciated that the positioning of the hole making equipment on the assembly may vary from one embodiment to the next without departing from the general concept of the present invention.

[0101] Preferably the hole making equipment 13 is in the form of a perforation gun. However it is envisaged that other suitable types of hole making equipment that might alternatively be employed to form the required openings in the wall of the tubular body 2 include a drill, a mechanical punch, a saw or indeed any other suitable cutting tools such as chemical cutters.

[0102] At the leading end of the assembly 11, below the rest of the assembly's components is provided a junk basket 14. In the preferred embodiment the junk basket is configured to be expandable towards the tubular body wall so as to maximise its ability to capture any materials that fall past the assembly 11 during the operation of the repair method.

[0103] In the first stage of the shown method the assembly is delivered down hole to the downhole target region. As with the assembly 6 shown in Figure 1, the delivery can be achieved using a range of common support devices and above-ground delivery means. As such, the comments made regarding the delivery of the annular seal repair tool assembly of Figure 1 also apply to the assembly shown in Figure 2.

[0104] The positioning of the assembly 11 in the first stage is such that, when the hole making equipment is operated, the one or more openings 15 that are formed in a portion of the tubular body wall that is located up-hole of the annular packer 4.

[0105] Once sufficient openings have been formed, the assembly 11 can be partially raised back up the wellbore by the delivery means until the deflector 12 is positioned adjacent (albeit slightly down hole) the openings 15 ready for the second stage of the method.

[0106] In the second stage alloy beads 9 are delivered to the downhole target region via the tubular body 2. As before, the alloy beads 9 are dumped downhole from dumping means located at the surface of the wellbore.

[0107] As with the previously described embodiment the alloy beads 9 descend the wellbore within the tubular body and those that strike the deflector 12 are re-directed towards the openings 15 and out into the annulus 3, where they accumulate on the up-hole face of the annular packer 4.

[0108] However, in contrast to the deflector 8 shown in Figure 1, the deflector 12 employed in

the assembly 11 shown in Figure 2 is not expandable. As a result, some of the alloy beads 9 miss the deflector and continue to descend past the heating tool 7. In such situations the alloy beads 9 that are not redirected into the annulus 3 are caught by the junk basket 14 located at the leading end of the assembly 11.

[0109] As in the method of the first embodiment described above, the heating tool 7 is operated to heat the downhole target region to a temperature that is sufficient to melt the alloy beads 9. Once melted, the alloy beads are allowed to cool and re-solidify to form an alloy plug 10 within the annulus 3, which sits on top of the annular packer 4 and seals any leaks therein.

[0110] The annular seal repair tool assembly 11 can then be retrieved from the wellbore using the above-ground delivery means.

[0111] Figure 3 show a third preferred embodiment of the annular seal repair method of the present invention. As will Figure 2, the downhole target region comprises two annuli. Also, as with Figure 1, the inner wellbore tubular body 2 is provided with pre-existing openings 5. It will be appreciated that if the openings were not present, or were unsuitable to facilitate the passage of the alloy beads from the tubular body to the annulus, hole making equipment could be employed on the annular seal repair tool assembly 20.

[0112] With that said, the annular seal repair tool assembly 20 employed in the method shown in Figure 3 comprises a heating tool 7 with a deflector mounted to it in an up-hole location. It is appreciated that the clearance between the heating tool 7 and the deflector 22 can range from 0 to 20 metres. This preferred range is applicable to all of the embodiments described herein.

[0113] Unlike the deflectors shown in Figures 1 and 2, the deflector 22 provided on the assembly employed in the method shown in Figure 3 does not have a sloped upper face. Instead the deflector is provided with agitation means that are configured to shake the alloy beads towards the openings 5 and into the annulus 3.

[0114] As with the deflector shown in Figure 1, the deflector 22 shown in Figure 3 is configured to be expandable radially outwards towards the tubular body wall; possibility in a manner similar to than achieved by a bridge plug.

[0115] Further, it is envisaged that the deflector may comprise heat insulating means that are configured to minimise the passage of heat through the deflector 22. In this way the deflector can serve a dual purpose of achieving alloy bead re-direction and also lowering the amount of heat lost from the downhole target region due to the upward flow of heated wellbore fluids.

[0116] In particular, it is noted that by at least partially occluding the tubular body 2 with the deflector it is possible to reduce the extent to which fluids heated by the operation of the heating tool are lost up-hole. In this way heat is retained locally and the overall efficiency of the heating tool is improved.

