(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
7 May 2015 (07.05.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/065387 A1

(51) International Patent Classification:
E21B 49/00 (2006.01) *E21B 47/13* (2012.01)
E21B 47/10 (2012.01)

(21) International Application Number:
PCT/US2013/067551

(22) International Filing Date:
30 October 2013 (30.10.2013)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant: **HALLIBURTON ENERGY SERVICES, INC.** [US/US]; 10200 Bellaire Blvd., Houston, TX 77072 (US).

(72) Inventors: **WOOD, Kevin**; 199 Jalan Tun Razak, 50400 Kuala Lumpur (MY). **WEBB, Alan**; Level 17, 444 Queen Street, Brisbane, Queensland 4000 (AU).

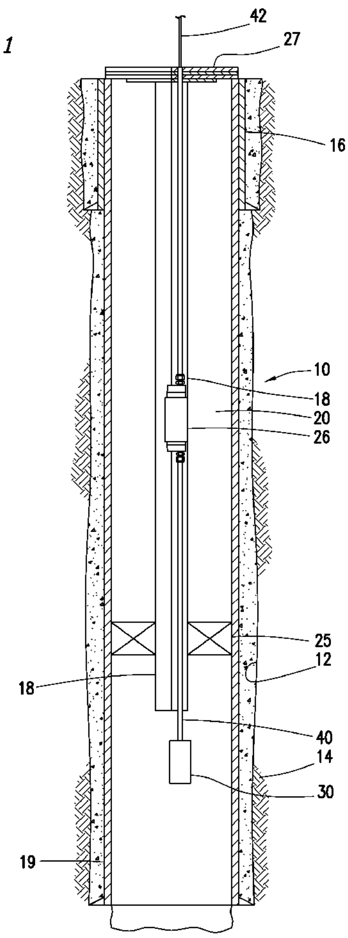
(74) Agent: **TIDWELL, Mark, A.**; Haynes and Boone, LLP, 2323 Victory Avenue, Ste. 700, Dallas, TX 75219 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM,

[Continued on next page]

(54) Title: ABANDONED WELL MONITORING SYSTEM

FIG. 1



(57) Abstract: Method and apparatus are presented for monitoring environmental parameters in one or more abandoned wellbores. A mandrel with a radially expandable sealing element is positioned downhole, such as in a tubing string, to provide pressure isolation. A measurement tool having one or more sensors or gauges is positioned below the mandrel to measure the environmental parameters. The data is transmitted to the surface via wire or wirelessly.

WO 2015/065387 A1

TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

ABANDONED WELL MONITORING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

None.

FIELD OF INVENTION

[0001] The present invention relates generally to operations performed and equipment utilized in conjunction with a subterranean well and, in an embodiment described herein, more particularly provides methods and apparatus for monitoring abandoned wellbores.

BACKGROUND OF INVENTION

[0002] Wells are abandoned for various reasons, typically at the end of their productive or commercially viable life span. A reservoir or productive zone eventually becomes depleted, such that it is no longer economical to produce hydrocarbons from the reservoir or zone. If the well is an injection well, then the need for such injection may no longer exist. Methods and apparatus for plugging and abandoning wells is known in the art and not described herein.

[0003] Even though a well is abandoned, however, it may be desirable to continue monitoring the well, the wellbore, or the downhole conditions in the wellbore, such as temperature and pressure. Where one or more wells in an oilfield is abandoned, but other wells in the field continue to be used for production, injections, or other operations, for example, it may be desirable to monitor the abandoned well or wells. The information gathering may be useful in determining how to treat the formation, other wellbores, or the efficacy of such procedures. Further, use of an abandoned well may prevent the need for and expense of drilling an observation well. Finally, environmental concerns regarding plugged and abandoned wells may be alleviated if the wells are monitored for stable or sustainable parameters.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

[0005] FIG. 1 is a schematic of an abandoned well monitoring system positioned in a wellbore according to an embodiment of the disclosure;

[0006] FIGS. 2A-B are schematic elevational and end views of the mandrel assembly according to an aspect of the disclosure; and

[0007] FIG. 3 is a schematic of an abandoned well monitoring system utilizing multiple mandrel assemblies and instrument tools positioned in a multi-zone wellbore according to an embodiment of the disclosure.

[0008] It should be understood by those skilled in the art that the use of directional terms such as above, below, upper, lower, upward, downward and the like are used in relation to the illustrative embodiments as they are depicted in the figures. Where this is not the case and a term is being used to indicate a required orientation, the specification will make such clear. Upstream, uphole, downstream and downhole are used to indicate location or direction in relation to the surface, where upstream indicates relative position or movement towards the surface along the wellbore and downstream indicates relative position or movement further away from the surface along the wellbore, unless otherwise indicated.

[0009] Even though the methods herein are discussed in relation to a vertical well, it should be understood by those skilled in the art that the system disclosed herein is equally well-suited for use in wells having other configurations including deviated wells, inclined wells, horizontal wells, multilateral wells and the like. Accordingly, use of directional terms such as "above", "below", "upper", "lower" and the like are used for convenience. Also, even though the discussion refers to a surface well operation, it should be understood by those skilled in the art that the apparatus and methods can also be employed in an offshore operation.

DETAILED DESCRIPTION

[0010] The present inventions are described by reference to drawings showing one or more examples of how the inventions can be made and used. In these drawings, reference characters are used throughout the several views to indicate like or corresponding parts. In the description which follows, like or corresponding parts are marked throughout the specification and drawings with the same reference numerals, respectively. The drawings are not necessarily to scale and the proportions of certain parts have been exaggerated to better illustrate details and features of the invention. In the following description, the terms “upper”, “upward”, “lower”, “below”, “downhole”, “longitudinally”, and the like, as used herein, shall mean in relation to the bottom, or furthest extent of, the surrounding wellbore even though the wellbore or portions of it may be deviated or horizontal. Correspondingly, the “transverse” or “radial” orientation shall mean the orientation perpendicular to the longitudinal orientation. In the discussion which follows, generally cylindrical well, pipe and tube components are assumed unless expressed otherwise.

[0011] The disclosed methods and apparatus are designed to provide long-term monitoring in wells where the operator may have a considerable amount of sunk capital, but rather than simply abandoning the well, it is used to provide downhole data. For example, downhole or formation pressure, temperature, salinity, etc., is measured using appropriate sensors and communicated to the surface for use by the operator of nearby wells.

[0012] FIG. 1 is a schematic of an abandoned well monitoring system 10 positioned in a wellbore according to an embodiment of the disclosure. Wellbore 12 extends through at least one subterranean zone or formation 14. A casing 16 is cemented into position along at least a portion of the length of the well. A liner 19 is shown hanging from the casing 16 and extending along the wellbore below the casing. The system is shown with a wellhead, tubing hanger, or other device 27 schematically represented. It is understood that the well can have various configurations, tubulars, surface and subsurface equipment, etc. Alternately, the liner can hang from a liner hanger or other tubular. The liner is often cemented into position as well. A tubing string 18 has been run-in to the well and extends to the surface. The tubing string defines an open bore therein. The tubing string 18 can be coiled tubing, a series of tubulars made-up into a string, etc., as is known in the art. A tubing annulus 20 is defined between the casing and tubing.

