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[Continued on next page]

(54) Title: SYSTEM AND METHOD FOR PERFORATING AND TUNNELING CASSED WELLS

(57) Abstract: A system is for forming tunnels in formation radially surrounding a wellbore. The system is characterized by: a perforating tool arrangement having a perforating tool for forming an opening within the casing and a perforating tool sensor disposed upon the perforating tool to detect at least one wellbore parameter useful to identify a location or attributes of the opening; a tunneling tool arrangement having a tunneling tool for forming a tunnel within the formation through the opening; and a controller to receive data from the perforating tool sensor indicative of the wellbore parameter and to at least partially control operation of the tunneling tool based upon the at least one wellbore parameter sensed by the perforating tool sensor.

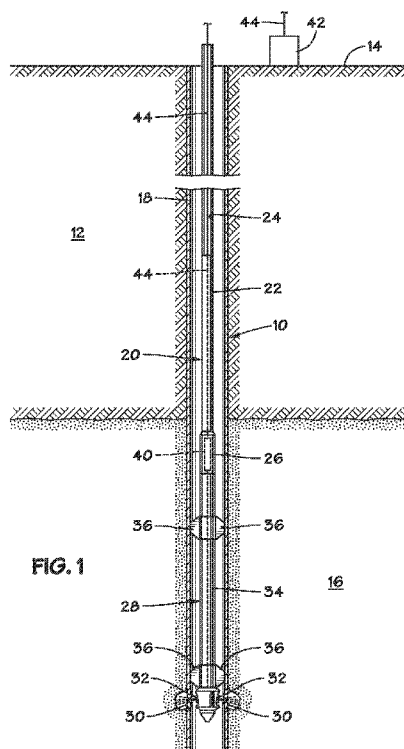


FIG. 1



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

— *as to the applicant's entitlement to claim the priority of
the earlier application (Rule 4.17(iii))*

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted
a patent (Rule 4.17(ii))*

Published:

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SYSTEM AND METHOD FOR PERFORATING AND TUNNELING CASED WELLS

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The invention relates generally to systems and methods for creating tunnels within subterranean formations surrounding cased wellbores.

2. Description of the Related Art

[0002] Metallic casing is used to line wellbores. To date, it has been necessary to use explosive perforating guns to form openings in the casing and the surrounding formation. Abrasive jetting has also been used, although it is not as common. Both explosive perforating and abrasive jetting used for perforating existing casing have the purpose to make tunnels as long as possible through the casing, cement and near wellbore region. The shape and length of these tunnels cannot be controlled.

SUMMARY OF THE INVENTION

[0003] The invention provides systems and methods for creating controlled tunnel openings in formations surrounding cased bores. Fluid, or fluid-solid jetting is used to form a controlled opening in the casing, if casing is present. Thereafter, acid tunneling is used to create tunnels in the formation.

[0004] In preferred embodiments, the perforating tool (if used) and the acid tunneling tool include sensors which can measure one or more downhole parameters, including deviation, azimuth, pressure, temperature and gamma ray. These sensors are installed within or upon the bottom hole assembly. In some embodiments, the bottom

hole assembly incorporates a casing collar locator for measuring depth and/or a lateral camera.

[0005] Preferably, Telecoil® is used to transmit information obtained by the sensors of the bottom hole assembly to surface. Other telemetry means, such as optical fiber, could also be used. Information obtained by the sensors is used to control the abrasive jetting and acid tunneling tools as well as the perforating and tunneling processes. The abrasive perforating tool may have one or multiple nozzles. If the perforating tool has more than one nozzle, these nozzles could be distributed radially (i.e., at the same depth) or axially (i.e., at different depths) along the tool body.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] For a thorough understanding of the present invention, reference is made to the following detailed description of the preferred embodiments, taken in conjunction with the accompanying drawings, wherein like reference numerals designate like or similar elements throughout the several figures of the drawings and wherein:

[0007] Figure 1 is a side, cross-sectional view of an exemplary wellbore containing a perforating tool arrangement in accordance with the present invention.