[0117] Although this benefit is achieved to a greater or lesser extent by all of the deflectors employed in the method of the present invention, it is also appreciated that further heat retaining benefits may be achieved by providing the deflector with heat insulating means. In this way heat lost by conduction through the deflector is also reduced. In view of this it is envisaged that suitable heat insulation means could be employed in any of the deflectors shown in the preferred embodiments described above.

[0118] In addition to the heating tool and the deflector, the assembly 20 is provided with a dump bailer 21. The dump bailer 21 is located up-hole of both the deflector 22 and the heating tool 7. The dump bailer is used to deliver the alloy beads down hole with the assembly so that the alloy can be deployed locally onto the deflector rather than by dumping the alloy from the surface of the wellbore.

[0119] Turning now to Figure 3, it will be seen that in the first stage the assembly 20 is deployed down hole to the downhole target region and the unexpanded deflector 22 is positioned at a location that is up-hole of the annular packer 4 and down-hole of the openings 5 in the tubular body 2. Once in position the deflector 22 is expanded towards the tubular body. Again this can be achieved by hydraulic means, pneumatic means, mechanical means and combinations thereof.

[0120] Following the expansion of the deflector 22, the dump bailer 21 can be operated and the alloy beads can be deployed onto the upper face of the deflector 22. Although some of the alloy beads will naturally pass through the openings 5, the redirection of the majority of the alloy beads will be achieved by the application of an agitating force within the downhole target region.

[0121] In the shown embodiment the agitation force is provided by vibrating the deflector 22 to shake the alloy beads through the openings 5. However, it is envisaged that the tubular body may also be agitated either alone or in combination with the deflector to assist the re-direction of the alloy beads towards the openings in the wall of the tubular body and into the annulus.

[0122] Although the described embodiments show the deflectors are being either shaped (e.g. domed-shaped, cone-shaped) so as to re-direct alloy beads towards the openings or subject to vibrations to agitate the alloy beads, it is envisioned that both approaches may be used in concert to facilitate efficient re-direction of the alloy beads into the annulus 3.

[0123] Following the delivery of the alloy beads 9, the heating tool is operated to melt the alloy within the annulus. As before, the molten alloy is left to cool and re-solidify to form an alloy plug within the annulus on top of the existing annular packer.

[0124] The operation of the deflector will now be described with reference to Figure 4, which shows a partial view of a preferred embodiment of the annular seal repair tool assembly 30 of the present invention in both an unexpanded state and an expanded state in which the deflector extends beyond the outer diameter of the heating tool 32.

[0125] It will be appreciated that although only the deflector 31 and the heating tool 32 (in part) are shown in Figure 4, the other preferred components described above could also be combined with the described assembly 30.

[0126] The heater 11, of which only the uppermost portion is shown, is provided with a setting tool 33 that essentially houses the control mechanisms for operating the heater (e.g. ignition means in the case of a chemical heater).

[0127] The setting tool is then connected via a delivery support connection point 34 to a delivery support, which is shown as a wireline 35 but could be any suitable connection line, pipe or coil. The deflector 31 is located between the connection point 34 and the setting tool 33 of the heater 32.

[0128] The deflector 31 comprises a central shaft 36 that is connected between the setting tool 33 of the heater 32 and the delivery support connection point 34. A collar 37 is fixed in position on the shaft 36. Attached to the collar 37 is a web of flexible material 38 that essentially forms a canopy that is capable of changing shape to accommodate the expansion and contraction of the deflector 31.

[0129] It will be appreciated that the flexible material should be resistant to the downhole environment within which the assembly 30 is to be deployed. It is envisaged that a suitable flexible material for use in the deflector is a heat resistant canvas or a silicone rubber. However the skilled person will appreciate that other flexible materials could suitably be employed.

[0130] The deflector 31 further comprises a plurality of resiliently biased expansion bands 40 that are secured at their respective ends to the connection point 34 and a moveable collar 39, which is slidably mounted on the central shaft 36. In this way the unsecured middle portions of the bands are free to bend and flex in a radial direction relative to the central shaft.

[0131] It is envisaged that the resiliently biased expansion bands 40 may be formed from flexible strips of a suitable spring metal. However the skilled person will appreciate that an alternative resilient material may be employed without departing from the scope of the present invention.

[0132] In the preferred embodiment the moveable collar 39 is urged away from the setting tool 33 by way of actuation means 41, which may take the form of a coiled spring. It is envisaged that the actuation means 41 can be used to control the distance between the connection point 34 and the collar 39, which in turn will control the extent to which the resiliently biased expansion bands 40 can be deformed.

