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(54) Title: METHOD FOR ASCERTAINING INTEGRITY OF A DOWNHOLE ZONAL ISOLATION

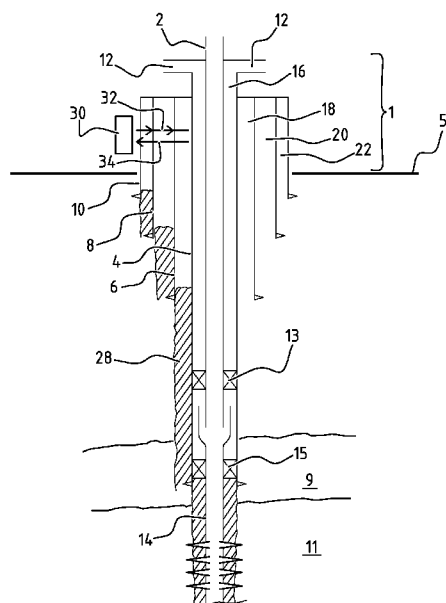


FIG. 1

(57) Abstract: Integrity of a downhole zonal isolation in an annulus (B, C, D) formed between two wellbore tubulars (4, 6, 8, 10) of a sub-sea wellbore is ascertained, by directing ultrasonic waves (32) at the at least two wellbore tubulars and the annulus in a direction at least transverse to the wellbore tubulars and at an inspection location above the downhole zonal isolation, detecting reflections caused by the ultrasonic waves from surfaces of at least the wellbore tubulars, and inferring from the detected reflections whether the annulus at the inspection location is filled with a liquid or a gas.



METHOD FOR ASCERTAINING INTEGRITY OF A DOWNHOLE ZONAL ISOLATION

FIELD OF THE INVENTION

The present invention relates to a method of ascertaining integrity of a downhole zonal isolation in at least one annulus formed between two wellbore tubulars of a sub-sea wellbore.

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BACKGROUND TO THE INVENTION

There is an upcoming increase in plugging and abandonment (P&A) needs for oil and gas wells, especially in mature, offshore areas such as the North Sea and Gulf of Mexico. It is important to ensure that plugged wells will not leak after abandonment, as there could be several potential leak paths such as micro-annuli in plugged wells.

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Notwithstanding, particularly in offshore areas, any downhole operation which requires rig time can incur significant cost. Significant time, and thus cost, can be saved if pulling of wellbore tubing, or milling of wellbore tubing, could be avoided. This is only possible, however, if the zonal isolation which exists in the annulus around the wellbore tubing above the caprock is sufficiently tight.

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Tightness of a zonal isolation may be ascertained by measuring temperature and pressure in the annulus at the wellhead, or anywhere above the above the zonal isolation. Due to the wellhead arrangements on subsea wells, it is generally only possible to monitor the annulus pressure between the production tubing and production casing, known as the A-annulus, and not possible to monitor the pressures in the outer annuli, i.e. in B- and C-annuli. For typical onshore and offshore wells using surface wellheads, each casing annulus is accessible through a penetration in the casing head or casing spool and is monitored with a pressure gauge for annulus pressure build up (API RP90-2). However, industry regulations prohibit penetrations in the high-pressure housing of subsea wellheads (API 17D; API 17TR3), and thus, the same technique is not used.

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The well integrity status of subsea wells is therefore partly unknown prior to P&A, which may significantly affect encountered problems during P&A operations and thus resulting durations. Technologies for wireless monitoring of B-annulus pressure is currently under development. In OTC paper 27886 (2017) Rodriquez *et al.* describe a method which involves installing conventional sensors and a transmitter on the casing

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joints below casing hangers. The sensor data is wirelessly transmitted through multiple layers of steel casing to the outside of the low pressure wellhead housing where the data can be easily recovered through conventional open water acoustic telemetry.

However, a vast majority of the wells that are in need of P&A have not been provided such sensing facilities, and therefore there is a need for other ways to assess integrity of the above caprock zonal isolations in the well.

SUMMARY OF THE INVENTION

In accordance to one aspect of the present invention, there is provided a method of ascertaining integrity of a downhole zonal isolation in at least one annulus formed between two wellbore tubulars of a sub-sea wellbore, whereby one of the two wellbore tubulars is arranged within the other thereby defining said at least one annulus, the method comprising:

- directing ultrasonic waves at the at least two wellbore tubulars and said annulus in a direction at least transverse to the wellbore tubulars and at an inspection location above the downhole zonal isolation;
- detecting reflections caused by the ultrasonic waves from surfaces of at least the wellbore tubulars;
- inferring from the detected reflections whether the annulus at the inspection location is filled with a liquid or a gas.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawing figures depict one or more implementations in accordance with the present teachings, by way of example only, not by way of limitation. In the figures, like reference numerals refer to the same or similar elements.

Fig. 1 schematically shows a configuration wherein the invention is employed; and
Fig. 2 schematically shows an alternative configuration.

DETAILED DESCRIPTION OF THE INVENTION

The person skilled in the art will readily understand that, while the detailed description of the invention will be illustrated making reference to one or more embodiments, each having specific combinations of features and measures, many of those

features and measures can be equally or similarly applied independently in other embodiments or combinations.

