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(54) Title: A METHOD OF PLUGGING AND ABANDONING A WELL

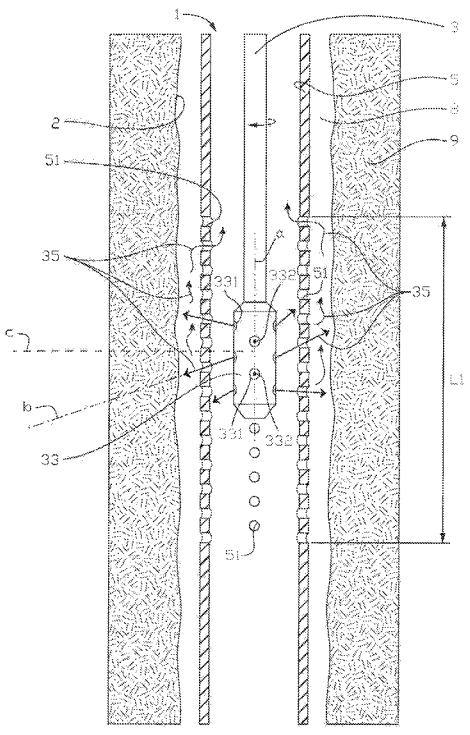

Fig. 6

(57) Abstract: A method of plugging and abandoning a well (1), comprising : (A) lowering a perforation tool (31) into a pipe string (5) onto a longitudinal section (LI); (B) with the perforation tool (31), forming perforations (51) along said longitudinal section (LI); (C) with a flushing tool (33) attached to a work string (3) and lowered onto said longitudinal section (LI), pumping a flushing fluid (35) through the work string (3), out through at least one flushing outlet (331) in the flushing tool (33), into the pipe string (5) and into said annulus (8) via the perforations (51), wherein an outlet axis (b) of said flushing outlet (331) is non-perpendicular to a longitudinal axis (a) of the flushing tool (33); (D) pumping a fluidized plugging material (37) through the work string (3) and into the pipe string (5) at said longitudinal section (LI); (E) placing the fluidized plugging material (37) in the pipe string (5) along at least said longitudinal section (LI), thereby also placing the fluidized plugging material (37) in said annulus (8) via the perforations (51); (F) pulling the work string (3) out of the well (1); and (G) abandoning the well (1).

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A METHOD OF PLUGGING AND ABANDONING A WELL

The invention concerns a method of plugging and abandoning (P & A) a subterranean well. As such, the present method may be used for temporary or permanent plugging and abandonment of such a well. Further, the present method may be used in any type of subterranean well, including petroleum wells, for example production wells and injection wells.

The present method involves perforation, cleaning and plugging of a longitudinal section of the well located at a desired depth interval in the well. More specifically, the invention concerns a method that provides hydraulic isolation, in the form of a well plug, across a complete cross section of the well along at least the longitudinal section thereof. The plug provides pressure-isolation both horizontally and vertically along said longitudinal section of the well. The well is also provided with a pipe string in at least the longitudinal section of the well where the pressure-isolating well plug is to be formed.

It is known to establish a pressure-isolating barrier in a well by virtue of mechanically milling and removing a longitudinal section of casing in the well. Cement slurry is then placed into the milled-away section of the well so as to form, upon curing, a pressure-isolating cement barrier across the complete cross section of this milled-away section of the well. This technology is generally referred to as "section milling" and has been used for decades to plug and abandon wells. Such section milling operations are very time-consuming and very costly for operators of the wells. Section milling operations generally require the presence of surface installations to allow metal shavings, so-called swarf, to be separated from the well fluids used during such milling operations. Various types of cleaning fluids are frequently required to allow transportation of such metal shavings (swarf) up to the surface of the well. Further, such metal shavings may become lodged in other equipment in the well, for example in a blowout preventer (BOP), so as to represent obstructions in the well. Such metal shavings are also troublesome to dispose of and generally represent hazardous materials to handle.

It is also known to establish such a well plug by means of the method and washing tool disclosed in WO 2012/096580 A1 (termed HydraWash technology). This method is suitable for use together with the displacement apparatus and method disclosed in WO 2012/128644 A2 (termed Archimedes technology).

The object of the invention is to remedy or reduce at least one disadvantage of the prior art, which includes said section milling technology, or at least to provide a useful alternative to the prior art.

The object is achieved by virtue of features disclosed in the following description and in the subsequent claims.

The invention concerns a method of plugging and abandoning (P & A) a well temporarily or permanently. The method involves perforation, cleaning and plugging of a longitudinal section of the well, said longitudinal section comprising a wellbore, a pipe string placed within the wellbore, and an annulus located between the wellbore and the pipe string.

The present method comprises the following steps:

(A) lowering a perforation tool into the pipe string onto said longitudinal section of the well;

(B) by means of the perforation tool, forming perforations (i.e. penetrating holes) in the pipe string along said longitudinal section;

(C) by means of a flushing tool attached to a lower end portion of a tubular work string, which is lowered into the pipe string onto said longitudinal section, pumping a flushing fluid down through the tubular work string, out through at least one flushing outlet in the flushing tool, into the pipe string and further out into said annulus via the perforations in the pipe string, thereby cleaning both the pipe string and the annulus along said longitudinal section,

wherein an outlet axis of at least one of said at least one flushing outlet in the flushing tool is non-perpendicular to a longitudinal axis of the flushing tool, whereby a corresponding flushing jet from the flushing tool also is non-perpendicular to the longitudinal axis of the flushing tool;

(D) pumping a fluidized plugging material down through the tubular work string and into the pipe string at said longitudinal section;

(E) placing the fluidized plugging material in the pipe string along at least said longitudinal section, thereby also placing the fluidized plugging material in said annulus via the perforations in the pipe string, whereupon the fluidized plugging material forms a plug covering substantially a complete cross section of the well along

at least said longitudinal section of the well;

(F) pulling the tubular work string out of the well; and

(G) abandoning the well.

This non-perpendicular configuration of the at least one flushing outlet in the flushing tool ensures very effective flushing and cleaning of both the pipe string and the annulus outside the pipe string. This in turn ensures good filling and good adhesion of the subsequent plugging material in the pipe string and in the annulus.

Said pipe string may be composed of a well pipe of a type known *per se*, for example a casing or a liner. As such, the pipe string may extend fully or partially, respectively, to the surface of the well.

Typically, the tubular work string is comprised of a drill string or a coiled-tubing string of a type known *per se*.

In one embodiment, the flushing tool is formed with a plurality of flushing outlets having respective outlet axes (i.e. longitudinal axes through the flushing outlets) angled within ± 80° of a plane being perpendicular to the longitudinal axis of the flushing tool. By so doing, corresponding flushing jets from the flushing tool are also angled within ± 80° of said perpendicular plane.

Each of the at least one flushing outlet may also be provided with a releasable nozzle insert. As such, the nozzle insert may be releasably connected to the flushing tool via a threaded connection or similar. Such a nozzle insert is of a suitable size and shape for generating a flushing jet of desired concentration and distribution. The feature of being releasable also ensures that the nozzle insert is readily replaceable, if desired or required.

As such, said nozzle insert may be radially telescopic relative to the flushing tool, and wherein the telescopic motion of the nozzle insert is selectively activated. Such a feature allows the nozzle insert to be selectively extended or retracted relative to the flushing tool. By so doing, the flushing tool may be lowered into the pipe string of the well with the at least one nozzle insert retracted into the flushing tool. Once placed in the well, said nozzle insert may be selectively extended outward from the body of the flushing tool. Such an embodiment of the flushing tool may prove advantageous in cases where the pipe string has one or more restrictions therein requiring a smaller sized flushing tool to be used for allowing access into the pipe string.

Further, the flushing fluid may comprise drilling mud. This is generally a suitable

flushing fluid given that drilling mud usually is readily available and also functions as a pressure barrier in a well.

The flushing fluid may also contain a cleaning agent, for example a suitable soap or acid.

Yet further, the fluidized plugging material may comprise cement slurry for formation of a cement plug.

As an alternative or addition, the fluidized plugging material may comprise a fluidized particulate mass for formation of a plug made of particulate mass. Such a particulate mass is generally in an unconsolidated form. A somewhat different use of such a fluidized particulate mass in a well is disclosed in e.g. WO 01/25594 A1 and in WO 02/081861 A1.

Between steps (B) and (C), the method may also comprise the following steps:
- pulling the perforation tool out of the well; and
- attaching the flushing tool to the lower portion of the tubular work string for subsequent performance of step (C). By so doing, perforation and flushing are performed in separate trips into the well.