[0133] In this regard the actuation means 41 can limit the extent to which the collar 39 can move up and down the central shaft, which in turn limits the extent to which deflector 31 can be expanded or contracted.

[0134] The central portion of the canopy of flexible material 38 is attached to the fixed collar 37 whilst the periphery of the canopy is attached to each of the plurality of resiliently biased expansion bands 40. By connecting the flexible material to the middle portions of the resiliently biased expansion bands 40, the deflector can be operated to expand and contract the flexible material so that the extent to which it can deflect the alloy beads is varied and also restrict the flow of fluid past the deflector.

[0135] When the resiliently biased expansion bands 40 are forced radially outwards they pull the flexible material outwards to form an expanded blocking structure that may extend across a large portion, if not all, of the inner diameter of the wellbore tubular body. Also, when the resiliently biased expansion bands 40 move radially inwards they pull in the flexible material and contract the deflector 31.

[0136] It is envisaged that preferably, at rest, the bands 40 will extend outwards beyond the outer diameter of the rest of the heater assembly 32 so that the canopy of flexible material will at least partially block the borehole and, in so doing, restrict the flow of fluids within the borehole.

[0137] However, the flexible nature of the bands allows the deflector to compress, as necessary, to accommodate narrowed portions of the borehole that might be encountered during the annular seal repair tool assembly's deployment. Once past the narrowed portion of a borehole, the resilient nature of the bands will cause the baffle to once again return to its expanded state, in which the deflector restricts the movement of alloy beads and fluid within the wellbore tubular body.

[0138] It is further envisaged that, in use, the canopy may be caused to expand even further under the influence of heated fluids rising within the borehole. That is rising fluid could become trapped by partially opened canopy and then urge it to open further.

[0139] In an alternative arrangement of the mechanical arrangement shown in Figure 4, the actuation means 41 may be operated to force moveable collar 39 to slide up the shaft 36, thereby urging the resiliently biased expansion bands 40 outwards and opening the canopy.

[0140] It is envisaged that this arrangement could be employed in embodiments where the deflector's default position in the unexpanded state.

REFERENCES CITED IN THE DESCRIPTION

Cited references

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Patent documents cited in the description

- WO0194741A1 [0008]
- US20180003001A1 [0010]

Patentkrav

1. Fremgangsmåde til reparation af en lækkende, ringformet tætning (4) placeret inde i et ringvolumen (3), der omgiver et olie-/gasbrøndboringsrørlegeme (2), hvor fremgangsmåden omfatter:

anbringelse af et opvarmningsværktøj (7, 32), der omfatter mindst ét varmelegeme, i borehullet via rørlegemet til et borehulsmålområde, der ligger i umiddelbar nærhed af, og fortrinsvis oppe i hullet i forhold til, den ringformede tætning (4);

placering af en deflektor (8, 12, 22, 31) i borehulsmålområdet, således at deflektoren er nede i hullet i forhold til en del af rørlegemets væg, der omfatter én eller flere åbninger (5);

tilførsel af legeringskugler (9) til borehulsmålområdet via rørlegemet (2), således at deflektoren (8, 12, 22, 31) omdirigerer legeringskuglerne (9) radialt udefter mod den ene eller flere åbninger (5) og ind i ringvolumenet (3), hvor legeringskuglerne ophobes oven på den ringformede tætning (4); og

anvendelse af opvarmningsværktøjet (7, 32) til at hæve temperaturen inde i borehulsmålområdet til en temperatur, der er tilstrækkelig til at smelte legeringskuglerne (9) ophobet inde i ringvolumenet (3), før den smeltede legering kan afkøles og danne en legeringsprop (10), der reparerer den lækkende, ringformede tætning (4); og

kendetegnet ved placering af deflektoren (8, 12, 22, 31) i borehulsmålområdet, således at deflektoren er oppe i hullet i forhold til den ringformede tætning (4) og opvarmningsværktøjet (7, 32).

2. Fremgangsmåde ifølge krav 1, hvor opvarmningsværktøjet (7, 32) omfatter flere varmelegemer, der styres uafhængigt for at tilvejebringe varme på forskellige tidspunkter; hvor varmelegemerne fortrinsvis styres uafhængigt til at:

a) påbegynde generering af varme, før opvarmningsværktøjet (7, 32) når borehulsmålområdet;

b) forvarme legeringskuglerne (9), før de omdirigeres ind i ringvolumenet (3) af deflektoren (8, 12, 22, 31);

c) forvarme borehulsmålområdet, før legeringskuglerne (9) ophobes oven på den ringformede tætning (4);

d) tilvejebringe legeringens smeltetemperatur inde i borehulsmålområdet, efter at legeringskuglerne (9) er begyndt at ophobes oven på den ringformede tætning (4); og/eller

e) tilvejebringe legeringens smeltetemperatur inde i borehulsmålområdet, når legeringskuglerne (9) er ophobet oven på den ringformede tætning (4).

3. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 2, hvor opvarmningsværktøjet (7, 32) og deflektoren (8, 12, 22, 31) tilvejebringes som en ringformet tætningsreparationsredskabsanordning (6, 11, 20, 30), der anbringes i borehullet via en fælles tilførselsbærer, som er forbundet med et tilførselsmiddel placeret over jorden ved brøndboringens overflade; og

hvor den fælles tilførselsbærer, der anvendes til at anbringe den ringformede tætningsreparationsredskabsanordning i borehullet, fortrinsvis vælges blandt: spiralrør, rør, slick-line og metalkabel.

4. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 3, hvor tilførslen af legeringskuglerne (9) opnås enten ved:

- a) dumpning af legeringskuglerne (9) ind i brøndboringens rørlegeme (2) fra et sted over jorden ved brøndboringens overflade;
- b) en aflæsningsbeholder (21) anbragt i borehullet via rørlegemet (2), hvor aflæsningsbeholderen udgør en del af den ringformede tætningsreparationsredskabsanordning (20); eller
- c) spiralrør eller rør, der anvendes til at anbringe den ringformede tætningsreparationsredskabsanordning i borehullet.

5. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, og som endvidere omfatter dannelse af én eller flere åbninger (5) i den del af rørlegemets væg, der placeres oppe i hullet i forhold til den ringformede tætning (4), hvor den ene eller flere åbninger dannes før tilførslen af legeringskuglerne (9) ved hjælp af et hulfremstillingsredskab, der udgør en del af den ringformede tætningsreparationsredskabsanordning (11).

6. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor borehulsmålområdet bevæges for at medvirke til passage af legeringskuglerne (9) gennem den ene eller flere åbninger (5) ind i ringvolumenet (3);

hvor fortrinsvis deflektoren (8, 12, 22, 31) og/eller rørlegemet (2) vibreres for at bevæge borehulsmålområdet.

7. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor deflektoren (8, 12, 22, 31) omfatter isoleringsmidler konfigureret til at begrænse passage af varme ledt gennem deflektoren; og/eller

deflektoren (8, 22, 31) anbringes i borehullet i en uudvidet eller delvist udvidet tilstand og derefter udvides mod rørlegemetets væg i borehulsmålområdet for således at øge det omfang, hvori deflektoren omdirigerer legeringskuglerne (9).

8. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor legeringskuglerne (9) tilvejebringes i form af en lavtsmeltende legering, der har et smeltepunkt på under 300 °C; og hvor legeringskuglerne fortrinsvis tilvejebringes i form af en bismuthbaseret legering.

9. Ringformet tætningsreparationsredskabsanordning (6, 11, 20, 30) til borehul til anvendelse i dannelse af en legeringsprop (10) på en eksisterende, ringformet tætning (4), der i det væsentlige omgiver et olie-/gasbrøndboringsrørlegeme (2), hvor enheden omfatter:

et tilførselsbærerforbindelsespunkt, hvormed anordningen kan forbindes til tilførselsmidlet via en tilførselsbærer, således at anordningen kan føres til og hentes fra et målborehulsområde for brøndboringen via rørlegemet (2);

et opvarmningsværktøj (7, 32) med mindst ét varmelegeme, hvor opvarmningsværktøjet er konfigureret til at hæve temperaturen inde i borehulsmålområdet til en temperatur, der er tilstrækkelig til at smelte legeringskugler (9) ophobet inde i ringvolumenet (3) for således at muliggøre dannelse af legeringsproppen (10) på den eksisterende ringformede tætning (4); og

kendetegnet ved en deflektor (8, 12, 22, 31) anbragt oppe i hullet i forhold til opvarmningsværktøjet (7, 32), hvor deflektoren er konfigureret til at spærre for legeringskugler (9) tilført borehullet og omdirigere dem radiale udefter mod brøndboringsrørlegemetets vægge.

10. Anordning ifølge krav 9, hvor opvarmningsværktøjet (7, 32) omfatter flere varmelegemer, der styres uafhængigt.

11. Anordning ifølge krav 9 eller 10, hvor deflektoren (8, 12, 31) omfatter en flade, der vender op mod hullet, og som omfatter mindst ét hældende område; og

hvor fortrinsvis fladen af deflektoren, der vender op mod hullet, er kegleformet og keglens spids fortrinsvis placeres ved deflektorens midterakse.

