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(54) **PLUGGING TO-BE-ABANDONED WELLBORES IN THE EARTH**

(57) A to-be-abandoned underground wellbore(4) is plugged along any desired longitudinal interval and radial extent by:

- dropping capsules (2) filled with a grout, pyrotechnic, swelling, bismuth, clay, bentonite, (thermo)hardening, sintering, and/or other plug generating material(3) into the wellbore (4) at selected time intervals;
- inducing the capsules (2) to accumulate above a down-hole cement or other barrier (5) in the wellbore (4);
- inducing the accumulated capsules (2) to disintegrate and to release the plug generating material (3) into the wellbore (4); and
- inducing the released plug generating material to generate a fluid tight barrier (7) of a desired length and radial extent within the wellbore (4).

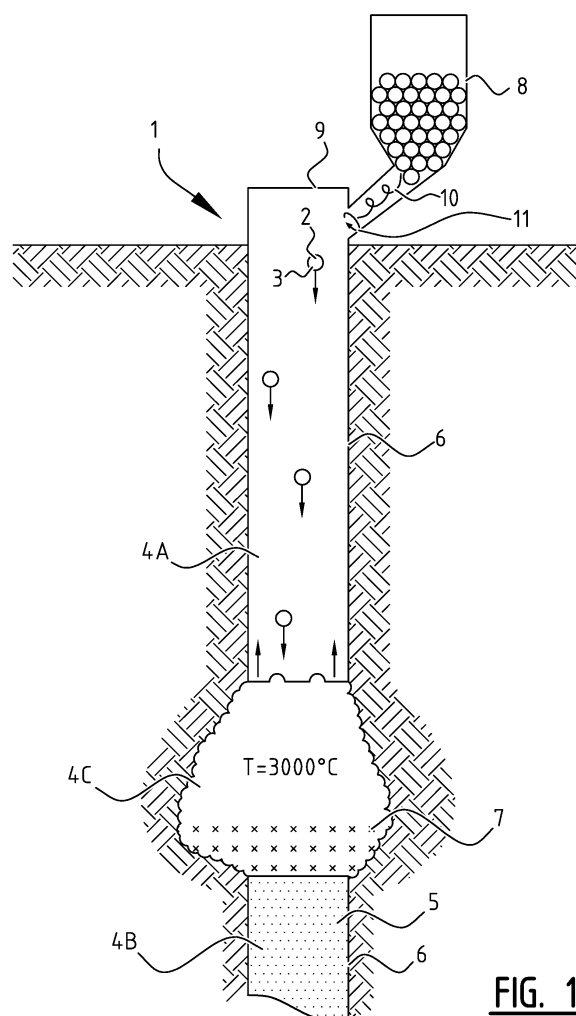


FIG. 1

Description

BACKGROUND OF THE INVENTION

[0001] The invention relates to a method for plugging wellbores in the earth created for the extraction of natural resources such as oil and/or gas, water, and/or heat.

[0002] Such wellbores may have been created for the production of crude oil and/or natural gas from underground crude oil and/or natural gas containing strata. When these strata are depleted these wellbores have no further use, and are plugged and abandoned in compliance with regulations and good industry practice. The objective of the plugging is to prevent undesired flow of fluids from strata via the wellbore into other strata and/or to the earth surface.

[0003] Temporary or permanent Well Plugging and Abandonment, often abbreviated as P&A, is also referred to as well decommissioning or well de-construction. A plug can also be referred to as a barrier, a permanent barrier or a permanent isolation.

[0004] P&A plugs may be set for permanent as well as for temporary abandonment of oil and/or gas production wells, the difference being the intent to re-enter the wellbore or not.

[0005] The to-be-abandoned wellbore can be vertical or inclined, and include metal components (tubulars), fluids (liquids, gas), as well as solids (rock particles, cement, solids suspended or sagged from fluids).

[0006] Currently, a common practice for P&A is to lower a hollow cement injection conduit into the well bore and pump a cement slurry into the wellbore to form a sealing plug after hardening. Usually a number of such plugs are placed in combination with full or partial retrieval of installed components such as production tubing, casings and/or liners.