[0008] Figure 2 is an isometric view of an exemplary perforating tool constructed in accordance with the present invention.

[0009] Figure 3 is an enlarged isometric view of a centralizer portion of the perforating tool of Figure 2.

[0010] Figure 4 is an enlarged isometric view of a nozzle portion of the perforating tool of Figure 2.

[0011] Figure 5 is a side, cross-sectional view of an exemplary wellbore containing an acid tunneling tool arrangement in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] Figure 1 illustrates an exemplary wellbore 10 that has been drilled through the earth 12 from the surface 14 down to a hydrocarbon-bearing formation 16. It is noted that, while wellbore 10 is illustrated as a substantially vertical wellbore, it might, in practice, have portions that are inclined or horizontally-oriented. The wellbore 10 is lined with a metallic casing 18. In alternative embodiments, the wellbore 10 would lack such a casing.

[0013] A perforating tool arrangement 20 is disposed within the wellbore 10. The perforating tool arrangement 20 includes a running string 22 which is preferably made up of coiled tubing. A flowbore 24 is defined along the length of the running string 22. A bottom hole assembly 26 is located at the distal end of the running string 22. A perforating tool 28 is affixed to the bottom hole assembly 26.

[0014] The perforating tool 28 is useful to create openings 30 in the casing 18 using fluid jetting or fluid-solid jetting. Fluid, or a fluid containing a solid such as sand, is injected through the flowbore 24 of the running string 22, the bottom hole assembly 26 and outwardly from lateral nozzles 32 of the perforating tool 28. Although there are multiple nozzles 32 shown, it should be understood that there may be only a single nozzle 32. In certain embodiments, the nozzle(s) 32 can be controlled from the surface 14 to open and/or close depending upon the requirements for forming an opening 30 of a particular size. An exemplary perforating tool 28 is shown in greater detail in Figs. 2-4 and includes a tubular body 34 with centralizer fins 36. In particular embodiments, perforating tool sensors 38 are incorporated into the body 34 of the perforating tool 28. The perforating tool sensors 38 can measure one or more downhole wellbore parameters, including depth, deviation, azimuth, pressure, temperature and gamma

ray, which are useful for identifying a location or attributes of one or more of the openings 30 being formed. Perforating tool sensors 38 may also include a camera which is capable of obtaining visual images of the wellbore 10 environment. A camera would be useful for determining the size of an opening 30 that has been made by the perforating tool 28. In accordance with certain embodiments, the camera could have registry marks on its lens which would be useful to visualize and measure the size of the opening 30.

[0015] Bottom hole assembly 26 preferably includes an electronics board with storage or memory 40 to receive and store information received from the perforating tool sensors 38. The bottom hole assembly 26 also preferably includes a deviation/azimuth sub and casing collar locator which will help identify the exact position of the openings 30 formed by the perforating tool 28 so that a tunneling tool that is subsequently run can be positioned at or near the openings 30. A data communications conduit 44, such as tube-wire, is preferably used to transmit the received information to a surface controller and storage medium 42 from memory 40 of the bottom hole assembly 26. Telecoil® is coiled tubing which incorporates tube-wire that can transmit power and data. Tube-wire is available commercially from manufacturers such as Canada Tech Corporation of Calgary, Canada. Tube-wire 44 is shown within the flowbore 24 of the coiled tubing running string 22 and is operably interconnected with the controller/storage medium 42 at surface 14. The controller/storage medium 42 preferably includes suitable programming to use mathematical modeling to determine the location where the acid tunneling tool needs to begin bending in order to have the nozzle 60 be moved through the opening 30. Suitable programming for this application includes CIRCA™ RT modeling software for coiled tubing applications which is available commercially from Baker Hughes

Incorporated. The entry location might be determine using information relating to the casing size, coiled tubing size and bottom hole size and length.