12. Anordning ifølge et hvilket som helst af kravene 9 til 11, og som endvidere omfatter en bevægelsesmekanisme konfigureret til at bevæge og/eller vibrere brøndboringens målborehulsområde;

hvor fortrinsvis bevægelsesmekanismen er konfigureret til at vibrere deflektoren (8, 12, 22, 31) og/eller rørlegemet (2) inde i brøndboringens målborehulsområde.

13. Anordning ifølge et hvilket som helst af kravene 9 til 12, hvor deflektoren (8, 22, 31) er konfigureret til at kunne udvides radialt udefter mod rørlegemets væg;

hvor den mekanisme, hvormed udvidelsen af deflektoren opnås, fortrinsvis vælges blandt hydrauliske midler, pneumatiske midler, mekaniske midler og kombinationer deraf;

hvor deflektoren mere fortrinsvis tvinges til at udvides og/eller sammentrækkes ved hjælp af ét eller flere elastiske forspændingsmidler; og

hvor deflektoren (31) endnu mere fortrinsvis omfatter en afdækning af fleksibelt materiale (38) forbundet med en paraplyfjedermekanisme (40).

14. Anordning ifølge et hvilket som helst af kravene 9 til 13, hvor deflektoren (8, 12, 22, 31) omfatter isoleringsmidler konfigureret til at begrænse passage af ledt varme gennem deflektoren.

15. Anordning ifølge et hvilket som helst af kravene 9 til 14, og som endvidere omfatter en tilførselsbærer valgt blandt: spiralrør, rør, slick-line og metalkabel;

hvor tilførselsbæreren fortrinsvis enten er spiralrør eller rør og således er konfigureret til at tilføre legeringskugler til brøndboringens målborehulsområde.

16. Anordning ifølge et hvilket som helst af kravene 9 til 14, og som endvidere omfatter legeringskugletilførselsmiddel i form af en aflæsningsbeholder (21) anbragt oppe i hullet i forhold til deflektoren (22) og opvarmningsværktøjet (7).

17. Anordning ifølge et hvilket som helst af kravene 9 til 16, og som endvidere omfatter hulfremstillingsudstyr (13) konfigureret til at danne én eller flere åbninger i brøndboringsrørlegemets vægge;

hvor hulfremstillingsudstyret fortrinsvis vælges blandt: en boremaskine, et mekanisk stempel, en perforeringspistol, en sav eller et hvilket som helst andet egnet skæreredskab, såsom kemiske skærere og væskestråleskærere.

18. Anordning ifølge et hvilket som helst af kravene 9 til 17, og som endvidere omfatter en skrotkurv (14) placeret ved anordningens forreste ende.