[0013] The well has been or is considered abandoned and can have zero or positive formation pressure at depth. Where the well has been plugged and abandoned it is common to place a cement plug 24 in the tubing annulus. Often a pressure barrier 25, such as a packer, plug tool, etc., is positioned downhole, below the cement plug, during plugging operations and left in the well. The system can be deployed in wells having various types of plugs, packers, etc. In some instances, the system can enhance or even replace a cement plug or packer since the mandrel assembly provides a pressure seal.

[0014] An abandoned well monitoring system 10 is seen deployed in the well. The system 10 includes a mandrel assembly 26 positioned uphole from, and connected to, an instrument tool 30 below. The system 10 is run-in via wireline, slick-line, coiled tubing, work string, or other method, in the tubing string 18. Alternately, the mandrel assembly can be pumped or flowed downhole. A cable 42 extends from the surface, through the mandrel assembly 26 and to the instrument tool 30. The cable 42 is preferably a control line and communicates the sensor, gauge, instrument readings, and various outputs from the instrument tool, etc., to the surface. The cable can also be a wireline, etc., as is known in the art. The instrument tool 30 can hang in the tubing string or below the tubing string, as shown. Depending on the wellbore and equipment in place, the tool can hang in a space defined by a perforated or non-perforated tubing, liner, casing, or open hole.

[0015] The disclosure focuses on a specific embodiment to facilitate discussion. It is understood, however, that the apparatus and methods are applicable to a wide variety of situations. For example, the monitoring system can be deployed in vertical, horizontal, or deviated wellbores; in cased, lined, or open-hole bores; in wellbores having multiple zones of interest; in played-out or dry wells; in wells having no, one, or multiple plugs or pressure isolation barriers; in zero pressure or positive pressure wells; onshore or offshore; with or without full rig and hoist; with various wellhead, Christmas tree, BOP, risers, and other termination and control equipment; etc.

[0016] FIGS. 2A-B are schematic elevational and end views of the mandrel assembly according to an aspect of the disclosure.

[0017] The mandrel assembly has a mandrel body 32, sealing element(s) 28, a longitudinal through-bore 34 defined therethrough, and connectors 36 for assembling the device on a tool string, tubular, etc. The mandrel assembly is seen having a threaded connector 36 and connected to hardware 38 and upper and lower tubular conduits 40. The hardware can include tube fittings, tubes, connectors, and the like. Swagelok (trade name) commercially supplies such hardware.

[0018] Since space is at a premium in most tubing strings, the mandrel body is preferably of relatively small OD, and more preferably about one inch OD. The sealing element 28 is preferably low-profile in its pre-expanded state, and more preferably has a run-in OD of about 1-1/8 inch. The mandrel body 32 defines a through-bore 34 which is preferably of about 3/8 inch ID. A communication cable 42 runs through the bore 34. Preferably the cable is about ¼ inch in diameter. The mandrel assembly includes connectors 36, which, in a preferred embodiment, include a 3/8 inch NPT female threaded connector. The hardware can include 3/8 inch NPT male threaded connections, bored-through. Cable options can include ¼ inch, of stainless steel, such as A825/316 Stainless. Where the system is deployed in a casing or open hole wellbore, the mandrel dimensions are preferably larger.

[0019] The mandrel assembly 26 has a gripping and sealing element 28, or elements, mounted on the mandrel 32 for sealingly engaging the interior surface of the tubing string. Such elements are well-known in the art and not described in detail herein. One or more elements can be employed. Preferably, due to the tight space restrictions in a typical tubing string, the sealing element(s) are low-profile on run-in and do not require bulky actuation devices such as slips, wedges, hydraulic or electric actuators, etc. In the preferred embodiment shown, the sealing element 28 is made of swellable materials. Swelling of the element causes radial expansion into sealing engagement with the interior of the tubing string. The sealing element 28 can be sized and made of selected materials according to the specifics of the wellbore. For example, when deployed in a casing, the element can have a greater OD. Similarly, when deployed in an open hole, the element materials may be selected to better seal against the open bore wall. Other arrangements will be apparent to those of skill in the art.

[0020] Swellable materials are known in the art and will not be described in detail herein. An example of a swellable material is a 50 duro nitrile with a low CAN content, or a soft EPDM. These substances swell in the presence of hydrocarbons, so the activating fluid can be *in situ* wellbore fluids. Alternately, the activating fluid can be pumped-down or introduced artificially to the wellbore. Further possible swellable materials include, but are not limited to, hydrogenated nitrile, polychloroprene, butyl, polyurethane and silicon, for instance, which swell in benzene. Similarly, brake fluid will swell elements made of fluorocarbon, hifluor, and flourosilicon, for example. Diesel will cause swelling of ethylene propylene, polyurethane, butyl, butadiene, isoprene and silicon, for example. Other swellable materials and activating fluids will present themselves to those skilled in the art, including those which activate in response to heat, pH, etc. Finally, in some embodiments of the disclosed apparatus, the sealing element can be made of swellable material with a delay mechanism which retards swelling for a period. The material itself can react slowly upon exposure to the activating fluid, or the element can have a temporary protective coating, etc. The time delay can be used to position the device in the wellbore.

[0021] Hung below the mandrel assembly 26, preferably by tubing 40, is one or more measuring or instrument tools 30. The instrument or measuring tool can include various sensors, gauges, optical cable, computing devices, recording devices, transmitters, and the like, all of which are known in the art. For example, tools and instruments can be used such as SmartLog (trade name) gauge, available commercially from DescoEMIT, ROC (trade name) downhole gauge, commercially available from Halliburton Energy Services, Inc., quartz gauges, strain gauges, piezoelectric gauges, fiber optic sensors, etc., as are known in the art. The instruments can be used in conjunction with fiber optic distributed measurements to provide distributed temperature sensing or distributed acoustic sensing. The parameters to be measured can include temperature, pressure, pH, salinity, and other parameters. Further, more than one instrument tool can be run-in, spaced apart from one another. For example, a single downhole permanent or temporary gauge, a multi-drop downhole permanent or temporary gauge (up to six or more), or a downhole permanent or temporary gauge with fiber optic DTS can be used. These are merely examples of gauge types which can be used. Downhole measurement or instrument tools are available which provide reliable, real-time data about downhole conditions. Such tools can be used for single or multi-zone monitoring applications. In multi-zone applications, dual, triple, or quad splitter block assemblies can be used for multi-drop capabilities.

[0022] Several methods of deployment are envisioned. For example, a low cost onshore monitoring method and system can be as simple as lowering an instrument tool, such as a Smartlog (trade name) gauge, on the mandrel inside the tubing on a well that is considered abandoned. The cable can be terminated at the surface through the top of the Christmas tree or other surface equipment. A pressure barrier is provided by the swellable mandrel and a secondary pressure barrier can be provided at the surface, for example, at the wellhead. This method allows use of an abandoned well, potentially avoiding the commercial outlay for drilling an observation well. The mandrel and instrument tool can preferably be run from a spooling unit rather than deploying a work-over hoist to recomplete the well, for example.