[0007] Lowering a hollow injection conduit into the well requires a suitably strong workunit. If there are obstructions in the well then it may be difficult to insert a hollow cement injection conduit into the well. The cement slurry may become contaminated during placement through the injection conduit, leading to an imperfect plug. Thus there is a need for a method of placing plug generating material in to-be-abandoned wellbores without requiring insertion of an injection conduit. When applying the method according to the present invention the need for lowering a hollow injection conduit into the wellbore is negated.

[0008] Pyrotechnic pipe cutting techniques are known from US patent application US2002/0170713 which discloses cutting a well sidetracking window using a pyrotechnic milling device with thermite material, which is identified as a mixture of metal oxide(s), often ferric oxide and aluminum powders, and a reducing agent, and US patent 4,298,063 disclosing a conduit severing method using a pyrotechnic composition that may contain nickel and aluminium known from US patent 3,503,814.

[0009] Known pyrotechnic Well Plugging and Aban-

donment (P&A) methods and systems are disclosed in International patent applications WO2013/135583 and WO2014/108431. In these known pyrotechnic P&A methods a canister containing pyrotechnic thermite granules is lowered on a wire into the well, after which the granules are ignited to melt the canister and surrounding soil and any well casing, liner or tubing sections to form a lava type seal after cooling. With these known techniques the length and radial extent of the lava type seal is limited by the length and diameter of the canister and it is not possible or at least dangerous to insert other canisters into the wellbore before the lava type seal has been created and cooled.

[0010] There is a need for an improved method for creating a lava type and/or other seal in an abandoned wellbore that can have an extended length and an extended radial size, or optionally a desired sandwich construction of different materials, and that can be inserted at any time, even when a pyrotechnic or other exothermal reaction takes place in the wellbore to melt materials to create a lava or other solid fluid tight seal.

[0011] There is a need for an improved method that meets these objectives and overcomes drawbacks of known systems.

SUMMARY OF THE INVENTION

[0012] In accordance with the invention there is provided a method for plugging an abandoned oil and/or gas production wellbore, the method comprising:

- providing capsules containing plug generating material, which filled capsules have a larger density than a fluid within the wellbore;
- The plug generating material can comprise solids and/or fluids and/or gas, and/or pyrotechnic materials. Different capsules may contain different fill-materials in order to control plug generation processes downhole and plug properties.
- dropping the filled capsules into the wellbore at selected time intervals of optionally at least 5, 10, 20, 30 or 60 seconds;
- inducing the filled capsules to accumulate above a downhole barrier in the wellbore;
- inducing the accumulated capsules to disintegrate and to release the plug generating material into the wellbore; and
- inducing the released plug generating material to generate a fluid tight barrier of a desired length and radial extent within the wellbore.

[0013] Optionally at least some of the capsules comprise pyrotechnic material that is ignited, thereby melting metallic well components and optionally also surrounding soil to a fluidic lava type mixture, which generates after cooling a lava type seal of a desired length along the wellpath.

[0014] At least some of the capsules may comprise

materials that are molten or sintered together by the combustion of pyrotechnic material.

[0015] At least some of the capsules may be made of materials that disintegrate by melting or cracking or by a chemical reaction with other capsules or materials downhole in the wellbore.

[0016] Furthermore, at least some of the capsules may comprise a first plug generating material that reacts with a second plug generating material in at least some other capsules, wherein the first plug generating material may react exothermally with the second plug generating material and the first plug generating material comprises a swellable thermo-hardening and/or elastomeric composition and the second plug generating material comprises a hardening, vulcanizing and/or swelling agent.

[0017] These and other features, embodiments and advantages of the well Plugging and Abandonment (P&A) method according to the invention are described in the accompanying claims, abstract and the following detailed description of non-limiting embodiments depicted in the accompanying drawing, in which description reference numerals are used which refer to corresponding reference numerals that are depicted in the drawing.

[0018] Objects and other features depicted in the figure and/or described in this specification, abstract and/or claims may be combined in different ways by a person skilled in the art.

BRIEF DESCRIPTION OF THE DRAWING

[0019] Figure 1 shows an abandoned wellbore, which is plugged using the method according to the invention.