DRAWINGS

Drawing

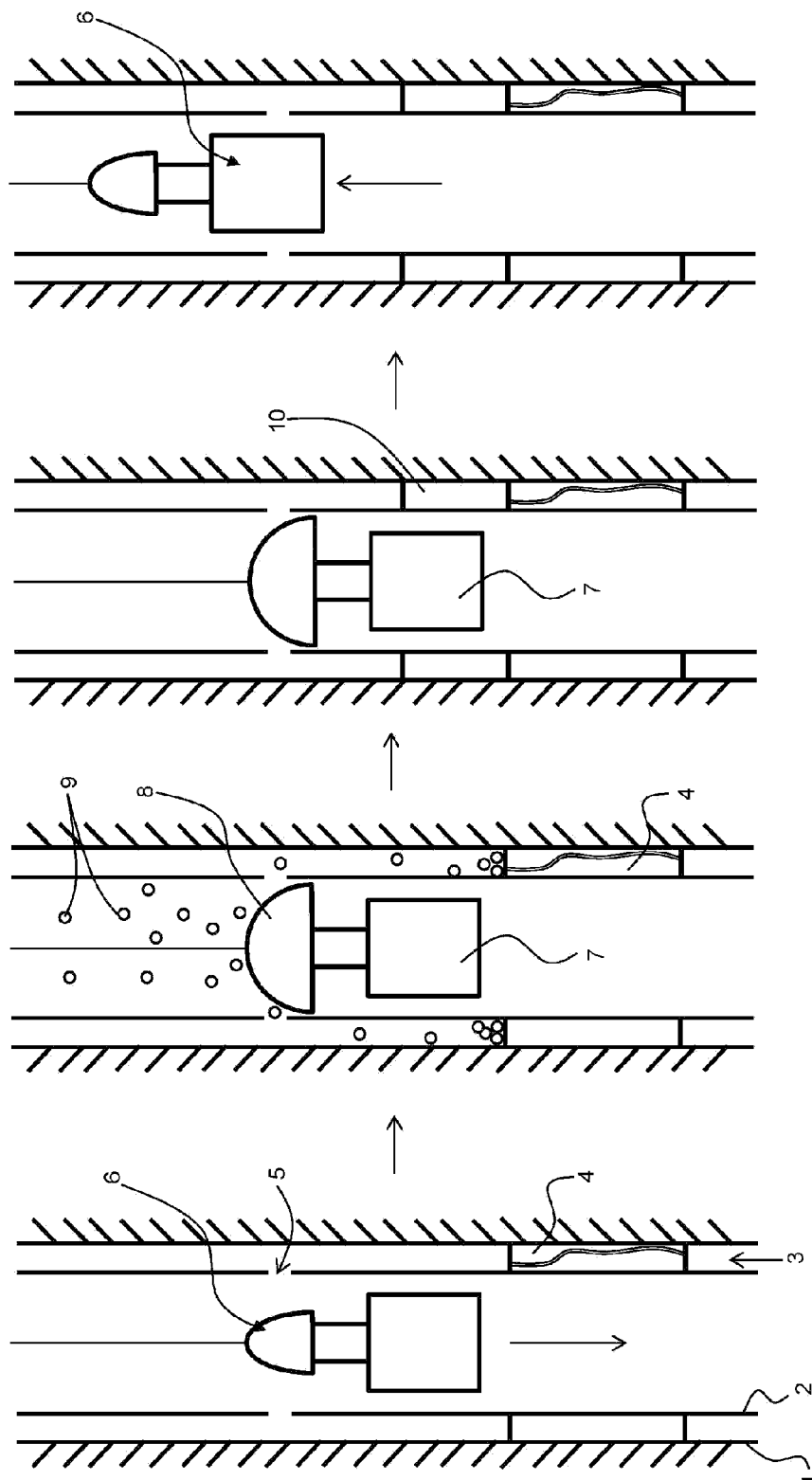


Fig. 1