As an alternative, and before step (A), the method may also comprise the following steps:
- connecting the perforation tool and the flushing tool into an assembly thereof; and
- connecting the assembly to said lower portion of the tubular work string. By so doing, perforation and flushing are performed in one and the same trip into the well. Naturally, these steps will save on the time and cost of plugging and abandoning the well.

Further to the latter alternative, the method may also comprise the following steps:
- releasably connecting, before step (A), the perforation tool to a lower end portion of the flushing tool; and
- disconnecting, between steps (B) and (C), the perforation tool from the flushing tool. By so doing, the perforation tool is dropped further down into the pipe string and is thus left behind in the well. This may facilitate the subsequent operation of the flushing tool in the well and, as such, may save further on the time and cost of carrying out the operation.

In another embodiment, step (C) of the method comprises rotating the tubular work string whilst flushing. Such rotation ensures larger area coverage of the flushing

motion and thus enables better cleaning of the pipe string and the annulus.

Additionally or alternatively, step (C) of the method may also comprise moving the tubular work string in a reciprocating motion whilst flushing. Such reciprocation also ensures larger area coverage of the flushing motion and thus enables better cleaning of the pipe string and the annulus.

Step (E) of the method may also comprise moving the tubular work string within the pipe string whilst placing the fluidized plugging material therein. As such, the tubular work string may be moved in a suitable manner along the perforated longitudinal section of the pipe string for effective placement of the plugging material in the well.

Before step (C), the method may comprise adding an abrasive agent to the flushing fluid. This is particularly appropriate if the annulus is filled with e.g. cement residues (or some other casting material) and/or solid particles settled out within the annulus, e.g. barite particles settled out from drilling mud in the annulus. Such solid materials may become difficult to remove from the annulus if the flushing fluid is void of such an abrasive agent.

In one embodiment, the method comprises adding the abrasive agent to the flushing fluid in an amount of between 0.05 per cent by weight and 1.00 per cent by weight. The abrasive agent may comprise sand particles. As such, and as an example, adding approximately 0.1 per cent by weight of sand to the flushing fluid appears to be a suitable mixture.

Further, the method may comprise discharging the flushing fluid from said at least one flushing outlet in the flushing tool at a discharge velocity of at least 15 metres per second. The present applicant has carried out tests showing that a discharge velocity of 15 metres per second is a minimum value required for allowing the flushing tool to clean sufficiently in the well.

In an advantageous embodiment, the method therefore comprises discharging the flushing fluid from the at least one flushing outlet at a discharge velocity of at least 50 metres per second. The above-mentioned tests have also shown that a discharge velocity of at least 50 metres per second provides a particularly effective cleaning result in the well.

Optimum discharge velocities for the flushing fluid, as well as optimum amounts of abrasive agent added thereto, depend on the type of flushing fluid used, and particularly with respect to the viscosity of the flushing fluid. High-viscosity flushing

fluids usually require higher discharge velocities from the flushing tool than those of low-viscosity flushing fluids. This is simply because high-viscosity flushing fluids experience more internal friction, hence are slowed down faster, than that of low-viscosity flushing fluids.

Another embodiment of the method comprises discharging the flushing fluid from the at least one flushing outlet as a substantially rotation-free flushing jet. If such a flushing jet discharges from a nozzle insert disposed in the flushing outlet, this nozzle insert requires less space for support in the flushing tool than that of an alternative nozzle insert having a design capable of instilling a rotational/spinning effect on the flushing jet.

Before step (D), the method may also comprise disposing and anchoring a plug base in the pipe string, and below the longitudinal section of the well. Such a plug base may comprise a mechanical plug, a packer element and/or at least one cup-shaped element, e.g. swab cup, of a type known *per se*. The purpose of such a plug base is to support the fluidized plugging material once placed in the well. Typically, such a plug base (e.g. mechanical plug) is deployed into the pipe string carried on a so-called wireline or on a tubular work string, e.g. drill pipe string or coiled tubing, extending up to the surface of the well.

Alternatively, a column of a viscous fluid, i.e. a so-called viscous pill, may be pumped into the pipe string, and below the longitudinal section of the well, to support said fluidized plugging material.

Further, if said longitudinal section is located at a relatively short distance from the bottom of the pipe string, it may not be necessary to set such a plug base in the pipe string. Instead, the fluidized plugging material is filled from the bottom of the pipe string and upward until the plugging material covers the longitudinal section of the well.

In yet another embodiment, and between steps (C) and (D), the method also comprises the following steps:

- pulling the tubular work string and the flushing tool out of the well;
- disconnecting the flushing tool from the tubular work string; and
- lowering an open-ended tubular work string into the pipe string onto said longitudinal section for subsequent performance of steps (D) and (E) of the method.

By so doing, flushing with the flushing fluid and displacement of the fluidized plugging material are performed in separate trips into the well.

Steps (D) and (E) of the method may also comprise pumping the fluidized plugging material into the pipe string via at least one spraying outlet in the flushing tool so as to discharge as a corresponding spraying jet from the flushing tool. By so doing, flushing with the flushing fluid and spraying with the fluidized plugging material are performed in one and the same trip into the well. Naturally, these steps will save on the time and cost of plugging and abandoning the well. By virtue of embodying the fluidized plugging material as a spraying jet emanating from the flushing tool, the plugging material also becomes directional and somewhat concentrated. This is advantageous in that such a spraying jet reaches further out from the flushing tool and may thus engage the formation wall defining the wellbore more readily and forcefully. Such a spraying jet also gains better access to potential voids in said annulus surrounding the pipe string along the longitudinal section of the well.

In one embodiment of the latter variant of the method, the flushing tool comprises a first section for discharging, in step (C), the flushing fluid via said at least one flushing outlet, and a second section for spraying, in steps (D) and (E), the fluidized plugging material via said at least one spraying outlet in the flushing tool.

As such, the diameter of said spraying jet of fluidized plugging material discharging from said second section of the flushing tool may be larger than the diameter of said flushing jet of flushing fluid discharging from said first section of the flushing tool. By so doing, and as opposed to general placing and displacement of the fluidized plugging material in the well, the plugging material may engage said formation wall more readily and forcefully. The fluidized plugging material will also gain better access to potential voids in the annulus along the longitudinal section of the well. A smaller diameter of said flushing jet of flushing fluid, however, ensures a more concentrated jet for breaking up and flushing away solids and particles along its flow path in the well.

In the latter context, the method may also comprise discharging said spraying jet of fluidized plugging material at a discharge velocity in the order of 15-25 metres per second, and preferably in the order of 18-22 metres per second. This range of discharge velocities is advantageous in achieving the spraying effect of the fluidized plugging material.

In another embodiment of said latter variant of the method, said at least one flushing outlet and said at least one spraying outlet in the flushing tool are one and the same, whereby both the flushing fluid and the fluidized plugging material will discharge through said at least one outlet in the flushing tool; and

- wherein the method comprises discharging said flushing jet of flushing fluid at a higher discharge velocity than that of said subsequent spraying jet of fluidized plugging material. Variations in the discharge velocity of the respective fluids may be achieved by changing the pump rate of the fluid in question.

As such, the method may comprise discharging the flushing fluid at a discharge velocity of at least 50 metres per second, and then discharging the subsequent fluidized plugging material at a discharge velocity in the order of 15-25 metres per second.

Yet further, the method may also comprise the following steps:
- connecting, before step (D), a displacement body to the tubular work string, and in vicinity of the flushing tool; and
- using, in step (E), the displacement body to further displace and distribute the fluidized plugging material in the pipe string and further out into said annulus via said perforations in the pipe string along the longitudinal section of the well. This facilitates the displacement and distribution of fluidized plugging material within said longitudinal section is facilitated. A displacement body suitable for this purpose is disclosed in WO 2012/128644 A2 (termed Archimedes technology), as mentioned initially.

Hereinafter, an exemplary embodiment of the method is described and depicted in the accompanying drawings, where:

Figure 1 shows, in side view, a well within which a casing string is disposed;

Figure 2 shows, in side view, the well after having removed a longer portion of the casing string in accordance with a prior art plugging method (i.e. section milling);

Figure 3 shows, in side view, the well of Figure 2 after having established a plug in the well in accordance with this prior art section milling plugging method;

Figure 4 shows, in side view, the well as used in context of the present method, and after having lowered a perforation tool into the casing string;

Figure 5 shows, in side view, the well after having perforated the casing string with the perforation tool, and after having pulled the perforation tool out of the well;

Figure 6 shows, in side view, the well after having lowered a flushing tool into the casing string, and whilst using the flushing tool to flush and clean away e.g. solid particles in the well;

Figure 7 shows, in side view, the well whilst filling and thus placing a fluidized plugging material into a portion of a longitudinal section of the well, thereby filling substantially the entire cross section of the well with the plugging material along the longitudinal section;

Figure 8 shows, in side view, the well after having plugged the well along the longitudinal section thereof by means of the present method; and

Figure 9 shows, in side view, a combined perforation and flushing tool for use in one embodiment of the present method.