DETAILED DESCRIPTION OF THE DEPICTED EMBODIMENT

[0020] Figure 1 shows a to-be-abandoned well 1, which is plugged along a desired length by dropping capsules 2 containing solids and/or fluids and/or gas, and/or exothermally reactive material 3, such as thermite, potassium and/or lithium, into the wellbore 4, of which an upper part 4A is filled with water and/or another liquid and of which a bottom part 4B may be filled with a cement barrier 5. The wellbore 4 may contain a casing or liner string 6 and other well tubulars, such as a production tubing (not shown) and other well equipment, such as sandscreens, packers, inflow control valves and other devices. The size of the capsules 2 will be adjusted such that the capsules can bypass any obstructions in the upper part of the wellbore and reach the area 4C where the plug is to be created

[0021] Optionally the capsules 2 have a cylindrical or ball shape form (also referred to as "Shape") to deploy sealing material into a well. The Shapes or capsules 2 may be hollow in which material ('fill') can be deployed into the wellbore. The capsules 2 can be a ball-shaped to allow it to roll down the tubular in an inclined part of the wellbore 4A. Where the inclination of a wellbore 4

allows, cylindrical Shapes or capsules 2 can be deployed. The capsules 2 and their fill together have a higher density than the surrounding water or other fluid, such as mud, in all parts of the wellbore 4A to ensure the capsules 2 will drop in the wellbore as a result of gravity force. The use of ball shaped capsules 2 will allow the capsules 2 to roll down an inclined borehole with minimum resistant and risk of stopping. To effect the installation of a P&A barrier downhole, a large number of capsules 2 will be deposited in the well.

[0022] Bars and balls are currently used in borehole construction to activate tools, e.g. activate perforating guns, setting packers, hangers, cycle sleeves open/close, etc. These bars and balls are not used to deploy material into the hole.

[0023] The shell of the capsules 2 can consist of metal, a corroded or painted top layer, artificial materials, polymers, fibers, re-inforcements and be matched to the material to be deployed and the downhole environment. The capsules 2 will sustain wear and impact during its travel to the downhole position above the cement or other existing barrier 5. Following arrival at the downhole position, the capsule 2 shell will be removed, broken, or disintegrated as a result of an activation methodology, which can include:

- Dissolution of the shell materials in the in situ downhole fluid, temperature, pressure
- Melting due to temperature, downhole present or applied by an heat generating mechanism
- Deformation, burst, collapse, squash, crush, as a result pressure difference, explosions mechanisms, external force
- A combination of the above
- The activation method will be time bound, constructed for a specific time delay.

[0024] The fill-material 3 can comprise solids and/or fluids and/or gas, and/or pyrotechnic materials. Different capsules may contain different fill-materials in order to control plug generation processes downhole and plug properties.

I. Solid fill materials 3 can comprise shale particles, clay mixtures that swell in downhole fluids, e.g. bentonitic clays, barites, salts, metals like bismuth alloys, which swell upon solidification, grouts and sized particle mixtures, solids/fluid suspensions, resins, swellable rubbers, cement-type materials, foaming materials, (geo)polymers.

II. Gaseous fill materials 3 can be deployed for activation purpose, foam creation, or testing of the sealing status of the plug 7. Different gasses can be deployed in Shapes for downhole reactivity.

III. Liquid fill materials 3 may comprise solidifying materials, like retarded cements. Different capsules 2 may comprise different liquid materials 3 which may be configured to cause, accelerate or deceler-

ate a chemical reaction under down hole conditions, e.g. agents to allow hardening, gelling (e.g. leading to gunk), dissolve shell material. Fluids like acids, caustic can be deployed downhole to stimulate the removal of material in wellbore and/or dissolve Shape-shell material.

[0025] As a special case of fill-material 3, it can be reactive and cause, after initiation, an exothermic reaction that will generate sufficient temperature to melt the capsules 2 or Shapes placed, or metal and other components in and around the wellbore, like tubulars, cements, etc. An example of such fill is pyrotechnic thermite material known from US patent application US2002/0170713, which discloses the use of a mixture of metal oxide(s), often ferric oxide and aluminum powders, and a reducing agent to cut a sidetracking window in a well casing. US patent 4,298,063 discloses a pyrotechnic conduit severing method using a pyrotechnic composition that may contain nickel and aluminium known from US patent 3,503,814.

[0026] The deployment by means of sequential drop-in Shapes or capsules 2 will allow sufficient mass of the exothermic reaction material to be placed prior and during the exothermic reaction to achieve an adequate energy source for melting wellbore components and/or volume of rock to form a barrier. It will also allow repeated treatment and close any gaps or conduits of previous treatments.