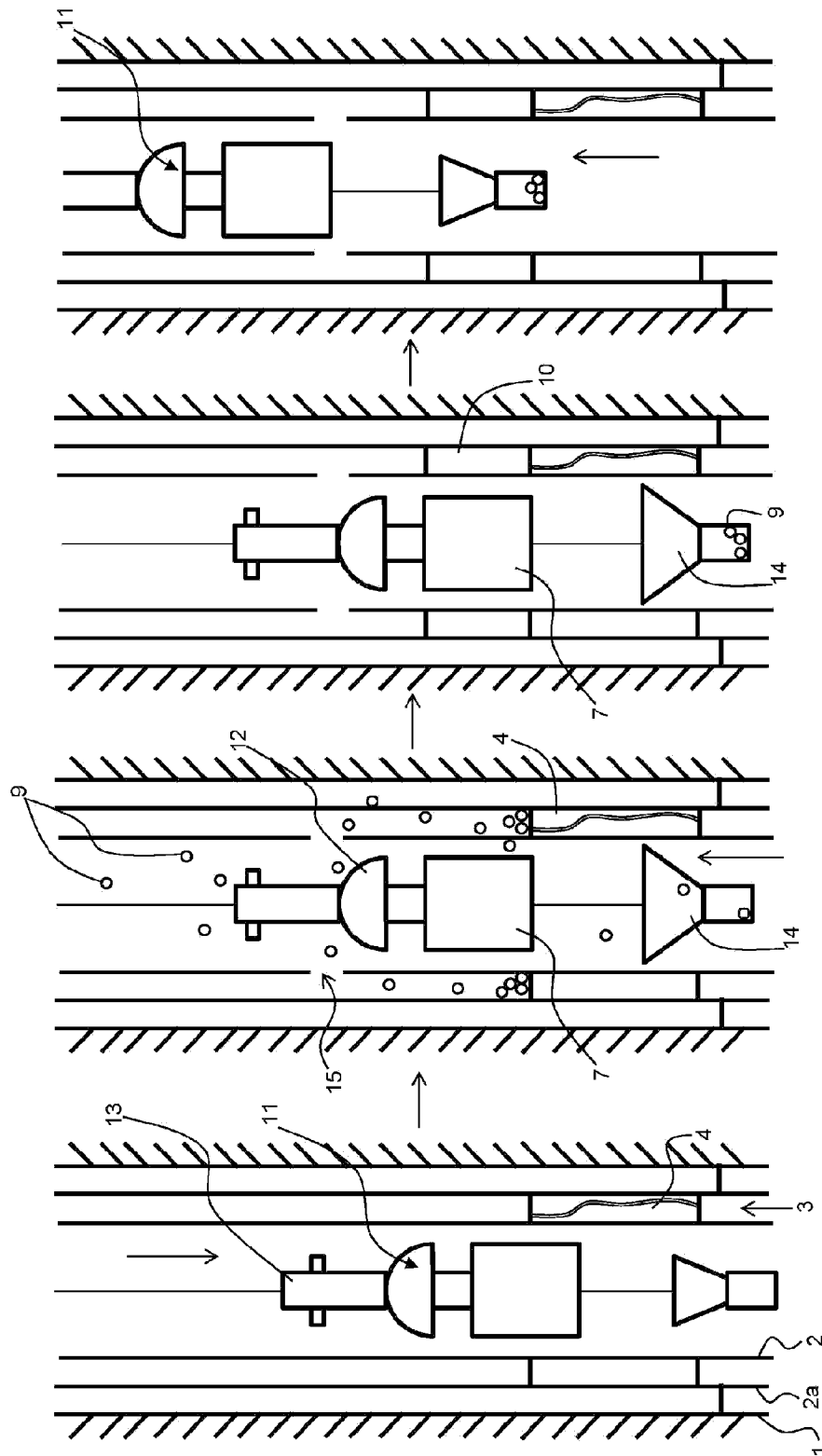


Fig. 2

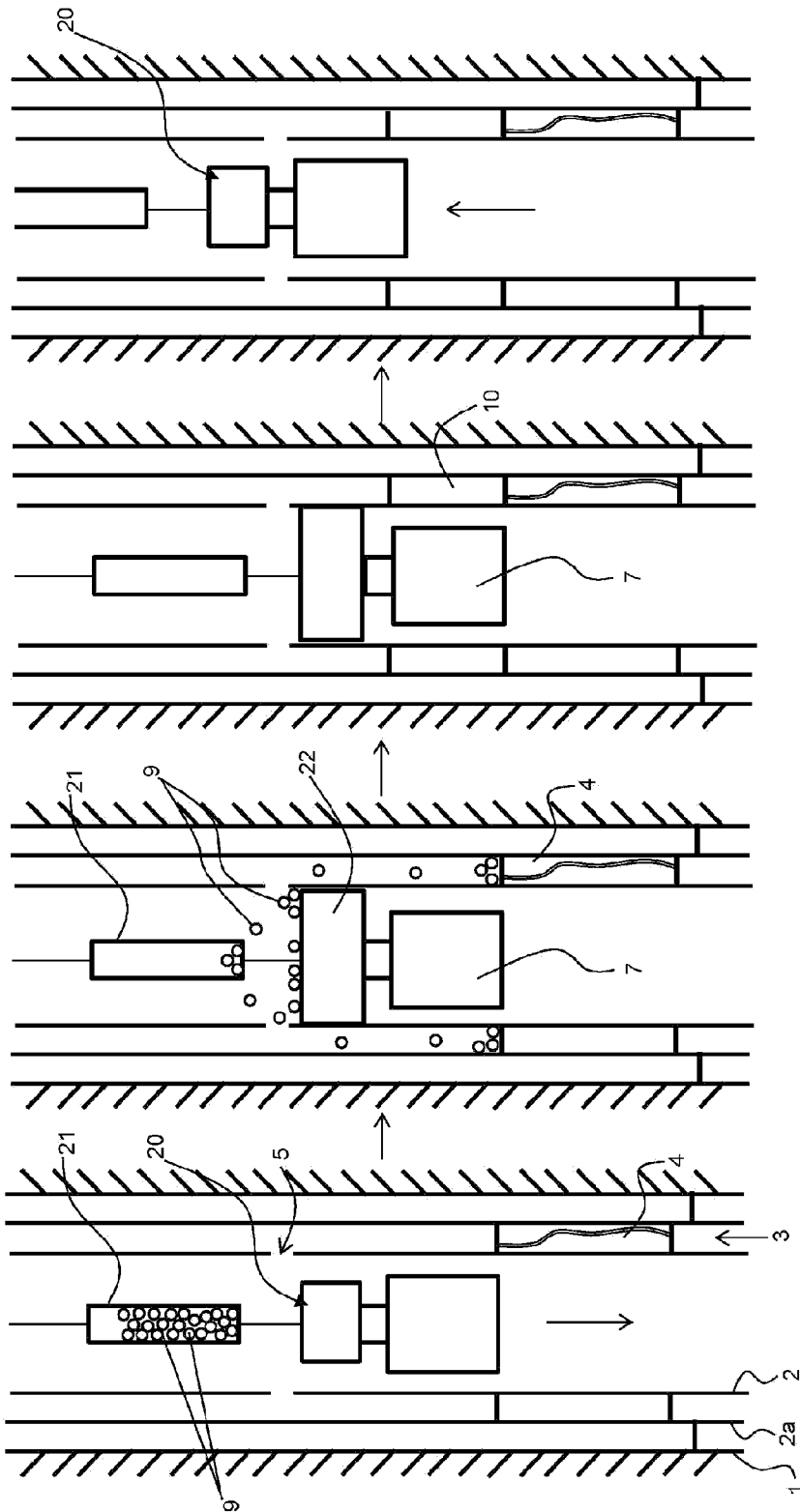