The figures are schematic and merely show steps, details and equipment being essential to the understanding of the invention. Further, the figures are distorted with respect to relative dimensions of elements and details shown in the figures. The figures are also somewhat simplified with respect to the shape and richness of detail of such elements and details. Elements not being central to the invention may also have been omitted from the figures. Further, equal, equivalent or corresponding details shown in the figures will be given substantially the same reference numerals.

Figure 1 shows a well 1 to be plugged and abandoned after having removed a longer portion of a pipe string, here in the form of a single casing string 5, in accordance with a prior art plugging method (i.e. so-called section milling). The figure shows the casing string 5 disposed within a wellbore 2 of the well 1. A surrounding rock formation 9 defines the wellbore 2. An annulus 8 also exists between the wellbore 2 and the casing string 5. Typical well fluids known to a person skilled in the art are also present in the well 1.

Figure 2 shows the well 1 after having removed a longer portion/section of the casing string 5 in accordance with the noted prior art section milling plugging method. A substantial length of the casing string 5 is thus milled away.

Figure 3 then shows the well 1 after having filled cement slurry, i.e. a fluidized plugging material, into the milled-away section of the well 1 so as to fill the entire cross section T1 thereof. Upon curing, this cement slurry forms a pressure-isolating cement plug 25 along the milled-away section of the well 1, as shown in Figure 3. This section milling method has several disadvantages, as mentioned initially.

Figure 4 shows a first step in the present method as applied in a similar well 1. Also here a single casing string 5 is disposed within a wellbore 2 of a well 1 so as to leave an annulus 8 between the wellbore 2 and the casing string 5. A tubular work string, here in the form of a drill string 3, has been lowered into the casing string 5 onto a longitudinal section L1 of the well 1 to be plugged and abandoned by virtue of the present method. A perforation tool, here in the form of a perforation gun 31 of a type known *per se*, has also been connected to a lower end portion of the drill string 3. Once placed at the longitudinal section L1 of the well 1, the perforation gun 31 is activated and forms a number of perforations 51 along the longitudinal section L1 and through the wall of the casing string 5, as shown in Figure 5. In one embodiment, the perforation gun 31 may be pulled out of the well 1 and disconnected from the drill string 3 after having completed the perforation operation.

Figure 6 shows the well 1 after having lowered a flushing tool 33 into the casing string 5, and onto the longitudinal section L1, whilst being connected to a lower end portion of a drill string 3. This drill string may be the same drill string used in the preceding perforation step, or it may be another type of tubular work string, for example coiled tubing. This figure also shows the flushing tool 33 whilst flushing and cleaning away e.g. solid particles (not shown in the figures) in the well 1 along the longitudinal section L1 thereof. A curved arrow at the upper portion of the drill string 3 indicates rotation of the drill string 3, and hence rotation of the flushing tool 33 connected thereto, whilst flushing and cleaning with the flushing tool 33. Additionally or alternatively, the drill string 3, and thus the flushing tool 33, may be moved in a reciprocating motion whilst flushing and cleaning the longitudinal section L1 with the flushing tool 33. Rotation and/or reciprocation of the flushing tool 33 along the longitudinal section L1 whilst flushing ensures better and possibly repeated area coverage so as to enable better cleaning of the casing string 5 and the surrounding annulus 8 along the longitudinal section L1 of the well 1.

In this particular embodiment, the flushing tool 33 is formed with several flushing outlets 331 distributed in a desired pattern around the flushing tool 33. These flushing outlets 331 have respective outlet axes "b" angled within ± 80° of a plane "c" being perpendicular to the longitudinal axis "a" of the flushing tool 33. By so doing, corresponding flushing jets discharging from the flushing tool 33 are also angled within ± 80° of the perpendicular plane "c". Longitudinal axis "a", outlet axis "b" and perpendicular plane "c" are also shown in Figure 9.

Figure 6 also shows a flushing fluid 35 in the form of flushing jets discharging at high

velocity, and as substantially rotation-free jets, from corresponding nozzle inserts 332 provided in the flushing outlets 331 of the flushing tool 33. These nozzle inserts 332 ensure a desired concentration and distribution of the flushing jets upon discharging from the outlets 331 of the flushing tool 33. The flushing jets discharge at various angles relative to said perpendicular plane "c" and go through the corresponding perforations 51 and enter the annulus 8 at different angles. This ensures better access to areas of the annulus 8 located between the perforations 51, thereby ensuring better flushing and cleaning of these intermediate areas of the annulus 8. These angled flushing jets are depicted with straight arrows pointing outward from some of the flushing outlets 331 shown in Figure 6. The flow direction and potential flow paths of the discharging flushing fluid 35 are depicted with curved arrows located around the flushing tool 33 in Figure 6. At a particular instant, the discharging flushing fluid 35 therefore flows out through perforations 51 proximate to the flushing outlets 331, via the annulus 8 outside the casing string 5, and then flows back into the casing string 5 via perforations 51 more distal to the flushing outlets 331. The flushing tool 33 is moved slowly along the longitudinal section L1 whilst simultaneously flushing the casing string 5 and the annulus 8, thereby continuously repeating this instant flushing scenario along the longitudinal section L1 of the well 1. This flushing motion goes on until the entire longitudinal section L1 has been covered and cleaned sufficiently.

Before plugging the longitudinal section L1 of the well 1, a further cleaning and conditioning fluid is typically pumped in the described manner through the flushing tool 33 and into the casing string 5 and annulus 8, thereby further cleaning and conditioning the wellbore 2 and the casing string 5 for the purpose of allowing cement slurry 37, i.e. a fluidized plugging material, to be introduced into at least the longitudinal section L1 thereafter (cf. Figs. 7 and 8). This further cleaning and conditioning fluid may be comprised of a so-called spacer fluid, which is typically used to clean away remaining solids in the wellbore 2/annulus 8 and also to ensure water-wetting and conditioning of the casing string 5 and the surrounding rock formation 9 (which defines the wellbore 2) so as to bond well with the subsequent cement slurry 37 to be introduced therein. Such a spacer fluid is generally of less density than the cement slurry 37 used in plugging steps (D) and (E) of the present method. Therefore, the cement slurry 37 easily displaces the spacer fluid during these plugging steps.

Figure 7 shows the well 1 whilst pumping and thus placing cement slurry 37 into a lower portion of the longitudinal section L1 of the well 1, thereby filling substantially the entire cross section T1 of the well 1 with cement slurry 37. The figure shows cement slurry 37 flowing out of the lower end of the drill string 3 so as to fill the inside

of the casing string 5, after which the cement slurry 37 flows onward into the annulus 8 via the perforations 51 in the wall of the casing string 5. By so doing, the denser cement slurry 37 easily displaces the less dense spacer fluid (or other less dense well fluid), if present, upward within the well 1 and thus removes the spacer fluid from said longitudinal section L1. In context of pumping and displacing the cement slurry 37, the drill string 3 is moved slowly upward whilst filling and placing cement slurry 37 into the casing string 5 along the entire longitudinal section L1 of the well 1. This filling and moving step may also continue until cement slurry 37 has been filled into the casing string 5 to some desired level above the longitudinal section L1, whereby at least the longitudinal section L1 of the well 1 is filled with cement slurry 37. Before pumping the cement slurry 37 into the casing string 5, a mechanical plug 38 has been disposed and anchored within the casing string 5, and below the longitudinal section L1, to provide a supporting base for the cement slurry 37 once placed in the casing string 5.

Alternatively, and not shown in the figures, the flushing tool 33 may remain connected to the drill string 3 after having flushed and cleaned the longitudinal section L1. Cement slurry 37 is then pumped down the drill string 3 and discharges from the nozzle inserts 332 provided in the flushing outlets 331 of the flushing tool 33. In this case, the cement slurry 37 may discharge as spraying jets from the flushing tool 33, and at a significantly lower discharge velocity than that of the high discharge velocity of the preceding flushing jets of flushing fluid 35.

Figure 8 shows the well 1 after having filled cement slurry 37 into the casing string 5 and the surrounding annulus 8, as described hereinbefore, and after having cured therein so as to form a pressure-isolating cement plug 25 covering substantially the entire cross section T1 of the well 1 along at least the longitudinal section L1 thereof.

Upon having placed the cement slurry 37 into and along at least said longitudinal section L1 of the well 1, the drill string 3 is pulled out of the well 1. The well 1 is then abandoned temporarily or permanently.