[0027] The required amount of exothermic material will vary with the wellbore situation and objectives. The ignition, if applied, may be timed to allow a sequence of Shapes or capsules 2 to be fed into position. Ignition systems can be present in every Shape or capsule 2 or in a number of discrete Shapes or capsules 2 that cause ignition of adjacent Shapes or capsules 2.

[0028] The Shapes or capsules 2 may also be filled with plugging material, such as grouts, clay particles, to be sequenced between the exothermic material Shapes of capsules 2, to fit the required heat profile, or provide heat isolation to certain parts in the well 1.

[0029] A foundation for the Shapes or capsules 2 is provided by an obstruction in the wellbore, such as a cement plug 5 at bottom of the hole, a fill, a mechanical plug, a sand bridge or previously molten and solidified material 7.

[0030] The diameter of the Shapes or capsules 2 is chosen to pass any restriction in the wellbore. The use of different size Shapes or capsules 2 will allow variations in packing density in the downhole space available.

[0031] Multiple tubular strings may be present in the wellbore 1. In case the inner production string or tubing string has been (partly) removed, the Shapes or capsules 2 will accumulate in the larger space created by removing the inner string. A similar configuration exists with kill-strings, i.e. a tubular with its lower end some distance off bottom of the wellbore through which a high density mud is pumped into the well 1 to stop flow of crude oil and/or

gas.

[0032] A sequence of Shapes or capsules 2 will be inserted into the well 1 at predetermined time intervals by means of a surface capsule storage and release assembly 8 at the wellhead 9. The time interval between releasing two Shapes or capsules 2 will be chosen to allow singular travel of Shapes or capsules 2 and prevent accumulations and possibly development of an obstruction in the upper part 4A of the wellbore 4. The capsule release assembly 8 comprises a rotating helical spring 10 of which the speed of rotation, illustrated by arrow 11, is adjusted to generate a desired time interval of at least 5 seconds, or optionally at least 10, 20, 30 or 60 seconds, depending on the amount of obstructions in and the inclination of the upper part 4A of the wellbore 4.

[0033] When fluid containment is required, e.g. when wellbore is capable of flow or is located under water (sub-sea), a surface capsule storage and release assembly 8 with sealing gates can be used that is attached to the well's surface equipment, like the wellhead 9, christmas tree assembly, Blow-Out Preventer (BOP), adapter flange. A wireline lubricator system may also be used. A reciprocating or rotating gate assembly with one or multiple feed-lines of Shapes or capsules 2 can also be used. The wellhead 9 may comprise a check valve or other fluid release assembly, which allows displaced wellbore fluid in the upper part 4A of the wellbore 4 to be released. For verification purposes the time of release, serial number and weight of each Shape or capsule 2 can be recorded at the surface capsule storage and release assembly 8. The drop speed of the capsules 2 can be accelerated by pumping a fluid into the well.

[0034] If the Shapes or capsules 2 are ball-shaped then the amount of inserted capsules 2 may be selected by estimating how many balls fit into a cylindrical space. This depends on the packing. Random packing of same size balls generally is about 65 vol%, which could be improved by shaking or mixture of various ball diameters. Applying the 65% rule to a situation of about 5 cm (about 2", or two inches) diameter ball-shaped capsules 2, indicates that about 10 balls/liter will be required. For a casing 6 with an inner diameter of about 17.5 cm (7" or seven inches) this equates to 200 ball shaped capsules 2 per meter, so that about 2,000 ball shaped capsules 2 are required to fill a well interval of about 10 m. Assuming a 1 minute interval for launching, this requires 1.4 days continuous capsule release activity of the capsule storage and release assembly 8.

[0035] The downward velocity of each capsule 2 through the upper part 4A of the wellbore will depend on the weight of each capsule 2 and its content 3, fluid density buoyancy of the fluid in the upper part 4A of the wellbore 4, capsule diameter relative to the Inner Diameter (ID) of the casing 6 or other well tubular, well fluid viscosity and well inclination.

[0036] If the upper part 4A of the well 1 is longer than 1 kilometer then a descent time of about 1 hour may be assumed, which can be verified in advance by dropping

instrumented balls and/or bars of similar size and weight as the capsule 2 into the well 1 and monitor their speed of descent and arrival time at the downhole barrier 5 using wireless acoustic fluid pulse or other signal transmission techniques.