[0016] Figure 5 illustrates the wellbore 10 now with the perforating tool arrangement 20 removed and openings 30 having been created in the casing 18. An acid tunneling arrangement 50 is now disposed within the wellbore 10 after the openings 30 have been created in the casing 18. The acid tunneling tool arrangement 50 includes a running string 22 which is preferably made up of coiled tubing. A bottom hole assembly 26 is secured to the distal end of the running string 22 and may be the same bottom hole assembly as described previously. An indexing tool 52 is preferably incorporated into the acid tunneling arrangement 50 which permits components below the indexing tool 52 to be rotated angularly within the wellbore 10 with respect to the running string 22. An acid tunneling tool 54 is secured to the indexing tool 52. The acid tunneling tool 54 is preferably jointed and useful to form tunnels 56 within the formation 16 radially surrounding the wellbore 10 by injection of acid into the formation 16. The acid tunneling tool 54 may be constructed and operate in the same manner as the tool which is described in U.S. Patent No. 8,205,672 issued to Misselbrook et al. U.S. Patent No. 8,205,672 is owned by the assignee of the present application and is herein incorporated by reference in its entirety.

[0017] Tunneling tool sensors 58 are preferably incorporated into the acid tunneling tool 54 to detect downhole parameters such as those detected by perforating tool sensors 38 described previously. These downhole parameters can include depth, deviation, azimuth, pressure, temperature and gamma ray. The bottom hole assembly 26 receives data sensed by the tunneling tool sensors 58 and transmits the data to processor/storage medium 42 at surface 14.

[0018] In accordance with preferred methods of operation, openings 30 are formed by the perforating tool 28 which are large enough for a distal nozzle 60 of the acid tunneling tool 54 to be inserted through the openings 30 in order to effectively create tunnels using acid injection. At least some portion of the process of forming tunnels 56 within the formation 16 is controlled based upon wellbore parameter sensed by the perforating tool sensors 38 of the perforating tool 28. The acid tunneling tool 54 run in is assisted in locating the opening(s) 30 as well as appropriately-sized openings 30 in the casing 18 which were created previously by the wellbore parameters detected by the perforating tool sensors 38 of the perforating tool arrangement 20. Insertion of the acid tunneling tool 54 into an opening 30 is more accurate. In a non-limiting example, the openings 30 are large enough to allow the nozzle of a 2 1/8" StimTunnel tool to pass through the casing 18. Injection of acid into the formation by the acid tunneling tool 54 will create small tunnels 56 within the formation 16. If desired, hydraulic fracturing can thereafter be used to increase reservoir connectivity further.

[0019] It can be seen that the invention provides a system for forming tunnels within a formation surrounding a subterranean wellbore 10 which includes a perforating tool arrangement 20 and an acid tunneling arrangement 50. The perforating tool arrangement 20 includes a perforating tool 28 for forming an opening 30 within casing 18 of the wellbore 10 using fluid jetting or fluid-solid jetting. Perforating tool sensors 38 are located upon the perforating tool 28 and are configured to detect at least one wellbore parameter which is useful for identifying a location or attributes of one or more of the openings 30 being formed in the casing 18. The perforating tool arrangement 20 preferably also includes a bottom hole assembly 26 having on-board memory storage 40 for retaining data provided by the sensors 38. In described embodiments, the perforation tool arrangement 20 further includes a controller 42 which is configured

to determine location or attributes of one or more of the openings 30 being formed in the casing 18 based upon the wellbore parameter(s) sensed by the perforating tool sensors 38. A data communications conduit 44 transmits data from the bottom hole assembly 26 to the controller 42.

- 5 **[0020]** The acid tunneling arrangement 50 of the system for forming tunnels includes an acid tunneling tool 54 for forming a tunnel 56 within the formation 16 radially surrounding the wellbore 10. Tunneling tool sensors 58 are disposed upon or within the acid tunneling tool 54 and are configured to detect wellbore parameters that are useful for controlling operation of the acid tunneling tool 54 to create one or more
- 10 tunnels 56. The acid tunneling arrangement 50 also includes a bottom hole assembly 26 which transmits data representative of the wellbore parameters sensed by the tunneling tool sensors 58 to the controller 42.