[0023] In another embodiment, a platform-based, offshore monitoring method and system are provided. Such a system is more suited for higher-end applications where several zones have been drilled but deemed uneconomical to produce. Multiple mandrels can be run-in hole, with the swellable sealing elements providing isolation between zones. Alternately, packers, plugs and the like can provide isolation. Distributed temperature, and single-point pressure and temperature gauges can be employed. The system provides valuable data on field pressure depletion, monitoring of enhanced recovery operations, such as water flood, validation of reserves, and long-term field pressure monitoring. Deployment can be by spooling unit, or using a hoist to make-up a string. It may be necessary in some applications to use a side-door splitter or BOP stack for pressure control.

[0024] In this regard, FIG. 3 is a schematic of an abandoned well monitoring system utilizing multiple mandrel assemblies and instrument tools positioned in a multi-zone wellbore according to an embodiment of the disclosure. An abandoned wellbore 50, with multiple zones 51 of interest isolated by packers 53 or other isolation devices for sealing the annulus between the string 57 and casing 55. A monitoring system 52 is deployed having a plurality of mandrel assemblies 54 and instrument tools 56. The swellable elements can provide isolation between zones. Alternately, isolation can be provided by packers and other devices known in the art. Within the zones of interest, one or more instrument tools is positioned to measure environmental parameters. The gathered data is transmitted uphole, preferably by wire 28. Alternately, the data can be transmitted wirelessly or by any other known means. Multiple instrument tools can be daisy-chained together to utilize a shared computer and/or transmission device.

[0025] In another embodiment, a subsea well monitoring method and system are provided. Rather than abandon a subsea well that has been drilled, the well can be populated with instrument tools and mandrels, providing value in the form of field data. In projects where the wells are batch-drilled for completion at a later time, the system can be deployed in conjunction with a downhole computer and transmission system. For example, a tree transmission system, such as commercially available from Sonardyne Group of Companies, can be used to provide data back to surface before the subsea infrastructure and Floating Production Storage and Offloading unit are in place. For the methods and systems described herein, the transmission of data from downhole can be via wire or wireless, or by any known or future means.

[0026] In another embodiment, a horizontal well monitoring method and system are provided. In wells with significant wellbore deviation, where the deviation has passed the feasible limits for using wireline deployment, one method of deployment is pumping or flowing the mandrel assembly into the wellbore. A time-delay for activation of the swellable seal can be used to prevent the mandrel from deploying prematurely. Alternately, suction cups can be employed to pump the system into the well.

[0027] The methods and systems disclosed herein allow savings in utilizing a depleted well for long-term observation and monitoring rather than drilling a dedicated observation well. Further, savings are available where the system can be deployed on a wireline intervention set-up instead of a work-over hoist and rig. Savings are also realized since the system can be run inside an existing completion instead of pulling the existing completion and running new tubing. Savings in deploying gauges allows longer term monitoring in a field instead of running production logging tool interventions. Running data transmission systems allows longer term monitoring of single-phase and multi-zone wells to validate operations such as water flood, polymer flood, etc. The low cost barrier provided by the swellable element reduces cost in comparison to a cement pumping operation.

[0028] Support for the claimed methods and steps of methods is provided here. It is explicitly understood that each of the steps can be performed in any order, repeated, omitted, performed before or after additional steps, named and unnamed, etc., unless stated otherwise. A preferred method of monitoring an abandoned wellbore extending through a subterranean formation, comprises the steps of: a) running into an abandoned wellbore an environmental parameter measuring device below a pressure isolation assembly; b) providing annular pressure isolation across the annulus defined exterior to the pressure isolation assembly; c) measuring at least one downhole environmental parameter in the wellbore downhole from the isolation assembly using the measuring device; and d) transmitting data related to a measured parameter to the surface. In a preferred method step a) can further comprise running the measuring device and isolation assembly in hole on a wire line, slick line, coiled tubing, or tubing string. In a preferred method, step a) further comprises running the measuring device and isolation assembly into a tubing string positioned in the wellbore. In a preferred method, step b) further comprises radially expanding at least one sealing element. In a preferred method, the sealing element is radially expanded into sealing engagement with the tubing string. In a preferred method, the sealing element is swellable upon contact with an activating fluid. In a preferred method, step c) further comprises measuring a downhole temperature, pressure, pH, or salinity. In a preferred method, step c) further comprises using at least one of a quartz gauge, piezoelectric gauge, or distributed optical cable. In a preferred method, step d) further comprises transmitting data via wire or wirelessly to the surface. In a preferred method, the wellbore extends through multiple zones, and further comprising the steps of: positioning a plurality of environmental parameter measuring devices in the wellbore, at least one measuring device in each of the plurality of zones. A preferred method, further comprises the step of: positioning a plurality of pressure isolation assemblies adjacent the plurality of zones. A preferred method further comprises steps of radially expanding the plurality of isolation devices and isolating a plurality of zones.

[0029] While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments as well as other embodiments of the invention will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

ABANDONED WELL MONITORING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

None.

TECHNICAL FIELD

[0001] The present disclosure relates generally to operations performed and equipment utilized in conjunction with a subterranean well and, in an embodiment described herein, more particularly provides methods and apparatus for monitoring abandoned wellbores.

BACKGROUND INFORMATION

[0002] Wells are abandoned for various reasons, typically at the end of their productive or commercially viable life span. A reservoir or productive zone eventually becomes depleted, such that it is no longer economical to produce hydrocarbons from the reservoir or zone. If the well is an injection well, then the need for such injection may no longer exist. Methods and apparatus for plugging and abandoning wells is known in the art and not described herein.

[0003] Even though a well is abandoned, however, it may be desirable to continue monitoring the well, the wellbore, or the downhole conditions in the wellbore, such as temperature and pressure. Where one or more wells in an oilfield is abandoned, but other wells in the field continue to be used for production, injections, or other operations, for example, it may be desirable to monitor the abandoned well or wells. The information gathering may be useful in determining how to treat the formation, other wellbores, or the efficacy of such procedures. Further, use of an abandoned well may prevent the need for and expense of drilling an observation well. Finally, environmental concerns regarding plugged and abandoned wells may be alleviated if the wells are monitored for stable or sustainable parameters.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] For a more complete understanding of the features and advantages of the present disclosure, reference is now made to the detailed description of the disclosure along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

[0005] FIG. 1 is a schematic of an abandoned well monitoring system positioned in a wellbore according to an embodiment of the disclosure;

[0006] FIGS. 2A-B are schematic elevational and end views of the mandrel assembly according to an aspect of the disclosure; and

[0007] FIG. 3 is a schematic of an abandoned well monitoring system utilizing multiple mandrel assemblies and instrument tools positioned in a multi-zone wellbore according to an embodiment of the disclosure.

[0008] It should be understood by those skilled in the art that the use of directional terms such as above, below, upper, lower, upward, downward and the like are used in relation to the illustrative embodiments as they are depicted in the figures. Where this is not the case and a term is being used to indicate a required orientation, the specification will make such clear. Upstream, uphole, downstream and downhole are used to indicate location or direction in relation to the surface, where upstream indicates relative position or movement towards the surface along the wellbore and downstream indicates relative position or movement further away from the surface along the wellbore, unless otherwise indicated.