Figure 9 shows a selectively releasable perforation tool 31 connected in a releasable manner to a lower end portion of a flushing tool 33 so as to form an assembly 34 thereof. The assembly 34 is connected to a lower portion of the drill string 3 (not shown in Figure 9). Selective release of the perforation tool 31 from the flushing tool 33 may be carried out by technical means and methods known *per se*. Use of such an assembly 34 allows perforation and flushing to be performed in one and the same trip into the well 1. By so doing, the perforation tool 31 is dropped further down into the casing string 5 and is thus left behind in the well 1. This may facilitate the subsequent

operation of the flushing tool 33 in the well 1 and, as such, may save further on the time and cost of carrying out such a plugging operation.

C l a i m s

1. A method of plugging and abandoning a well (1), the method involving perforation, cleaning and plugging of a longitudinal section (L1) of the well (1), said longitudinal section (L1) comprising a wellbore (2), a pipe string (5) placed within the wellbore (2), and an annulus (8) located between the wellbore (2) and the pipe string (5), wherein the method comprises the following steps:

(A) lowering a perforation tool (31) into the pipe string (5) onto said longitudinal section (L1) of the well (1);

(B) by means of the perforation tool (31), forming perforations (51) in the pipe string (5) along said longitudinal section (L1);

(C) by means of a flushing tool (33) attached to a lower end portion of a tubular work string (3), which is lowered into the pipe string (5) onto said longitudinal section (L1), pumping a flushing fluid (35) down through the tubular work string (3), out through at least one flushing outlet (331) in the flushing tool (33), into the pipe string (5) and further out into said annulus (8) via the perforations (51) in the pipe string (5), thereby cleaning both the pipe string (5) and the annulus (8) along said longitudinal section (L1),

wherein an outlet axis (b) of at least one of said at least one flushing outlet (331) in the flushing tool (33) is non-perpendicular to a longitudinal axis (a) of the flushing tool (33), whereby a corresponding flushing jet from the flushing tool (33) also is non-perpendicular to the longitudinal axis (a) of the flushing tool (33);

(D) pumping a fluidized plugging material (37) down through the tubular work string (3) and into the pipe string (5) at said longitudinal section (L1);

(E) placing the fluidized plugging material (37) in the pipe string (5) along at least said longitudinal section (L1), thereby also placing the fluidized plugging material (37) in said annulus (8) via the perforations (51) in the pipe string (5), whereupon the fluidized plugging material (37) forms a plug (25) covering substantially a complete cross section (T1) of the well (1) along at least said longitudinal section (L1) of the well (1);

(F) pulling the tubular work string (3) out of the well (1); and

(G) abandoning the well (1).

2. The method according to claim 1, wherein the flushing tool (33) is formed with a plurality of flushing outlets (331) having respective outlet axes (b) angled within ± 80° of a plane (c) being perpendicular to the longitudinal axis (a) of the

flushing tool (33), whereby corresponding flushing jets from the flushing tool (33) also are angled within ± 80° of said perpendicular plane (c).

3. The method according to claim 1 or 2, wherein each of the at least one flushing outlet (331) is provided with a releasable nozzle insert.

4. The method according to claim 3, wherein said nozzle insert is radially telescopic relative to the flushing tool (33), and wherein the telescopic motion of the nozzle insert is selectively activated.

5. The method according to any one of claims 1-4, wherein the flushing fluid (35) comprises drilling mud.

6. The method according to any one of claims 1-5, wherein the fluidized plugging material (37) comprises cement slurry for formation of a cement plug.

7. The method according to any one of claims 1-6, wherein the fluidized plugging material (37) comprises a fluidized particulate mass for formation of a plug made of particulate mass.

8. The method according to any one of claims 1-7, wherein the method, between steps (B) and (C), also comprises the following steps:
- pulling the perforation tool (31) out of the well (1); and
- attaching the flushing tool (33) to said lower end portion of the tubular work string (3) for subsequent performance of step (C);
whereby perforation and flushing are performed in separate trips into the well (1).

9. The method according to any one of claims 1-7, wherein the method, before step (A), also comprises the following steps:
- connecting the perforation tool (31) and the flushing tool (33) into an assembly (34) thereof; and
- connecting the assembly (34) to said lower portion of the tubular work string (3);
whereby perforation and flushing are performed in one and the same trip into the well (1).

10. The method according to claim 9, wherein the method also comprises the following steps:
- releasably connecting, before step (A), the perforation tool (31) to a lower end

portion of the flushing tool (33); and
- disconnecting, between steps (B) and (C), the perforation tool (31) from the flushing tool (33);
whereby the perforation tool (31) is dropped further down into the pipe string (7) and is left behind in the well (1).

11. The method according to any one of claims 1-10, wherein step (C) comprises rotating the tubular work string (3) whilst flushing.

12. The method according to any one of claims 1-11, wherein step (C) comprises moving the tubular work string (3) in a reciprocating motion whilst flushing.

13. The method according to any one of claims 1-12, wherein step (E) comprises moving the tubular work string (3) within the pipe string (5) whilst placing the fluidized plugging material (37) therein.

14. The method according to any one of claims 1-13, wherein the method, before step (C), comprises adding an abrasive agent to the flushing fluid (35).

15. The method according to claim 14, comprising adding the abrasive agent to the flushing fluid (35) in an amount of between 0.05 per cent by weight and 1.00 per cent by weight.

16. The method according to claim 14 or 15, wherein the abrasive agent comprises sand particles.

17. The method according to any one of claims 1-16, comprising discharging the flushing fluid (35) from said at least one flushing outlet (331) in the flushing tool (33) at a discharge velocity of at least 15 metres per second.

18. The method according to claim 17, comprising discharging the flushing fluid (35) from the at least one flushing outlet (331) at a discharge velocity of at least 50 metres per second.

19. The method according to any one of claims 1-18, comprising discharging the flushing fluid (35) from the at least one flushing outlet (331) as a substantially rotation-free flushing jet.

20. The method according to any one of claims 1-19, wherein the method, before step (D), also comprises disposing and anchoring a plug base (38) in the pipe string (5), and below the longitudinal section (L1) of the well (1).

21. The method according to claim 20, wherein the plug base (38) comprises at least one cup-shaped element.

22. The method according to any one of claims 1-21, wherein the method, between steps (C) and (D), also comprises the following steps:
- pulling the tubular work string (3) and the flushing tool (33) out of the well (1);
- disconnecting the flushing tool (33) from the tubular work string (3); and
- lowering an open-ended tubular work string (3) into the pipe string (5) onto said longitudinal section (L1) for subsequent performance of steps (D) and (E) of the method;
whereby flushing with the flushing fluid (35) and displacement of the fluidized plugging material (37) are performed in separate trips into the well (1).

23. The method according to any one of claims 1-22, wherein the method, in steps (D) and (E), comprises pumping the fluidized plugging material (37) into the pipe string (5) via at least one spraying outlet in the flushing tool (33) so as to discharge as a corresponding spraying jet from the flushing tool (33), whereby flushing with the flushing fluid (35) and spraying with the fluidized plugging material (37) are performed in one and the same trip into the well (1).

24. The method according to claim 23, wherein the flushing tool (33) comprises a first section for discharging, in step (C), the flushing fluid (35) via said at least one flushing outlet (331), and a second section for spraying, in steps (D) and (E), the fluidized plugging material (37) via said at least one spraying outlet in the flushing tool (33).

25. The method according to claim 24, wherein the diameter of said spraying jet of fluidized plugging material (37) discharging from said second section of the flushing tool (33) is larger than the diameter of said flushing jet of flushing fluid (35) discharging from said first section of the flushing tool (33).

26. The method according to claim 25, comprising discharging said spraying jet of fluidized plugging material (37) at a discharge velocity in the order of 15-25 metres per second.

27. The method according to claim 26, comprising discharging said spraying jet of fluidized plugging material (37) at a discharge velocity in the order of 18-22 metres per second.

28. The method according to claim 23, wherein said at least one flushing outlet (331) and said at least one spraying outlet in the flushing tool (33) are one and the same, whereby both the flushing fluid (35) and the fluidized plugging material (37) will discharge through said at least one outlet (331) in the flushing tool (33); and
- wherein the method comprises discharging said flushing jet of flushing fluid (35) at a higher discharge velocity than that of said subsequent spraying jet of fluidized plugging material (37).

29. The method according to claim 28, comprising discharging the flushing fluid (35) at a discharge velocity of at least 50 metres per second, and then discharging the subsequent fluidized plugging material (37) at a discharge velocity in the order of 15-25 metres per second.

30. The method according to any one of claims 1-29, wherein the method also comprises the following steps:
- connecting, before step (D), a displacement body to the tubular work string (3), and in vicinity of the flushing tool (33); and
- using, in step (E), the displacement body to further displace and distribute the fluidized plugging material (37) in the pipe string (5) and further out into said annulus (8) via said perforations (51) in the pipe string (5) along the longitudinal section (L1) of the well (1);
thereby facilitating the displacement and distribution of fluidized plugging material (37) within said longitudinal section (L1).