CLAIMS

What is claimed is:

1. A method of forming tunnels (56) within a formation (16) radially surrounding a subterranean wellbore (10), the method characterized by the steps of:

forming an opening (30) within casing (18) of the wellbore with a perforating tool (28);

disposing a portion of a tunneling tool (58) through the opening; and

injecting acid into the formation through the tunneling tool to form tunnels (56) within the formation.

2. The method of claim 1 further comprising the step of:

sensing one or more wellbore parameters with a perforating tool sensor (38) operably associated with the perforating tool to identify a location or attributes of the opening.

3. The method of claim 2 wherein the step of sensing one or more wellbore parameters further comprises sensing at least one of the wellbore parameters in the group consisting of deviation, azimuth, pressure, temperature and gamma ray.

4. The method of claim 2 further comprising the step of transmitting sensed wellbore parameters to a surface controller (42).

5. The method of claim 4 further comprising the step of at least partially controlling the forming of tunnels based upon the sensed wellbore parameters.

1 6. The method of claim 1 further comprising the step of sensing one or more
2 wellbore parameters with a tunneling tool sensor (58) operably associated with the
3 tunneling tool to identify a location or attributes of the opening.

1 7. The method of claim 4 wherein the sensed wellbore parameters are
2 transmitted to the controller via a data communications conduit (44).

1 8. A system for forming tunnels within a formation surrounding a subterranean
2 wellbore lined with casing, the system characterized by:

3 a perforating tool arrangement (20) having a perforating tool (28) for forming
4 an opening (30) within the casing (18) and a perforating tool sensor (38) disposed
5 upon the perforating tool to detect at least one wellbore parameter useful to identify a
6 location or attributes of the opening;

7 a tunneling tool arrangement (50) having a tunneling tool (54) for forming a
8 tunnel (56) within the formation (16) through the opening (30); and

9 a controller (42) to receive data from the perforating tool sensor (38) indicative
10 of the wellbore parameter and to at least partially control operation of the tunneling
11 tool based upon the at least one wellbore parameter sensed by the perforating tool
12 sensor.

1 9. The system of claim 8 further comprising a tunneling tool sensor (58)
2 disposed upon the tunneling tool to detect at least one wellbore parameter useful for
3 controlling operation of the tunneling tool (54) to create a tunnel.

1 10. The system of claim 8 wherein the tunneling tool further comprises an acid
2 tunneling tool which forms tunnels by injection of acid into the formation.