[0009] Even though the methods herein are discussed in relation to a vertical well, it should be understood by those skilled in the art that the system disclosed herein is equally well-suited for use in wells having other configurations including deviated wells, inclined wells, horizontal wells, multilateral wells and the like. Accordingly, use of directional terms such as "above", "below", "upper", "lower" and the like are used for convenience. Also, even though the discussion refers to a surface well operation, it should be understood by those skilled in the art that the apparatus and methods can also be employed in an offshore operation.

DETAILED DESCRIPTION

[0010] The present disclosures are described by reference to drawings showing one or more examples of how the disclosures can be made and used. In these drawings, reference characters are used throughout the several views to indicate like or corresponding parts. In the description which follows, like or corresponding parts are marked throughout the specification and drawings with the same reference numerals, respectively. The drawings are not necessarily to scale and the proportions of certain parts have been exaggerated to better illustrate details and features of the disclosure. In the following description, the terms “upper”, “upward”, “lower”, “below”, “downhole”, “longitudinally”, and the like, as used herein, shall mean in relation to the bottom, or furthest extent of, the surrounding wellbore even though the wellbore or portions of it may be deviated or horizontal. Correspondingly, the “transverse” or “radial” orientation shall mean the orientation perpendicular to the longitudinal orientation. In the discussion which follows, generally cylindrical well, pipe and tube components are assumed unless expressed otherwise.

[0011] The disclosed methods and apparatus are designed to provide long-term monitoring in wells where the operator may have a considerable amount of sunk capital, but rather than simply abandoning the well, it is used to provide downhole data. For example, downhole or formation pressure, temperature, salinity, etc., is measured using appropriate sensors and communicated to the surface for use by the operator of nearby wells.

[0012] FIG. 1 is a schematic of an abandoned well monitoring system 10 positioned in a wellbore according to an embodiment of the disclosure. Wellbore 12 extends through at least one subterranean zone or formation 14. A casing 16 is cemented into position along at least a portion of the length of the well. A liner 19 is shown hanging from the casing 16 and extending along the wellbore below the casing. The system is shown with a wellhead, tubing hanger, or other device 27 schematically represented. It is understood that the well can have various configurations, tubulars, surface and subsurface equipment, etc. Alternately, the liner can hang from a liner hanger or other tubular. The liner is often cemented into position as well. A tubing string 18 has been run-in to the well and extends to the surface. The tubing string defines an open bore therein. The tubing string 18 can be coiled tubing, a series of tubulars made-up into a string, etc., as is known in the art. A tubing annulus 20 is defined between the casing and tubing.

[0013] The well has been or is considered abandoned and can have zero or positive formation pressure at depth. Where the well has been plugged and abandoned it is common to place a cement plug 24 in the tubing annulus. Often a pressure barrier 25, such as a packer, plug tool, etc., is positioned downhole, below the cement plug, during plugging operations and left in the well. The system can be deployed in wells having various types of plugs, packers, etc. In some instances, the system can enhance or even replace a cement plug or packer since the mandrel assembly provides a pressure seal.

[0014] An abandoned well monitoring system 10 is seen deployed in the well. The system 10 includes a mandrel assembly 26 positioned uphole from, and connected to, an instrument tool 30 below. The system 10 is run-in via wireline, slick-line, coiled tubing, work string, or other method, in the tubing string 18. Alternately, the mandrel assembly can be pumped or flowed downhole. A cable 42 extends from the surface, through the mandrel assembly 26 and to the instrument tool 30. The cable 42 is preferably a control line and communicates the sensor, gauge, instrument readings, and various outputs from the instrument tool, etc., to the surface. The cable can also be a wireline, etc., as is known in the art. The instrument tool 30 can hang in the tubing string or below the tubing string, as shown. Depending on the wellbore and equipment in place, the tool can hang in a space defined by a perforated or non-perforated tubing, liner, casing, or open hole.

[0015] The disclosure focuses on a specific embodiment to facilitate discussion. It is understood, however, that the apparatus and methods are applicable to a wide variety of situations. For example, the monitoring system can be deployed in vertical, horizontal, or deviated wellbores; in cased, lined, or open-hole bores; in wellbores having multiple zones of interest; in played-out or dry wells; in wells having no, one, or multiple plugs or pressure isolation barriers; in zero pressure or positive pressure wells; onshore or offshore; with or without full rig and hoist; with various wellhead, Christmas tree, BOP, risers, and other termination and control equipment; etc.

[0016] FIGS. 2A-B are schematic elevational and end views of the mandrel assembly according to an aspect of the disclosure.

[0017] The mandrel assembly has a mandrel body 32, sealing element(s) 28, a longitudinal through-bore 34 defined therethrough, and connectors 36 for assembling the device on a tool string, tubular, etc. The mandrel assembly is seen having a threaded connector 36 and connected to hardware 38 and upper and lower tubular conduits 40. The hardware can include tube fittings, tubes, connectors, and the like. Swagelok (trade name) commercially supplies such hardware.

[0018] Since space is at a premium in most tubing strings, the mandrel body is preferably of relatively small OD, and more preferably about one inch OD. The sealing element 28 is preferably low-profile in its pre-expanded state, and more preferably has a run-in OD of about 1-1/8 inch. The mandrel body 32 defines a through-bore 34 which is preferably of about 3/8 inch ID. A communication cable 42 runs through the bore 34. Preferably the cable is about ¼ inch in diameter. The mandrel assembly includes connectors 36, which, in a preferred embodiment, include a 3/8 inch NPT female threaded connector. The hardware can include 3/8 inch NPT male threaded connections, bored-through. Cable options can include ¼ inch, of stainless steel, such as A825/316 Stainless. Where the system is deployed in a casing or open hole wellbore, the mandrel dimensions are preferably larger.

[0019] The mandrel assembly 26 has a gripping and sealing element 28, or elements, mounted on the mandrel 32 for sealingly engaging the interior surface of the tubing string. Such elements are well-known in the art and not described in detail herein. One or more elements can be employed. Preferably, due to the tight space restrictions in a typical tubing string, the sealing element(s) are low-profile on run-in and do not require bulky actuation devices such as slips, wedges, hydraulic or electric actuators, etc. In the preferred embodiment shown, the sealing element 28 is made of swellable materials. Swelling of the element causes radial expansion into sealing engagement with the interior of the tubing string. The sealing element 28 can be sized and made of selected materials according to the specifics of the wellbore. For example, when deployed in a casing, the element can have a greater OD. Similarly, when deployed in an open hole, the element materials may be selected to better seal against the open bore wall. Other arrangements will be apparent to those of skill in the art.

[0020] Swellable materials are known in the art and will not be described in detail herein. An example of a swellable material is a 50 duro nitrile with a low CAN content, or a soft EPDM. These substances swell in the presence of hydrocarbons, so the activating fluid can be *in situ* wellbore fluids. Alternately, the activating fluid can be pumped-down or introduced artificially to the wellbore. Further possible swellable materials include, but are not limited to, hydrogenated nitrile, polychloroprene, butyl, polyurethane and silicon, for instance, which swell in benzene. Similarly, brake fluid will swell elements made of fluorocarbon, hifluor, and flourosilicon, for example. Diesel will cause swelling of ethylene propylene, polyurethane, butyl, butadiene, isoprene and silicon, for example. Other swellable materials and activating fluids will present themselves to those skilled in the art, including those which activate in response to heat, pH, etc. Finally, in some embodiments of the disclosed apparatus, the sealing element can be made of swellable material with a delay mechanism which retards swelling for a period. The material itself can react slowly upon exposure to the activating fluid, or the element can have a temporary protective coating, etc. The time delay can be used to position the device in the wellbore.