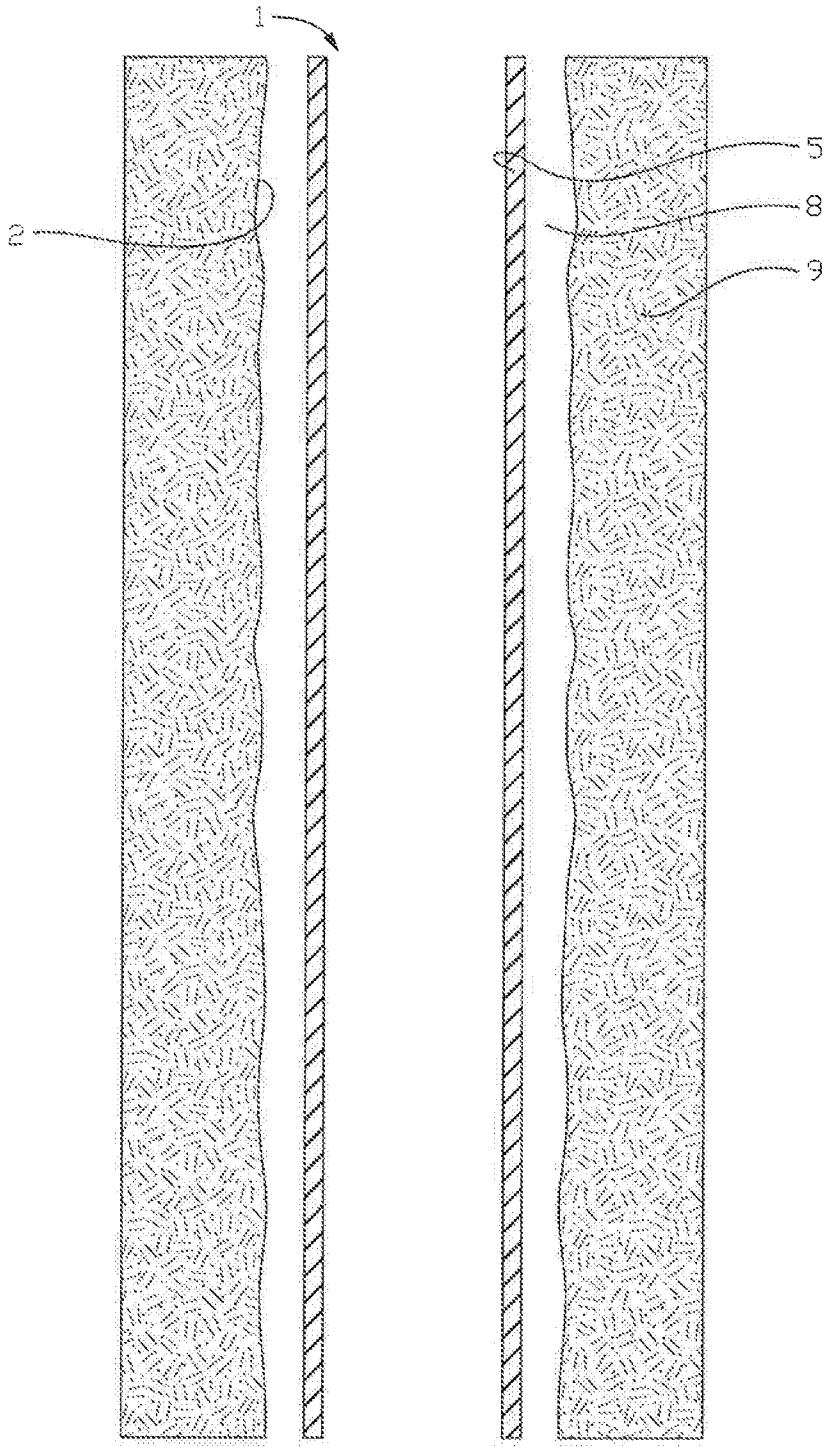

Fig. 1

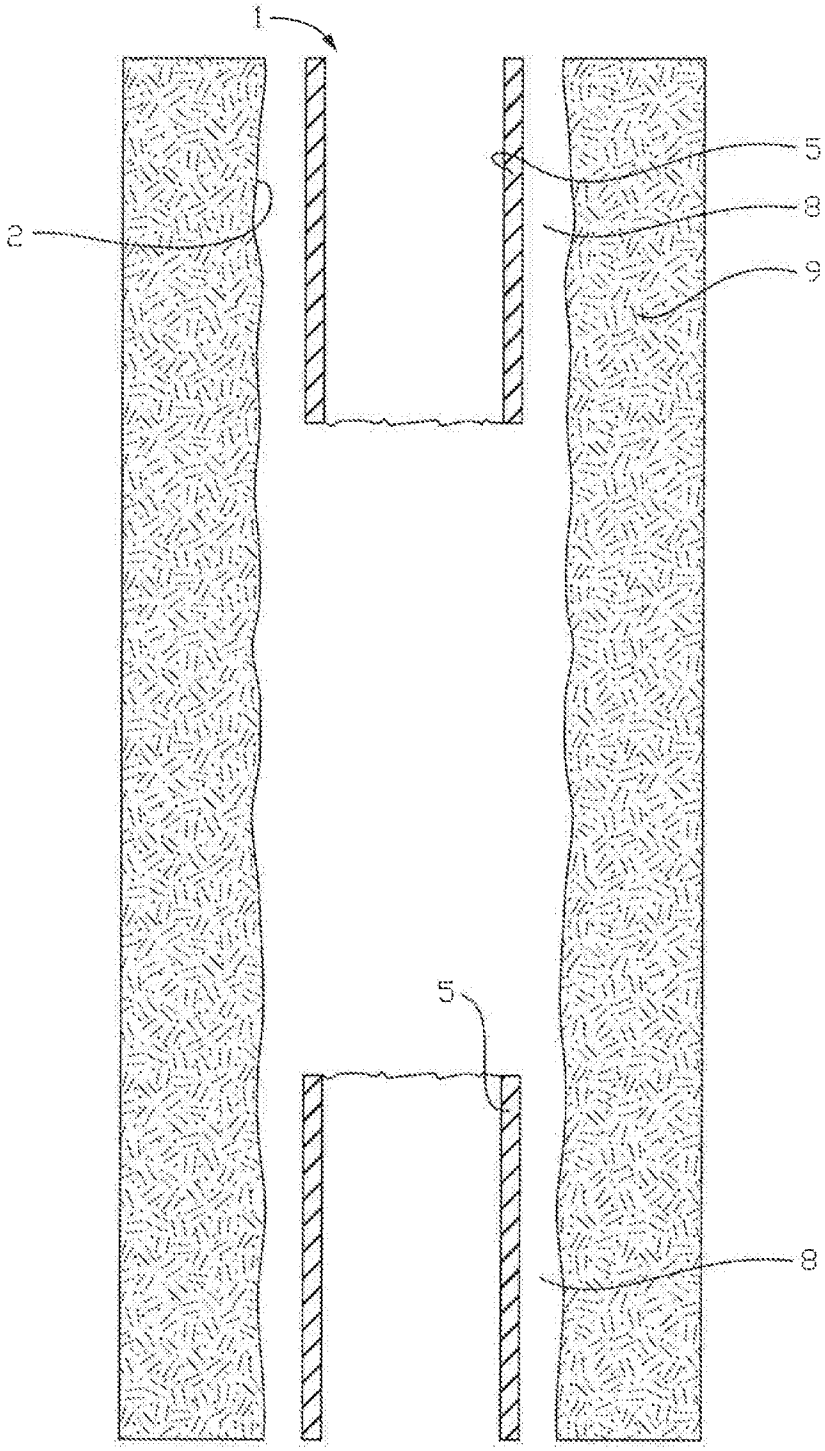

Fig. 2

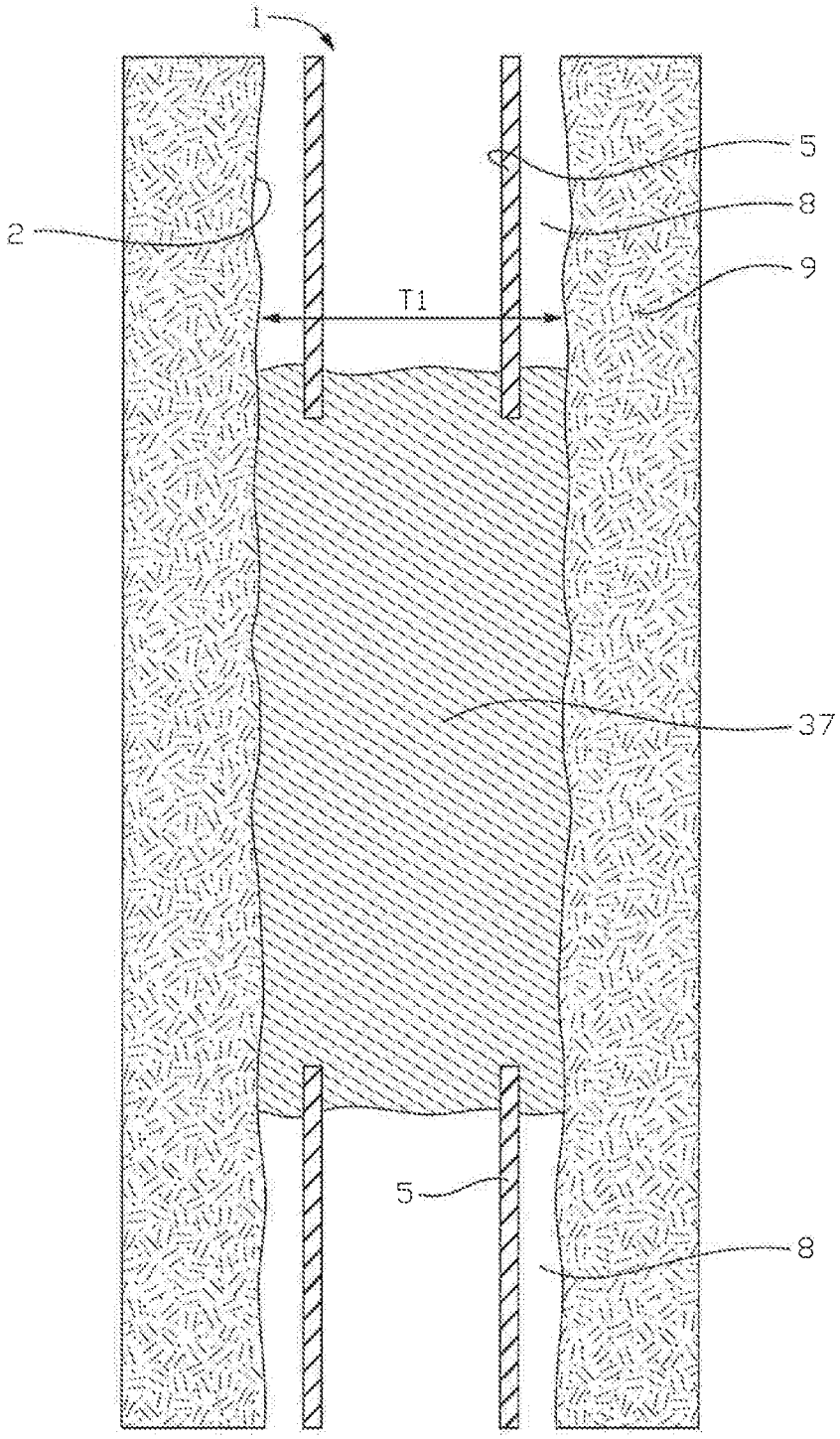

Fig. 3

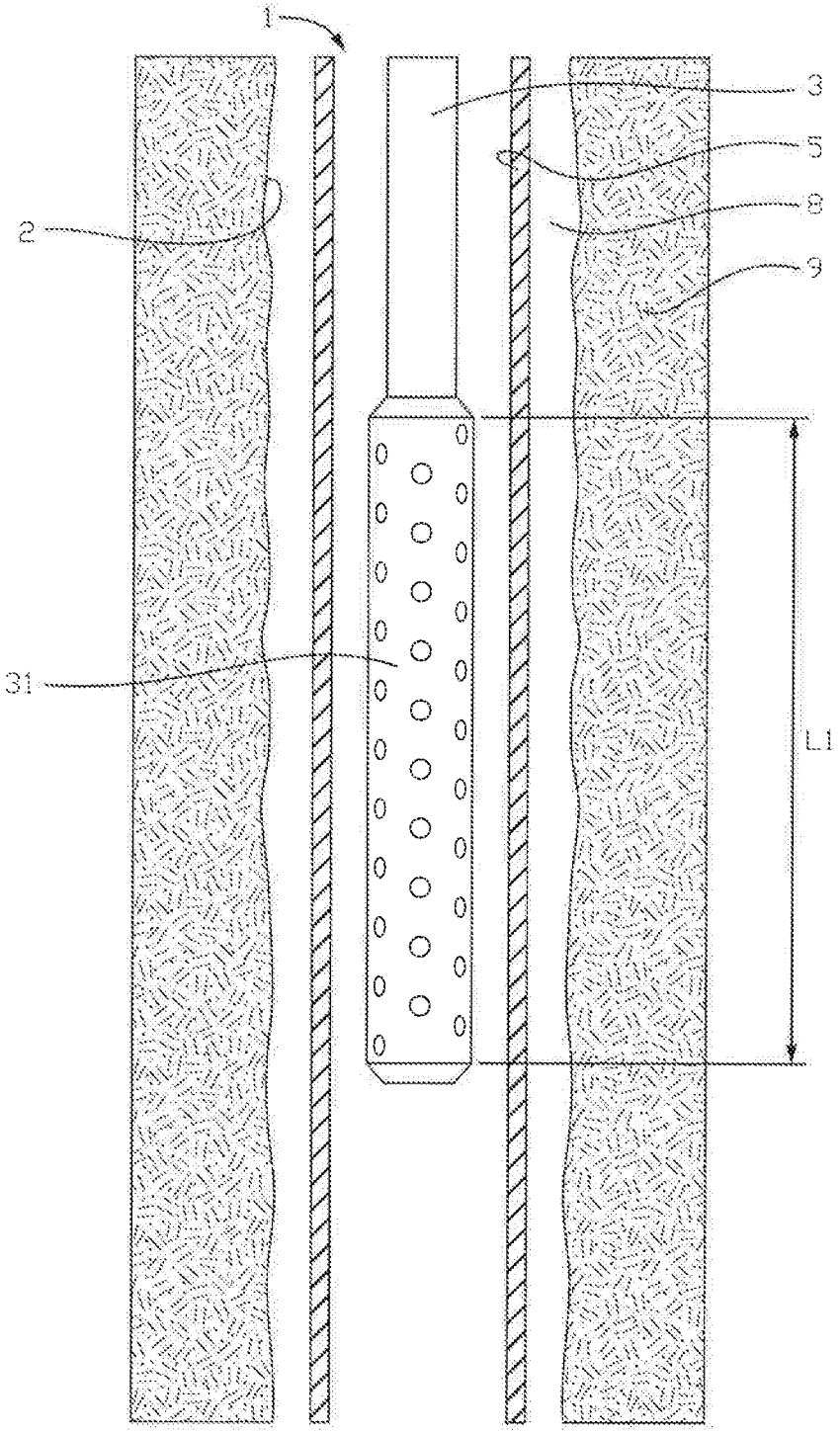

Fig. 4

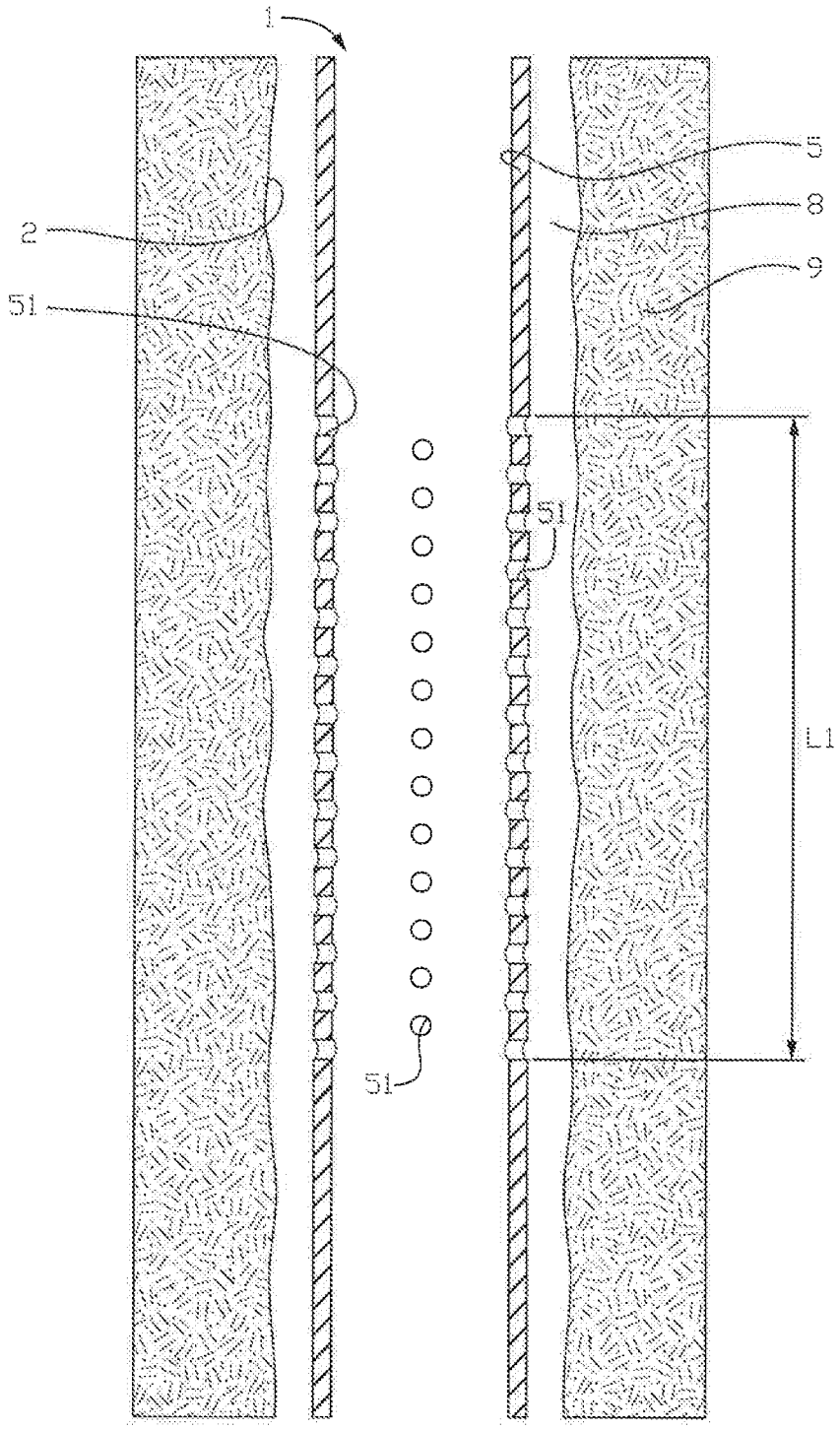

Fig. 5

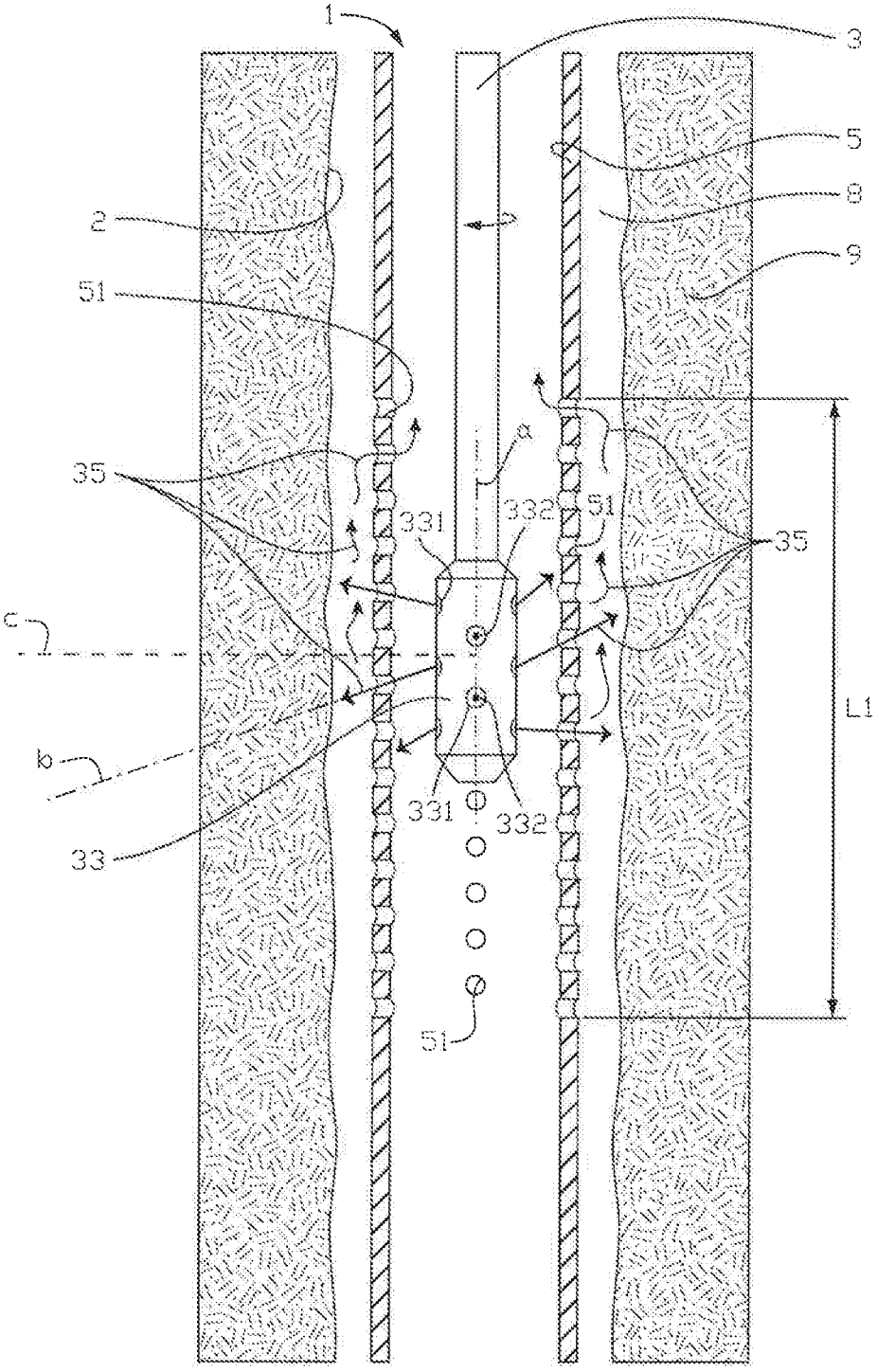

Fig. 6

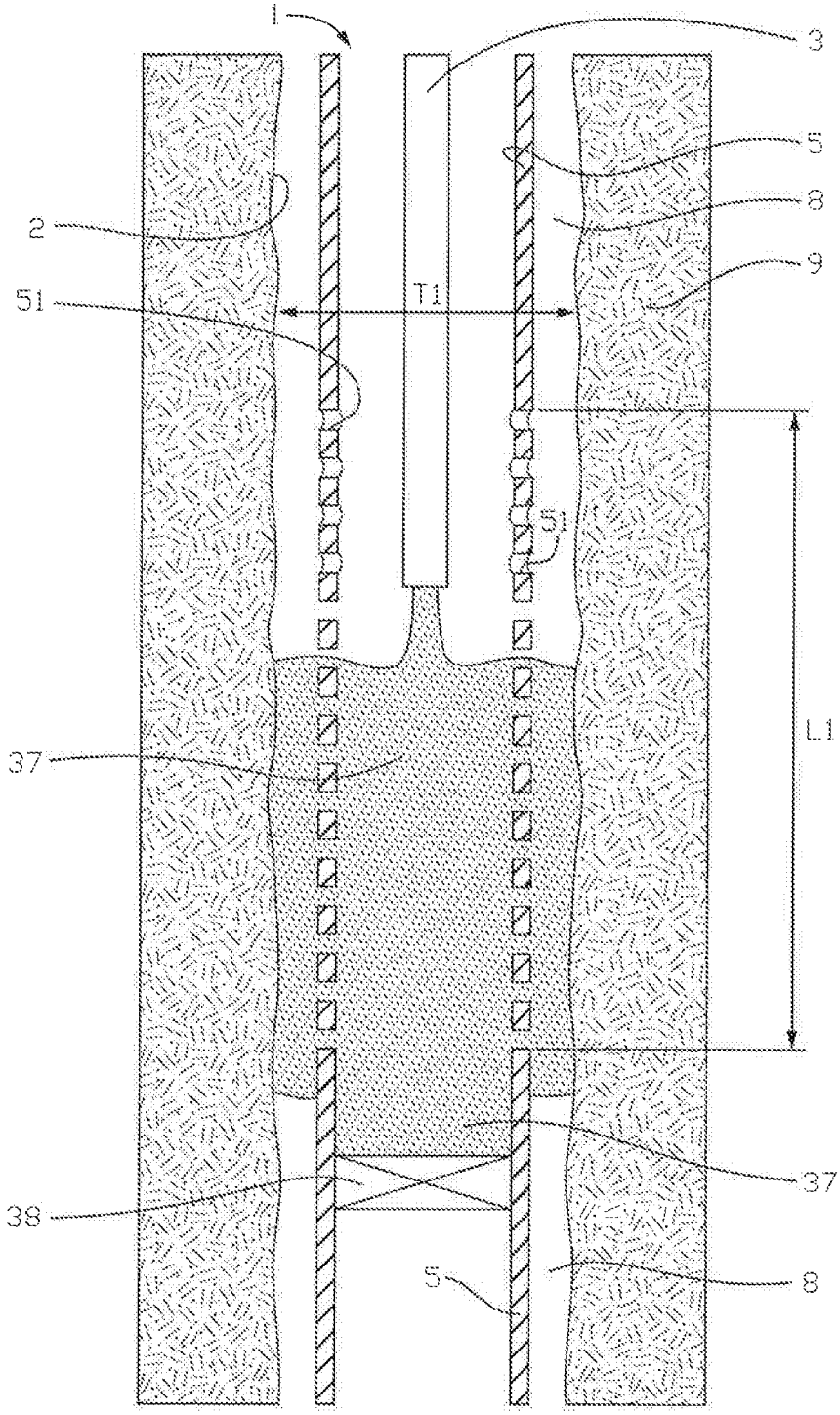

Fig. 7

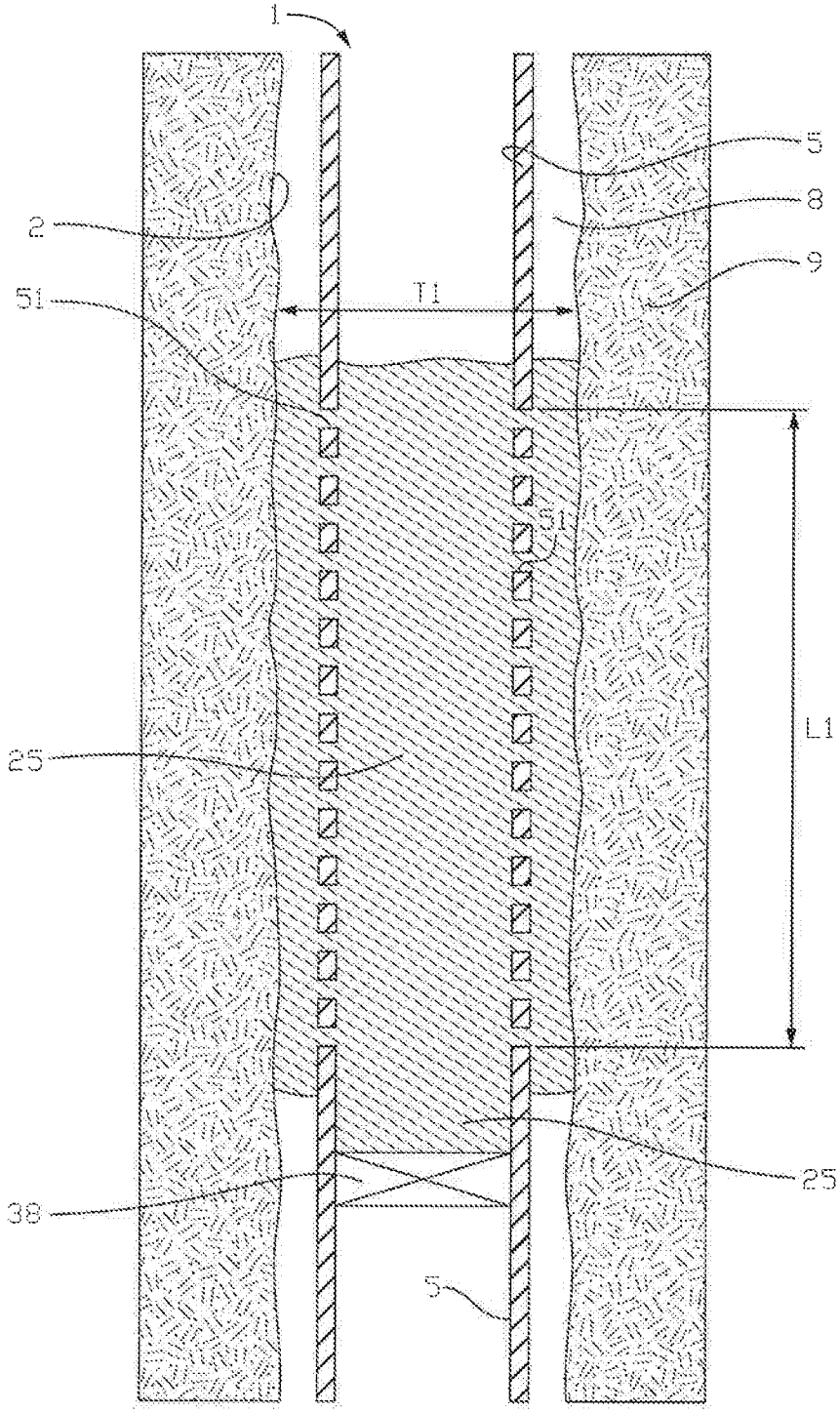

Fig. 8

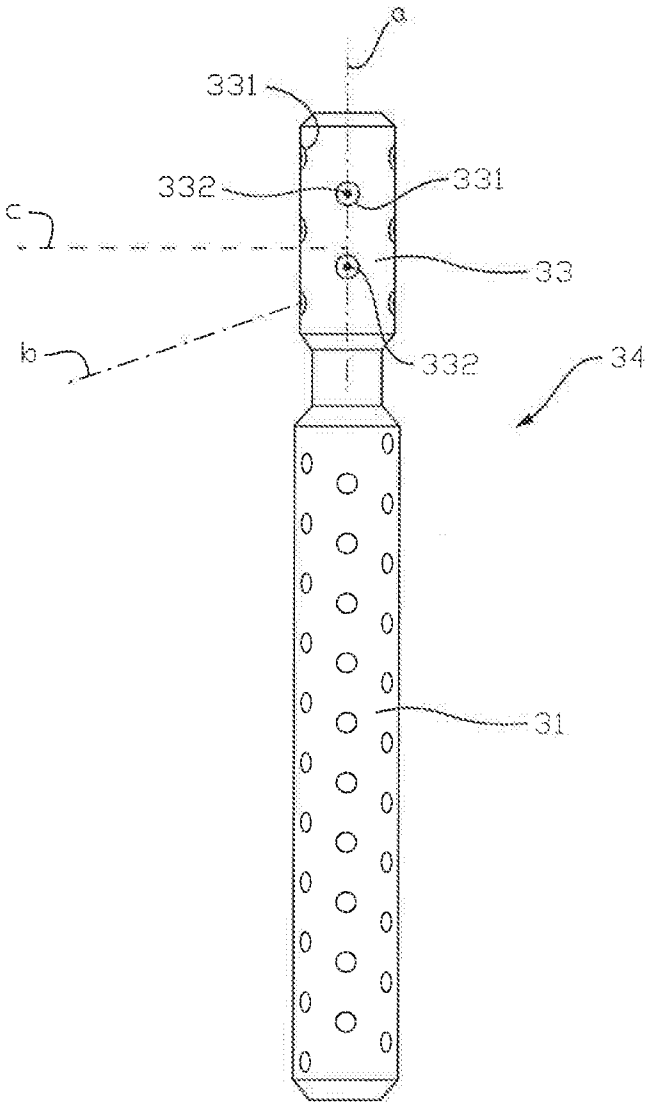

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO2016/050112

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, PAJ, WPI data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013133719 A1 (HYDRA SYSTEMS AS), 12 September 2013 (2013-09-12); abstract; page 6, line 23 - page 7, line 29; figures; claims	1, 2, 5-22, 30
A	--	3, 4, 23-29
A	WO 2015034369 A1 (HYDRA SYSTEMS AS), 12 March 2015 (2015-03-12); abstract; page 4, line 2 - page 10, line 19; page 14, line 15 - page 15, line 24; figures 2,4,5,7-11	1-30
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A	WO 2015026239 A2 (ARCHER OIL TOOLS AS), 26 February 2015 (2015-02-26); abstract; figures	1-30
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06-09-2016	09-09-2016

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO2016/050112

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5765756 A (JORDAN GARY D ET AL), 16 June 1998 (1998-06-16); abstract; figures --	1-30
A	US 20130312963 A1 (LARSEN ARNE GUNNAR ET AL), 28 November 2013 (2013-11-28); abstract; figures --	1-30

International application No.
PCT/NO2016/050112

Continuation of: second sheet

International Patent Classification (IPC)

E21B 33/13 (2006.01)
E21B 37/00 (2006.01)

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