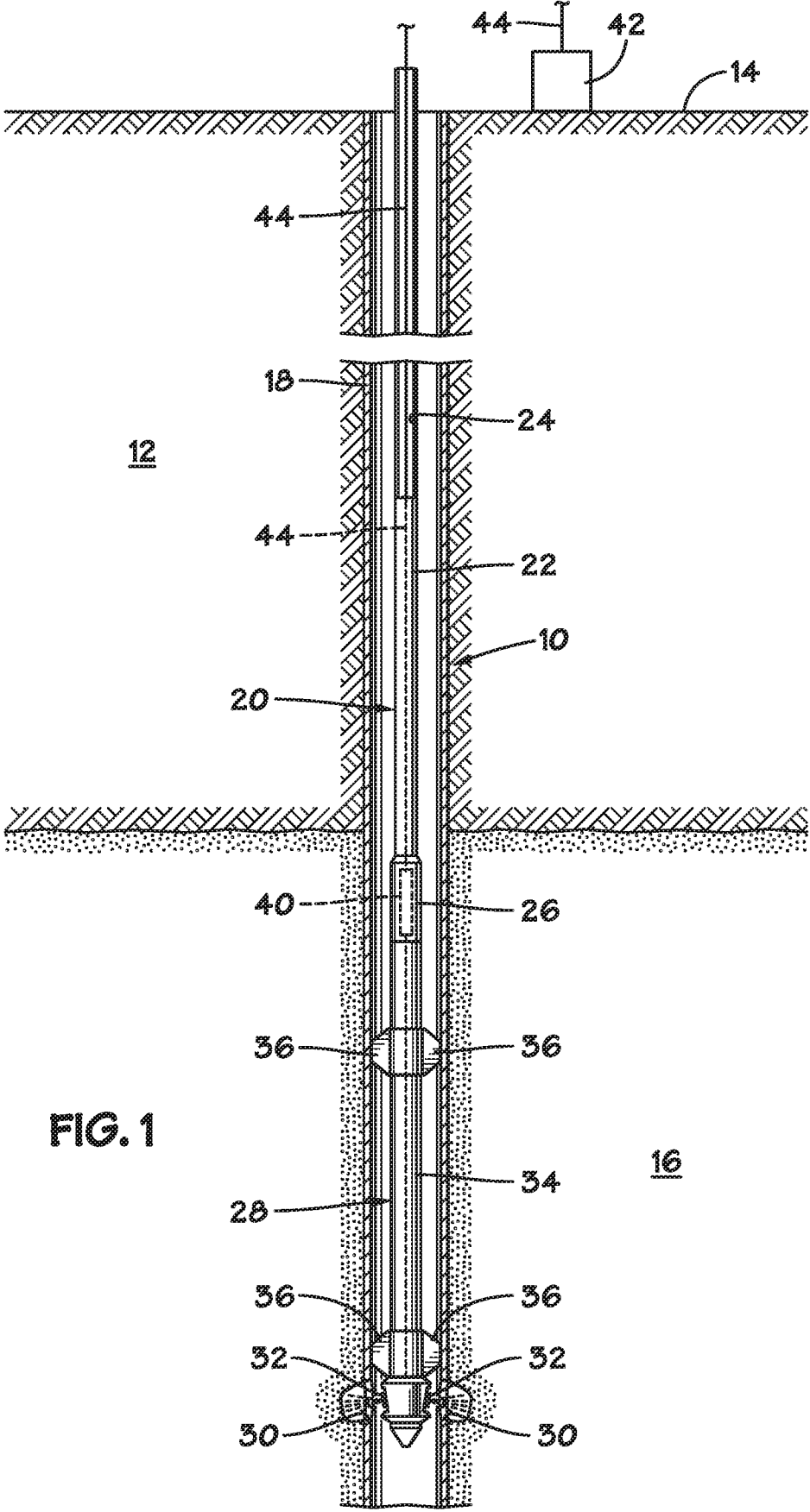
1 11. The system of claim 8 further comprising a data communications conduit (44)
2 to transmit the data from the perforating tool sensor to the controller.

1 12. The system of claim 11 wherein the data communications conduit comprises
2 tube-wire.

1 13. The system of claim 9 wherein data is transmitted from the tunneling tool
2 sensor to the controller.

1 14. The system of claim 9 wherein the at least one wellbore parameter useful for
2 controlling operation of the tunneling tool to create a tunnel is a wellbore parameter
3 of the group consisting of: deviation, azimuth, pressure, temperature and gamma
4 ray.