[0021] Hung below the mandrel assembly 26, preferably by tubing 40, is one or more measuring or instrument tools 30. The instrument or measuring tool can include various sensors, gauges, optical cable, computing devices, recording devices, transmitters, and the like, all of which are known in the art. For example, tools and instruments can be used such as SmartLog (trade name) gauge, available commercially from DescoEMIT, ROC (trade name) downhole gauge, commercially available from Halliburton Energy Services, Inc., quartz gauges, strain gauges, piezoelectric gauges, fiber optic sensors, etc., as are known in the art. The instruments can be used in conjunction with fiber optic distributed measurements to provide distributed temperature sensing or distributed acoustic sensing. The parameters to be measured can include temperature, pressure, pH, salinity, and other parameters. Further, more than one instrument tool can be run-in, spaced apart from one another. For example, a single downhole permanent or temporary gauge, a multi-drop downhole permanent or temporary gauge (up to six or more), or a downhole permanent or temporary gauge with fiber optic DTS can be used. These are merely examples of gauge types which can be used. Downhole measurement or instrument tools are available which provide reliable, real-time data about downhole conditions. Such tools can be used for single or multi-zone monitoring applications. In multi-zone applications, dual, triple, or quad splitter block assemblies can be used for multi-drop capabilities.

[0022] Several methods of deployment are envisioned. For example, a low cost onshore monitoring method and system can be as simple as lowering an instrument tool, such as a Smartlog (trade name) gauge, on the mandrel inside the tubing on a well that is considered abandoned. The cable can be terminated at the surface through the top of the Christmas tree or other surface equipment. A pressure barrier is provided by the swellable mandrel and a secondary pressure barrier can be provided at the surface, for example, at the wellhead. This method allows use of an abandoned well, potentially avoiding the commercial outlay for drilling an observation well. The mandrel and instrument tool can preferably be run from a spooling unit rather than deploying a work-over hoist to recomplete the well, for example.

[0023] In another embodiment, a platform-based, offshore monitoring method and system are provided. Such a system is more suited for higher-end applications where several zones have been drilled but deemed uneconomical to produce. Multiple mandrels can be run-in hole, with the swellable sealing elements providing isolation between zones. Alternately, packers, plugs and the like can provide isolation. Distributed temperature, and single-point pressure and temperature gauges can be employed. The system provides valuable data on field pressure depletion, monitoring of enhanced recovery operations, such as water flood, validation of reserves, and long-term field pressure monitoring. Deployment can be by spooling unit, or using a hoist to make-up a string. It may be necessary in some applications to use a side-door splitter or BOP stack for pressure control.

[0024] In this regard, FIG. 3 is a schematic of an abandoned well monitoring system utilizing multiple mandrel assemblies and instrument tools positioned in a multi-zone wellbore according to an embodiment of the disclosure. An abandoned wellbore 50, with multiple zones 51 of interest isolated by packers 53 or other isolation devices for sealing the annulus between the string 57 and casing 55. A monitoring system 52 is deployed having a plurality of mandrel assemblies 54 and instrument tools 56. The swellable elements can provide isolation between zones. Alternately, isolation can be provided by packers and other devices known in the art. Within the zones of interest, one or more instrument tools is positioned to measure environmental parameters. The gathered data is transmitted uphole, preferably by wire 28. Alternately, the data can be transmitted wirelessly or by any other known means. Multiple instrument tools can be daisy-chained together to utilize a shared computer and/or transmission device.

[0025] In another embodiment, a subsea well monitoring method and system are provided. Rather than abandon a subsea well that has been drilled, the well can be populated with instrument tools and mandrels, providing value in the form of field data. In projects where the wells are batch-drilled for completion at a later time, the system can be deployed in conjunction with a downhole computer and transmission system. For example, a tree transmission system, such as commercially available from Sonardyne Group of Companies, can be used to provide data back to surface before the subsea infrastructure and Floating Production Storage and Offloading unit are in place. For the methods and systems described herein, the transmission of data from downhole can be via wire or wireless, or by any known or future means.

[0026] In another embodiment, a horizontal well monitoring method and system are provided. In wells with significant wellbore deviation, where the deviation has passed the feasible limits for using wireline deployment, one method of deployment is pumping or flowing the mandrel assembly into the wellbore. A time-delay for activation of the swellable seal can be used to prevent the mandrel from deploying prematurely. Alternately, suction cups can be employed to pump the system into the well.

[0027] The methods and systems disclosed herein allow savings in utilizing a depleted well for long-term observation and monitoring rather than drilling a dedicated observation well. Further, savings are available where the system can be deployed on a wireline intervention set-up instead of a work-over hoist and rig. Savings are also realized since the system can be run inside an existing completion instead of pulling the existing completion and running new tubing. Savings in deploying gauges allows longer term monitoring in a field instead of running production logging tool interventions. Running data transmission systems allows longer term monitoring of single-phase and multi-zone wells to validate operations such as water flood, polymer flood, etc. The low cost barrier provided by the swellable element reduces cost in comparison to a cement pumping operation.

[0028] Support for the disclosed methods and portions thereof is provided here. It is explicitly understood that each stage, action, or portion of method can be performed in any order, repeated, omitted, performed before or after additional stages, actions, or portions of method, named and unnamed, etc., unless stated otherwise. A preferred method of monitoring an abandoned wellbore extending through a subterranean formation, comprises: a) running into an abandoned wellbore an environmental parameter measuring device below a pressure isolation assembly; b) providing annular pressure isolation across the annulus defined exterior to the pressure isolation assembly; c) measuring at least one downhole environmental parameter in the wellbore downhole from the isolation assembly using the measuring device; and d) transmitting data related to a measured parameter to the surface. In a preferred method a) can further comprise running the measuring device and isolation assembly in hole on a wire line, slick line, coiled tubing, or tubing string. In a preferred method, a) further comprises running the measuring device and isolation assembly into a tubing string positioned in the wellbore. In a preferred method, b) further comprises radially expanding at least one sealing element. In a preferred method, the sealing element is radially expanded into sealing engagement with the tubing string. In a preferred method, the sealing element is swellable upon contact with an activating fluid. In a preferred method, c) further comprises measuring a downhole temperature, pressure, pH, or salinity. In a preferred method, c) further comprises using at least one of a quartz gauge, piezoelectric gauge, or distributed optical cable. In a preferred method, d) further comprises transmitting data via wire or wirelessly to the surface. In a preferred method, the wellbore extends through multiple zones, and further comprising: positioning a plurality of environmental parameter measuring devices in the wellbore, at least one measuring device in each of the plurality of zones. A preferred method, further comprises: positioning a plurality of pressure isolation assemblies adjacent the plurality of zones. A preferred method further comprises radially expanding the plurality of isolation devices and isolating a plurality of zones.