[0037] It will be understood that the method according to the invention provides an improved Plugging and Abandonment (P&A) method wherein an abandoned oil and/or gas production well (1) is plugged and hermetically sealed along any desired longitudinal interval by:

- dropping capsules (2) filled with grout, fluid, a pyrotechnic, swelling, bismuth, clay, bentonite, (thermo)hardening, sintering, (geo)polymer and/or other plug generating material(3) into the well (1) at selected time intervals of at least 5 seconds;
- inducing the capsules (2) to accumulate above a downhole cement or other barrier (5) in the well (1);
- inducing the accumulated capsules (2) to disintegrate and to release the plug generating material (3) into the well (1); and
- inducing the released plug generating material to generate a fluid tight barrier (7) of a desired length and radial extent.

[0038] Therefore, the method, system and/or any well plugging products according to present invention are well adapted to attain the ends and advantages mentioned as well as those that are inherent therein.

[0039] The particular embodiments disclosed above are illustrative only, as the present invention may be modified, combined and/or practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein.

[0040] Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below.

[0041] It is therefore evident that the particular illustrative embodiments disclosed above may be altered, combined and/or modified and all such variations are considered within the scope of the present invention as defined in the accompanying claims.

[0042] While any methods, systems and/or products embodying the invention are described in terms of "comprising," "containing," or "including" various described features and/or steps, they can also "consist essentially of" or "consist of" the various described features and steps.

[0043] All numbers and ranges disclosed above may vary by some amount. Whenever a numerical range with a lower limit and an upper limit is disclosed, any number and any included range falling within the range is specifically disclosed. In particular, every range of values (of the form, "from about a to about b," or, equivalently, "from approximately a to b," or, equivalently, "from approximately a-b") disclosed herein is to be understood to set forth every number and range encompassed within the broader range of values.

[0044] Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee.

[0045] Moreover, the indefinite articles "a" or "an", as used in the claims, are defined herein to mean one or more than one of the element that it introduces.

[0046] If there is any conflict in the usages of a word or term in this specification and one or more patent or other documents that may be cited herein by reference, the definitions that are consistent with this specification should be adopted.

Claims

1. A method for plugging a to-be-abandoned wellbore in the earth, the method comprising:

- providing capsules containing plug generating material, which filled capsules have a larger density than a fluid within the wellbore;
- dropping the filled capsules into the wellbore at selected time intervals;
- inducing the filled capsules to accumulate above a downhole barrier in the wellbore;
- inducing the accumulated capsules to disintegrate and to release the plug generating material into the wellbore; and
- inducing the released plug generating material to generate a fluid tight barrier of a desired length and radial extent within the wellbore.

2. The method of claim 1, wherein at least some of the capsules comprise solids and/or fluids and/or gas to control plug generation processes downhole and final plug properties.

3. The method of claim 2, wherein at least some of the capsules comprise pyrotechnic plug generating material that is ignited by the combusting pyrotechnic material, thereby melting metallic well components and optionally surrounding soil to a fluidic lava type mixture, which generates after cooling a lava type seal of a desired length within the wellbore.

4. The method of claim 3, wherein at least some of the capsules comprise materials that are molten or sintered together by the combustion of pyrotechnic material.

5. The method of any one of claims 1-4, wherein at least some of the capsules are made of materials that disintegrate by melting or cracking or by a chemical reaction with other capsules or materials downhole in the wellbore.

6. The method of any one of claims 1-5, wherein at least some of the capsules comprise a first plug gen-

erating material that reacts with a second plug generating material in at least some other capsules.