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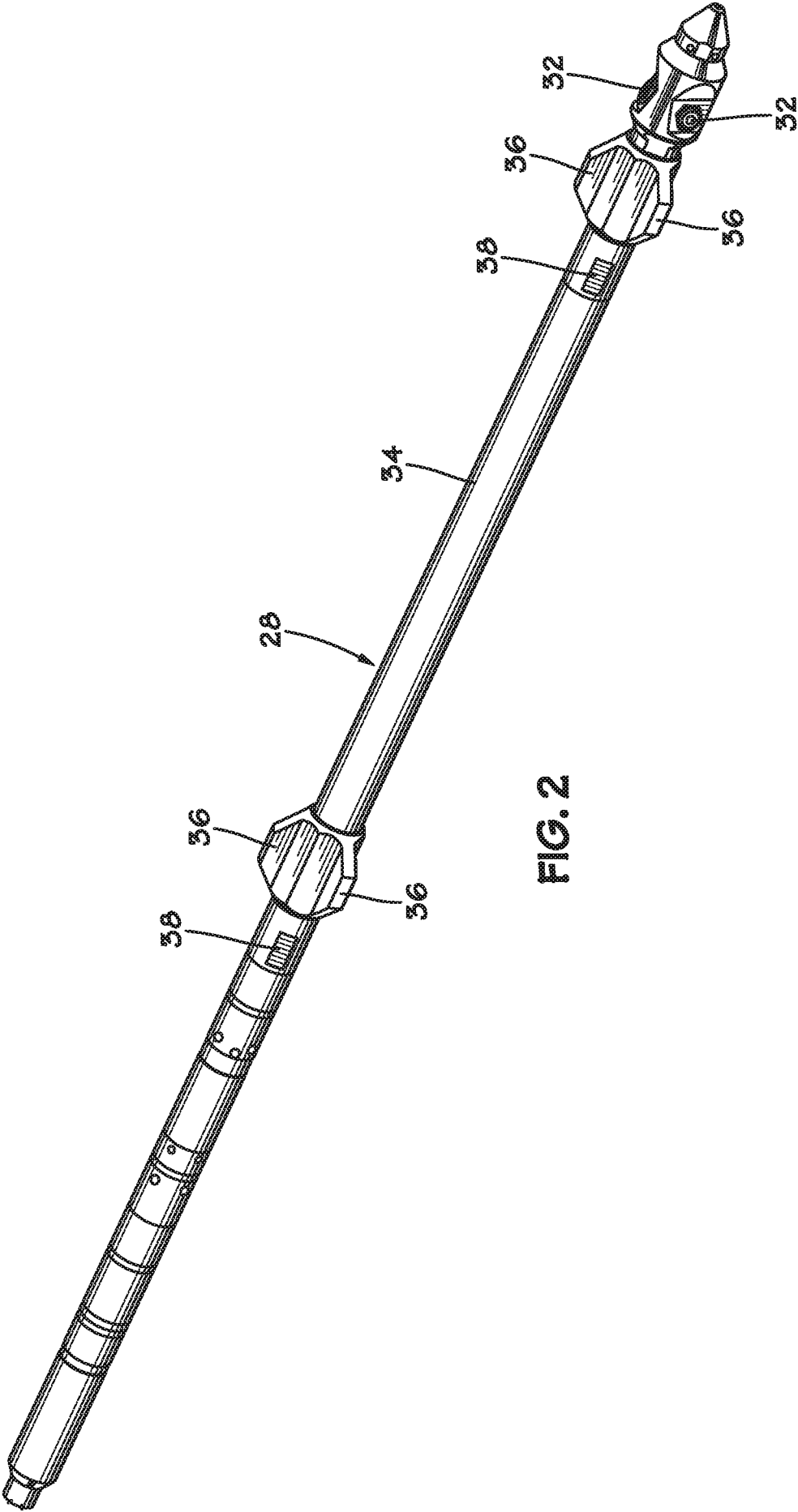