[0029] While this disclosure has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments as well as other embodiments of the disclosure will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

It is claimed:

1. A method of monitoring an abandoned wellbore extending through a subterranean formation, the method comprising the steps of:

a) running into an abandoned wellbore an environmental parameter measuring device below a pressure isolation assembly;

b) providing annular pressure isolation across the annulus defined exterior to the pressure isolation assembly;

c) measuring at least one downhole environmental parameter in the wellbore downhole from the isolation assembly using the measuring device; and

d) transmitting data related to a measured parameter to the surface.

2. The method of claim 1, wherein step a) further comprises running the measuring device and isolation assembly in hole on a wire line, slick line, coiled tubing, or tubing string.

3. The method of claim 1, wherein step a) further comprises running the measuring device and isolation assembly into a tubing string positioned in the wellbore.

4. The method of claim 1, wherein step b) further comprises radially expanding at least one sealing element.

5. The method of claim 4, further comprising radially expanding a sealing element into sealing engagement with the tubing string.

6. The method of claim 5, wherein the sealing element is swellable upon contact with an activating fluid.

7. The method of claim 1, wherein step c) further comprises measuring a downhole temperature, pressure, pH, or salinity.

8. The method of claim 1, wherein step c) further comprises using at least one of a quartz gauge, piezoelectric gauge, or distributed optical cable.

9. The method of claim 1, wherein step d) further comprises transmitting data via wire or wirelessly to the surface.

10. The method of claim 1, wherein the wellbore extends through multiple zones, and further comprising the steps of: positioning a plurality of environmental parameter measuring devices in the wellbore, at least one measuring device in each of the plurality of zones.

11. The method of claim 10, further comprising the step of: positioning a plurality of pressure isolation assemblies adjacent the plurality of zones.

12. The method of claim 11, further comprising the steps of radially expanding the plurality of isolation devices and isolating the plurality of zones.

13. A system for monitoring an abandoned wellbore extending through a subterranean formation, the system comprising:

a mandrel assembly having a mandrel and at least one radially expandable isolation element positioned thereon, and connected thereto

at least one downhole instrument tool for measuring downhole parameters.

14. The system of claim 13, wherein the radially expandable isolation element comprises a swellable sealing element.

15. The system of claim 14, wherein the radially expandable isolation element is activated to radially expand by contact with in situ fluids in the wellbore.

16. The system of claim 13, wherein the mandrel defines a through-bore.

17. The system of claim 13, wherein the mandrel assembly is connected to the downhole instrument tool by a tubular or wire.

18. The system of claim 13, further comprising connectors for attaching the mandrel assembly to a wireline, slick line, coiled tubing, or tubing string.

19. The system of claim 13, wherein the downhole instrument tool has sensors or gauges for measuring temperature or pressure.

20. The system of claim 13, further comprising a wireless transmission assembly for transmitting data from the instrument tool to the surface.

21. The system of claim 13, further comprising a plurality of mandrel assemblies and downhole instrument tools spaced apart to monitor multiple zones in the formation.

It is claimed:

1. A method of monitoring an abandoned wellbore extending through a subterranean formation, the method comprising:

a) running into an abandoned wellbore an environmental parameter measuring device below a pressure isolation assembly;

b) providing annular pressure isolation across the annulus defined exterior to the pressure isolation assembly;

c) measuring at least one downhole environmental parameter in the wellbore downhole from the isolation assembly using the measuring device; and

d) transmitting data related to a measured parameter to the surface.

2. The method of claim 1, wherein a) further comprises running the measuring device and isolation assembly in hole on a wire line, slick line, coiled tubing, or tubing string.

3. The method of claim 1, wherein a) further comprises running the measuring device and isolation assembly into a tubing string positioned in the wellbore.

4. The method of claim 1, wherein b) further comprises radially expanding at least one sealing element.

5. The method of claim 4, further comprising radially expanding a sealing element into sealing engagement with the tubing string.

6. The method of claim 5, wherein the sealing element is swellable upon contact with an activating fluid.

7. The method of claim 1, wherein c) further comprises measuring a downhole temperature, pressure, pH, or salinity.

8. The method of claim 1, wherein c) further comprises using at least one of a quartz gauge, piezoelectric gauge, or distributed optical cable.

9. The method of claim 1, wherein d) further comprises transmitting data via wire or wirelessly to the surface.

10. The method of claim 1, wherein the wellbore extends through multiple zones, and further comprising: positioning a plurality of environmental parameter measuring devices in the wellbore, at least one measuring device in each of the plurality of zones.

11. The method of claim 10, further comprising: positioning a plurality of pressure isolation assemblies adjacent the plurality of zones.

12. The method of claim 11, further comprising radially expanding the plurality of isolation devices and isolating the plurality of zones.

13. A system for monitoring an abandoned wellbore extending through a subterranean formation, the system comprising:

a mandrel assembly having a mandrel and at least one radially expandable isolation element positioned thereon, and connected thereto

at least one downhole instrument tool for measuring downhole parameters.

14. The system of claim 13, wherein the radially expandable isolation element comprises a swellable sealing element.

15. The system of claim 14, wherein the radially expandable isolation element is activated to radially expand by contact with in situ fluids in the wellbore.

16. The system of claim 13, wherein the mandrel defines a through-bore.

17. The system of claim 13, wherein the mandrel assembly is connected to the downhole instrument tool by a tubular or wire.

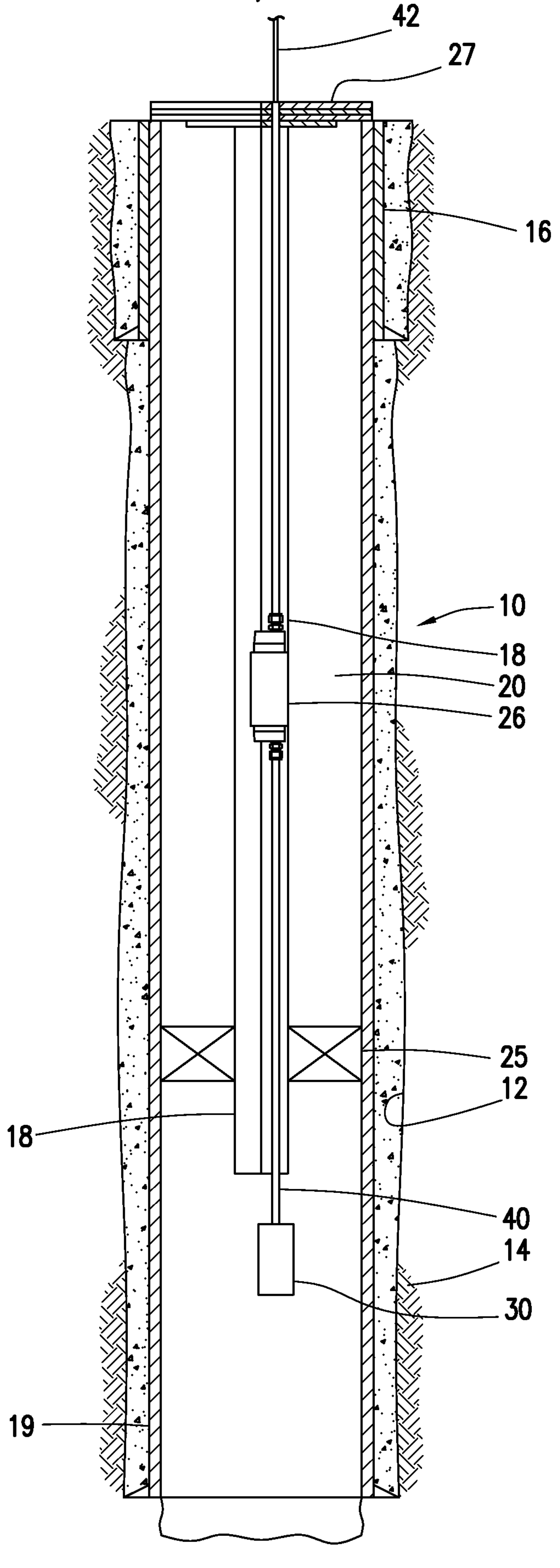
18. The system of claim 13, further comprising connectors for attaching the mandrel assembly to a wireline, slick line, coiled tubing, or tubing string.