Fig. 3

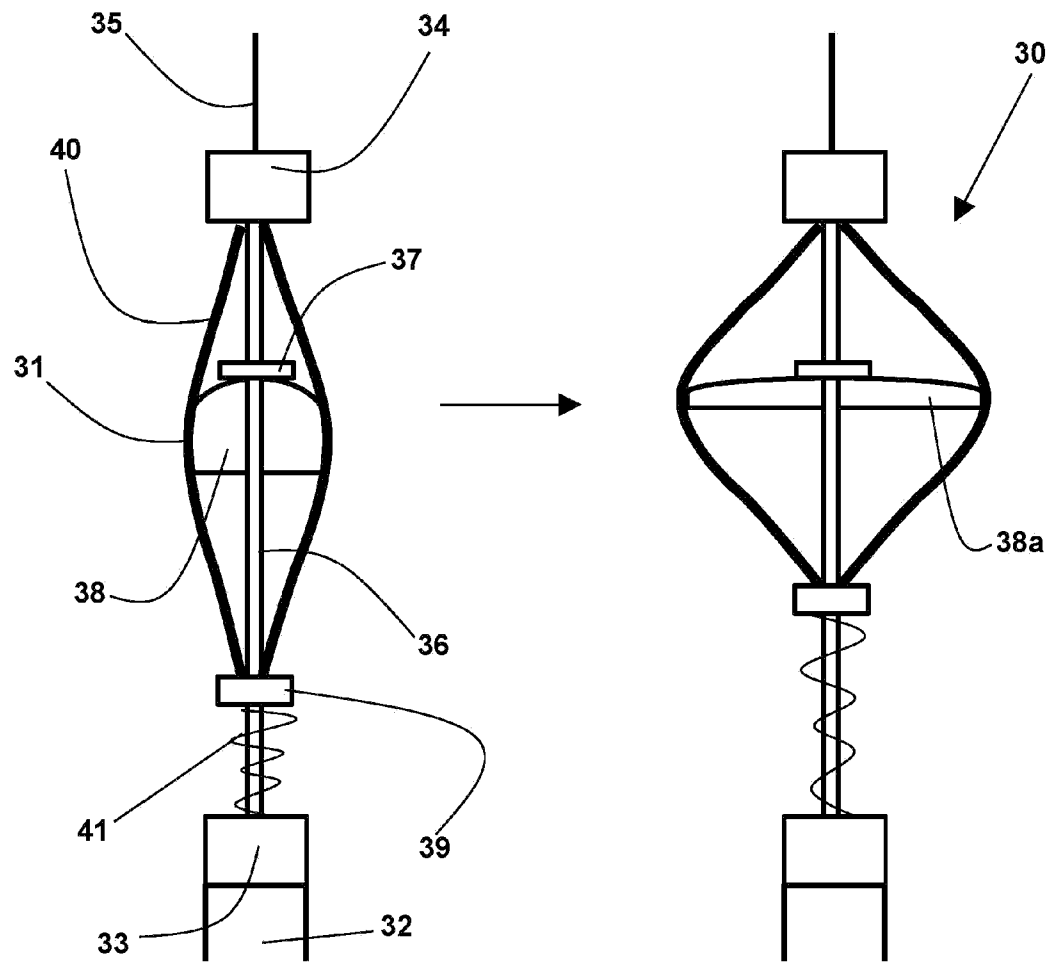


Fig. 4