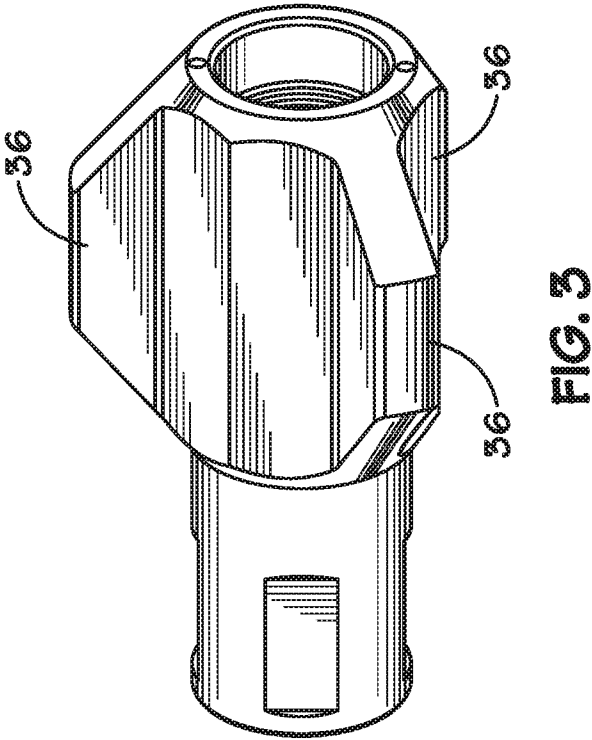
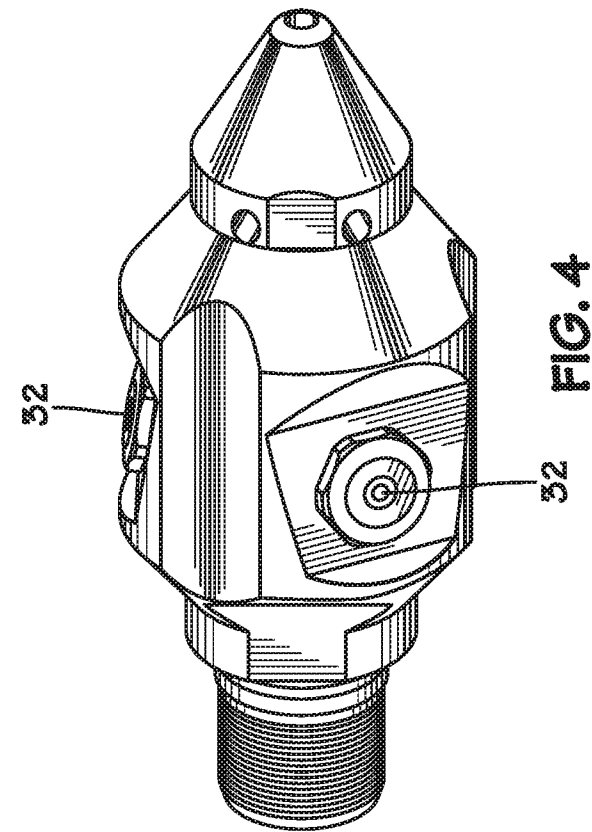