19. The system of claim 13, wherein the downhole instrument tool has sensors or gauges for measuring temperature or pressure.

20. The system of claim 13, further comprising a wireless transmission assembly for transmitting data from the instrument tool to the surface.

21. The system of claim 13, further comprising a plurality of mandrel assemblies and downhole instrument tools spaced apart to monitor multiple zones in the formation.

FIG. 1



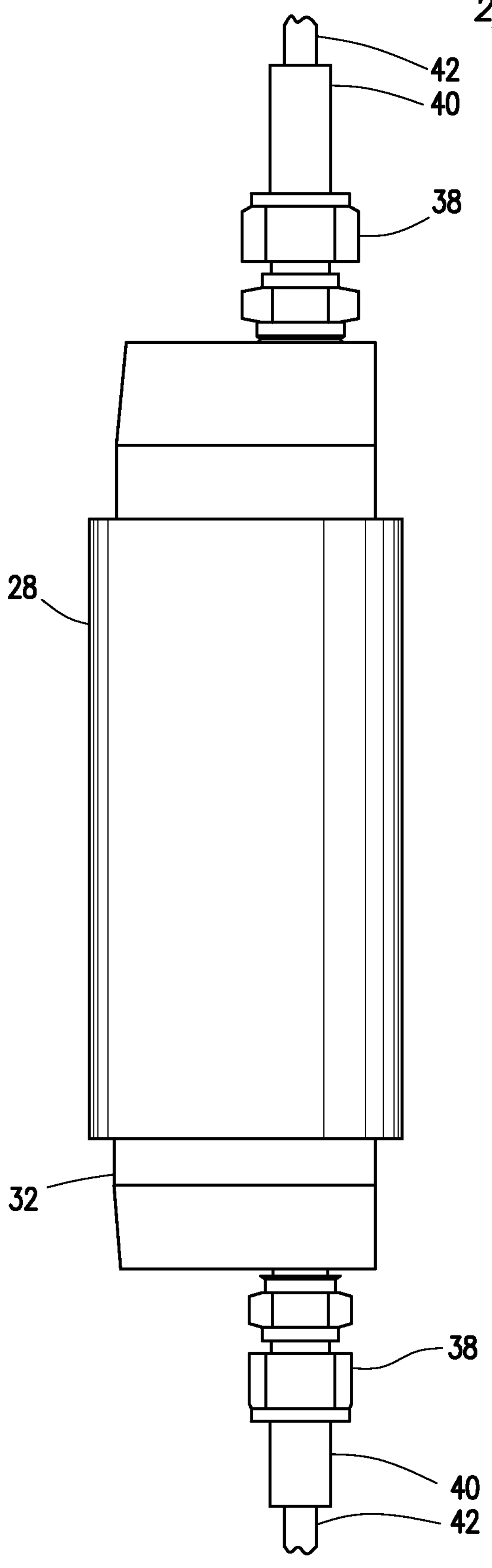


FIG. 2A

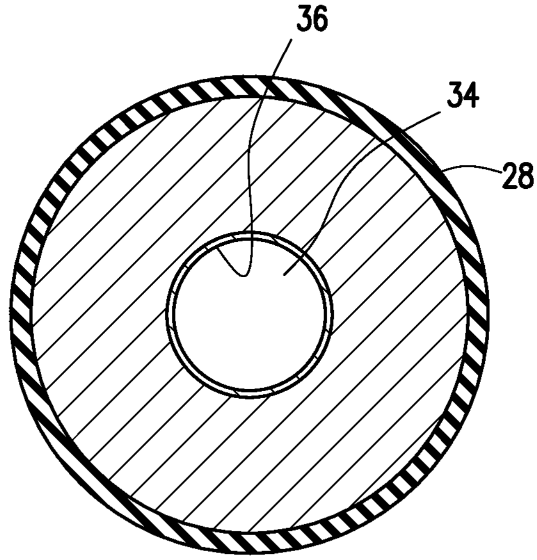


FIG. 2B

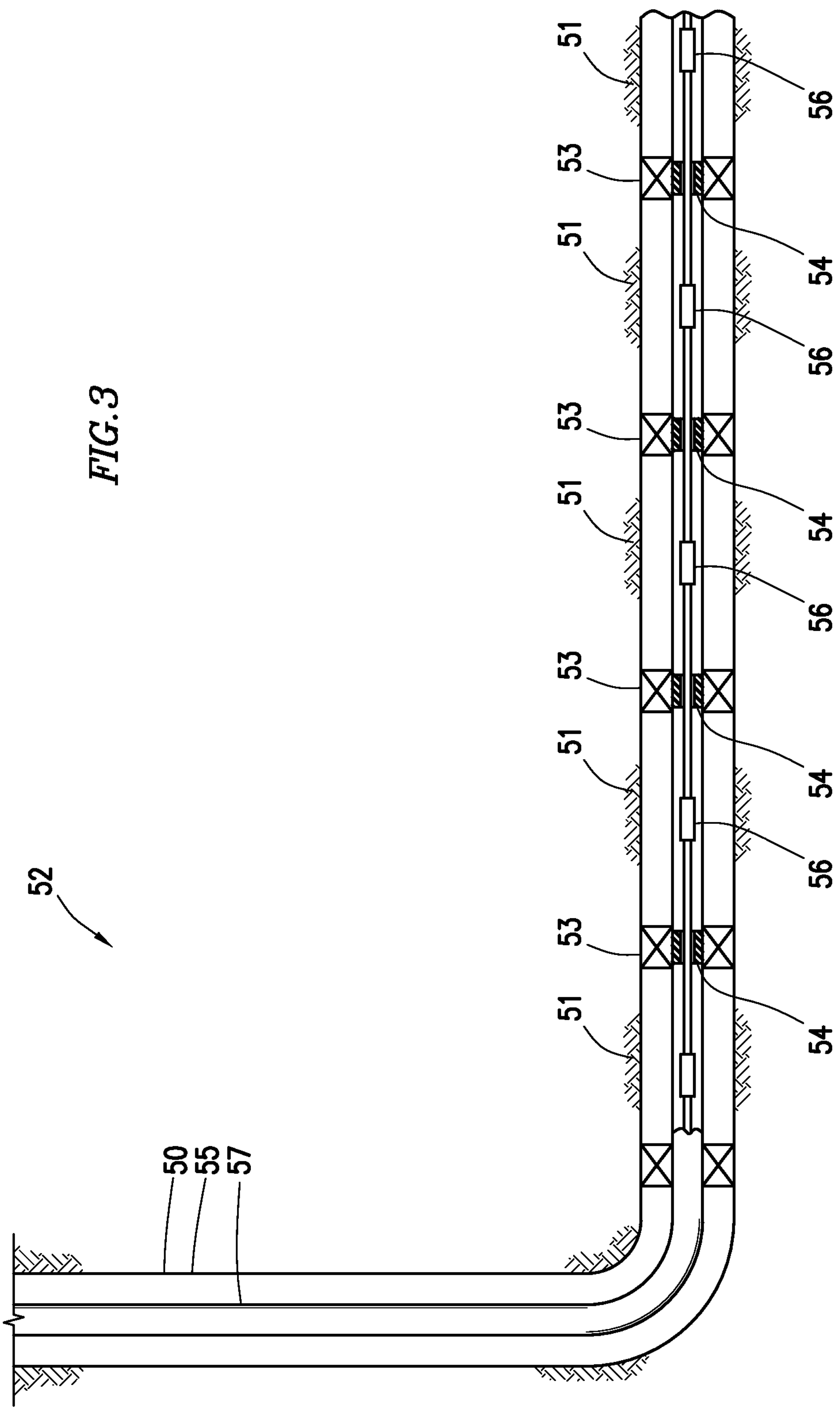


FIG.3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/067551

A. CLASSIFICATION OF SUBJECT MATTER

E21B 49/00(2006.01)i, E21B 47/10(2006.01)i, E21B 47/13(2012.01)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 49/00; E21B 23/04; E21B 33/128; E21B 23/06; E21B 47/00; G02B 6/26; E21B 47/09; E21B 34/10; E21B 4/18; E21B 47/10; E21B 47/13

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: abandoned well, monitoring, isolation, and mandrel

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006-0196670 A1 (RICHARDS et al.) 07 September 2006 See paragraphs [0038],[0058]-[0073],[0079]-[0080] and figures 1-4.	1-4,7-12
Y		5-6,13-21
Y	US 2011-0247835 A1 (CRABB, JAMES) 13 October 2011 See paragraphs [0025],[0028],[0033] and figure 1A,6B.	5-6,13-21
A	US 2003-0094281 A1 (TUBEL, PAULO S.) 22 May 2003 See paragraphs [0048]-[0056] and figures 1-3.	1-21
A	US 2005-0241825 A1 (BURRIS, II et al.) 03 November 2005 See paragraphs [0038]-[0048]; claims 1-3; and figures 1-4.	1-21
A	US 2008-0128128 A1 (VAIL et al.) 05 June 2008 See paragraphs [0384]-[0386] and figures 5-9.	1-21

☐ 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
29 July 2014 (29.07.2014)	**30 July 2014 (30.07.2014)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
SONG, Ho Keun
Telephone No. +82-42-481-5580

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2013/067551

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2006-0196670 A1	07/09/2006	AT 347021 T	15/12/2006
		AU 2001-292062 B2	16/11/2006
		AU 2001-92062 A1	15/04/2002
		BR 0114452 A	21/10/2003
		CA 2423232 A1	11/04/2002
		CA 2423232 C	15/07/2008
		DE 60124934 D1	11/01/2007
		EP 1322837 A2	02/07/2003
		EP 1322837 B1	29/11/2006
		GB 0024378 D0	22/11/2000
		NO 20031300 A	23/05/2003
		NO 20031300 D0	21/03/2003
		NO 326503 B1	15/12/2008