7. The method of claim 6, wherein the first plug generating material reacts exothermally with the second plug generating material. 5
8. The method of claim 7, wherein the first plug generating material comprises a swellable thermo-hardening and/or elastomeric composition and the second plug generating material comprises a hardening, vulcanizing and/or swelling agent. 10
9. The method of any one of claims 1-8, wherein the filled capsules are dropped into the wellbore at selected time intervals of at least 5 seconds. 15
10. The method of claim 9, wherein the filled capsules are dropped into the wellbore at selected time intervals of at least 10, 20, 30 or 60 seconds. 20
11. The method of claim 4, wherein the combustion temperature of the pyrotechnic material is at least 2000°C, optionally at least 3000°C. 25

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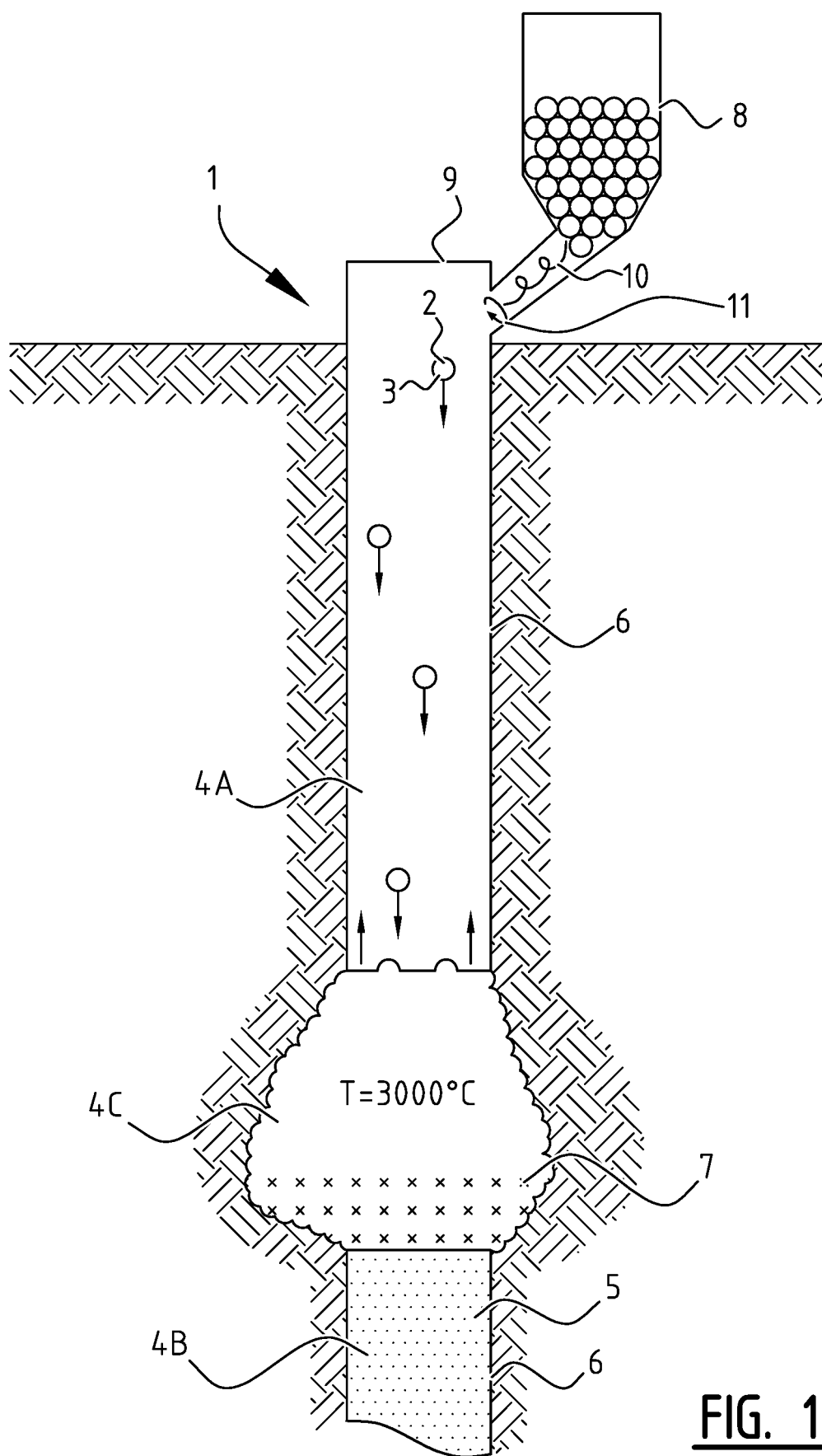


FIG. 1



EUROPEAN SEARCH REPORT

 Application Number
 EP 16 15 2418

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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 19 July 2016	Examiner Dantinne, Patrick
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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