FIG. 2



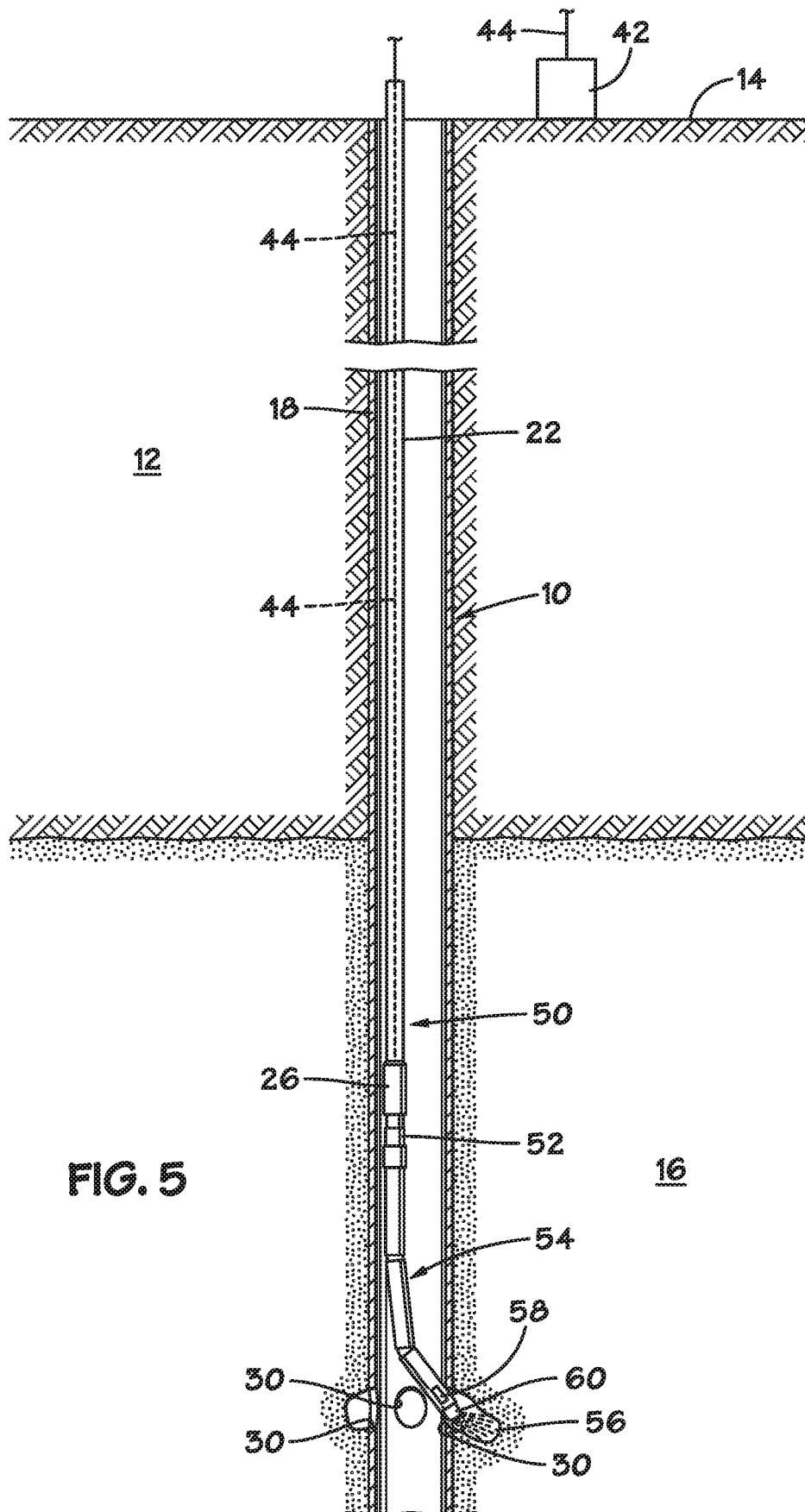


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/020353**A. CLASSIFICATION OF SUBJECT MATTER****E21B 29/02(2006.01)i, E21B 7/06(2006.01)i, E21B 47/06(2006.01)i, E21B 47/12(2006.01)i, G01V 5/12(2006.01)i**

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)

E21B 29/02; E21B 43/114; E21B 7/18; E21B 7/08; E21B 33/13; E21B 7/04; E21B 7/06; E21B 43/11; E21B 47/06; E21B 47/12; G01V 5/12

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: tunnel, formation, wellbore, opening, casing, inject, acid, and sensor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006-0278393 A1 (HUNT et al.) 14 December 2006 See paragraphs [0008], [0063]-[0065], [0073]-[0075], [0098] and figures 6-10, 14.	1,6
Y		2-5,7-14
Y	US 2012-0186809 A1 (MONTARON et al.) 26 July 2012 See paragraphs [0008], [0078]-[0079] and figure 4.	2-5,7-14
A	US 2014-0096966 A1 (MR. GARY FREITAG) 10 April 2014 See paragraphs [0045]-[0050] and figures 5-6.	1-14
A	US 2007-0151766 A1 (BUTLER et al.) 05 July 2007 See paragraphs [0024]-[0026] and figure 2.	1-14
A	US 2009-0114449 A1 (MISSELBROOK et al.) 07 May 2009 See paragraphs [0030]-[0031] and figures 3-4.	1-14



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/020353

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