		US 2004-0094296 A1	20/05/2004
		US 7086464 B2	08/08/2006
		US 7261161 B2	28/08/2007
		WO 02-29196 A2	11/04/2002
		WO 02-29196 A3	08/08/2002
US 2011-0247835 A1	13/10/2011	EP 2558677 A1	20/02/2013
		US 8602116 B2	10/12/2013
		WO 2011-130018 A1	20/10/2011
US 2003-0094281 A1	22/05/2003	AU 2002-246492 A1	30/07/2002
		AU 2002-246492 A8	30/07/2002
		CA 2412041 A1	25/07/2002
		GB 0229852 D0	29/01/2003
		GB 2383633 A	02/07/2003
		US 6913079 B2	05/07/2005
		WO 02-057805 A2	25/07/2002
		WO 02-057805 A3	17/10/2002
US 2005-0241825 A1	03/11/2005	US 2005-241824 A1	03/11/2005
		US 2005-241835 A1	03/11/2005
		US 2005-269083 A1	08/12/2005
		US 7322416 B2	29/01/2008
US 2008-0128128 A1	05/06/2008	AU 2002-331600 A8	03/03/2003
		AU 2003-297661 A1	30/06/2004
		AU 2003-297661 A8	30/06/2004
		CA 2454865 A1	27/02/2003
		EP 1436482 A2	14/07/2004
		EP 1436482 B1	18/04/2007
		US 2003-0034177 A1	20/02/2003
		US 2004-0108142 A1	10/06/2004
		US 2004-0112646 A1	17/06/2004
		US 2004-0118613 A1	24/06/2004
		US 2004-0123984 A1	01/07/2004
		US 2004-0124015 A1	01/07/2004

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		US 2004-0129456 A1	08/07/2004
		US 2004-0134662 A1	15/07/2004
		US 2004-0140128 A1	22/07/2004
		US 2004-0244982 A1	09/12/2004
		US 2006-0124306 A1	15/06/2006
		US 2006-0137911 A1	29/06/2006
		US 2006-0185906 A1	24/08/2006
		US 2006-0201711 A1	14/09/2006
		US 2007-0181345 A1	09/08/2007
		US 2008-0041631 A1	21/02/2008
		US 2008-0149343 A1	26/06/2008
		US 2009-0194338 A1	06/08/2009
		US 2009-0308656 A1	17/12/2009
		US 2010-0012320 A1	21/01/2010
		US 2011-0079439 A1	07/04/2011
		US 5551521 A	03/09/1996
		US 5894897 A	20/04/1999
		US 6158531 A	12/12/2000
		US 6263987 B1	24/07/2001
		US 6397946 B1	04/06/2002
		US 6857486 B2	22/02/2005
		US 6868906 B1	22/03/2005
		US 7013997 B2	21/03/2006
		US 7032658 B2	25/04/2006
		US 7036610 B1	02/05/2006
		US 7040420 B2	09/05/2006
		US 7048050 B2	23/05/2006
		US 7100710 B2	05/09/2006
		US 7108084 B2	19/09/2006
		US 7147068 B2	12/12/2006
		US 7165634 B2	23/01/2007
		US 7228901 B2	12/06/2007
		US 7234542 B2	26/06/2007
		US 7311151 B2	25/12/2007
		US 7325606 B1	05/02/2008
		US 7836950 B2	23/11/2010
		US 8353348 B2	15/01/2013
		WO 2003-016671 A2	27/02/2003
		WO 2003-016671 A3	22/04/2004
		WO 2004-053935 A2	24/06/2004
		WO 2004-053935 A3	05/08/2004
		WO 2004-083595 A2	30/09/2004
		WO 2004-083595 A3	12/04/2007
		WO 2005-052305 A1	09/06/2005