Figure 1 schematically shows an example of a completed subsea well extending from a wellhead 1 above a seabed 5 to the subsurface formation below the seabed 5. The example shown comprises a production tubing 2 inserted in a production casing 4. A liner 14 may typically be hung off from the production casing 4, as schematically indicated at liner hanger packer 15. A production packer 13 may be provided above the upper end of the liner 14. The liner 14 is typically perforated to allow hydrocarbons to flow from reservoir rock into the production liner 14 and ultimately the production tubing 2.

An A-annulus 16 is defined between the production tubing 2 and the production casing 4. The A-annulus 16 is typically provided with side outlets 12. Depending on the well design, one or more further casings may be provided, which for the purpose of the present specification will be referred to as first outer casing 6, second outer casing 8 and third outer casing 10. The outer casings have successively increasing diameters so that one can be inserted in the other and annuli are defined between each of these outer casings. For the purpose of the present specification, a B-annulus 18 is defined between the production casing 4 and the first outer casing 6, a C-annulus 20 is defined between the first outer casing 6 and the second outer casing 8, and a D-annulus 22 is defined between the second outer casing 8 and the third outer casing 10. For the purpose of clarity in illustrating the present invention, other details such as a conductor, valves, casing hangers and seals have either been omitted or represented very schematically. Typically, only the A-annulus 16 is accessible. In typical subsea wellheads, the remaining annuli (B, C, and D) are effectively “capped” at the wellhead and cannot be accessed hydraulically.

Parts of the annuli, where the respective casings extend into uncased hole, are generally filled with cement, such as cement sheath 28, to establish a zonal isolation between the annulus and the Earth layers below. It can be seen that the borehole in which the production casing 4 is cemented may reach as far as into the layer of caprock 9 directly above the reservoir 11. Clearly, a compromised cement sheath 28 may therefore cause fluids from the reservoir 11 to reach the wellhead 1.

The integrity of the downhole zonal isolation may be ascertained by providing an ultrasonic probe tool 30 capable of emitting ultrasonic waves 32 and detecting reflections 34 of the ultrasonic waves. Ultrasonic waves 32 are directed at the wellbore tubulars (in this example, including the outer casings 6, 8, 10, and the production casing 4) and in a

direction at least transverse to the wellbore tubulars. The waves propagate through the wellbore tubulars and the annuli, and are partly transmitted and partly reflected at the inner and outer facing surfaces of each of the wellbore tubulars. Various reflections caused by the ultrasonic waves from surfaces of the wellbore tubulars may be detected by the
5 ultrasonic probe tool 30, and from the detected reflections it can be inferred whether any of the annuli at the inspection location is filled with a liquid or a gas.

As the inspection location is above the downhole zonal isolation, potential leaks in the zonal isolation would be expected to change the content and the physical properties of the material in the annuli. Particularly, liquid may be expected to be partly replaced by gas in
10 case of leaks. Since the acoustic impedance and (hence) velocity of the ultrasonic wave is quite different between a liquid and a gas, the resulting distinctly different travel times for such a wave should be easily discernable. For a known geometry, the time of arrival of reflected waves reveals the speed of the ultrasound waves in the annular spaces and, hence, gives a direct indication of a liquid or a gas being present.

15 The illustration of Figure 1 shows the ultrasonic probe tool 30 at the outside of the wellhead 1 (or conductor). The ultrasonic probe tool 30 may suitably be deployed by means of a remotely operated vessel (ROV) or otherwise. In such geometry, the ultrasonic waves may be emitted in radially inward direction.

Alternatively, as illustrated in Fig. 2, the ultrasonic probe tool 30 may be placed
20 inside the wellhead, such as on a wireline 35 within the production tubing 2 or within the production casing 4. In such cases, the ultrasonic waves 32 may be emitted in radially outward direction. An advantage is that the B-annulus 18 may be closer to the ultrasonic probe tool 30 than in the case of Fig. 1, and the ultrasonic waves 32 have to pass through fewer casing. The production tubing 2 may still be present, such as shown in Fig. 2, or
25 production tubing 2 may have been pulled out before lowering the ultrasonic probe tool 30.

In any case, the inspection location is preferably in a place where the wellbore tubulars are arranged concentric to each other. This will make the interpretation of the reflected waves more reliable and easier. Concentricity of the wellbore tubulars may be expected at least in the wellhead 1. Moreover, if any gas has replaced liquid in an annulus,
30 the first place where this will show is at the gravitational top of the annulus, which is typically in the subsea wellhead 1. Therefore, the inspection location is suitably above a seabed 5.

The frequency of the ultrasonic waves 32 may be selected above a certain minimum value which is sufficient to resolve the annuli. Generally, at least one but preferably at least a few wavelengths of the ultrasonic waves 32 should fit within each of the annuli. Based on this insight, a suitable minimum frequency of the ultrasonic waves 32 is 150 kHz. At
5 frequencies of 2.5 MHz the casing walls may start to be resolved. Although there is no absolute required upper limit, attenuation tends to increase with frequency. Typically frequencies up to about 100 MHz are expected to be useful. Preferably, the (fundamental) frequency of the ultrasonic waves 32 is below 10 MHz, to avoid unnecessary attenuation.

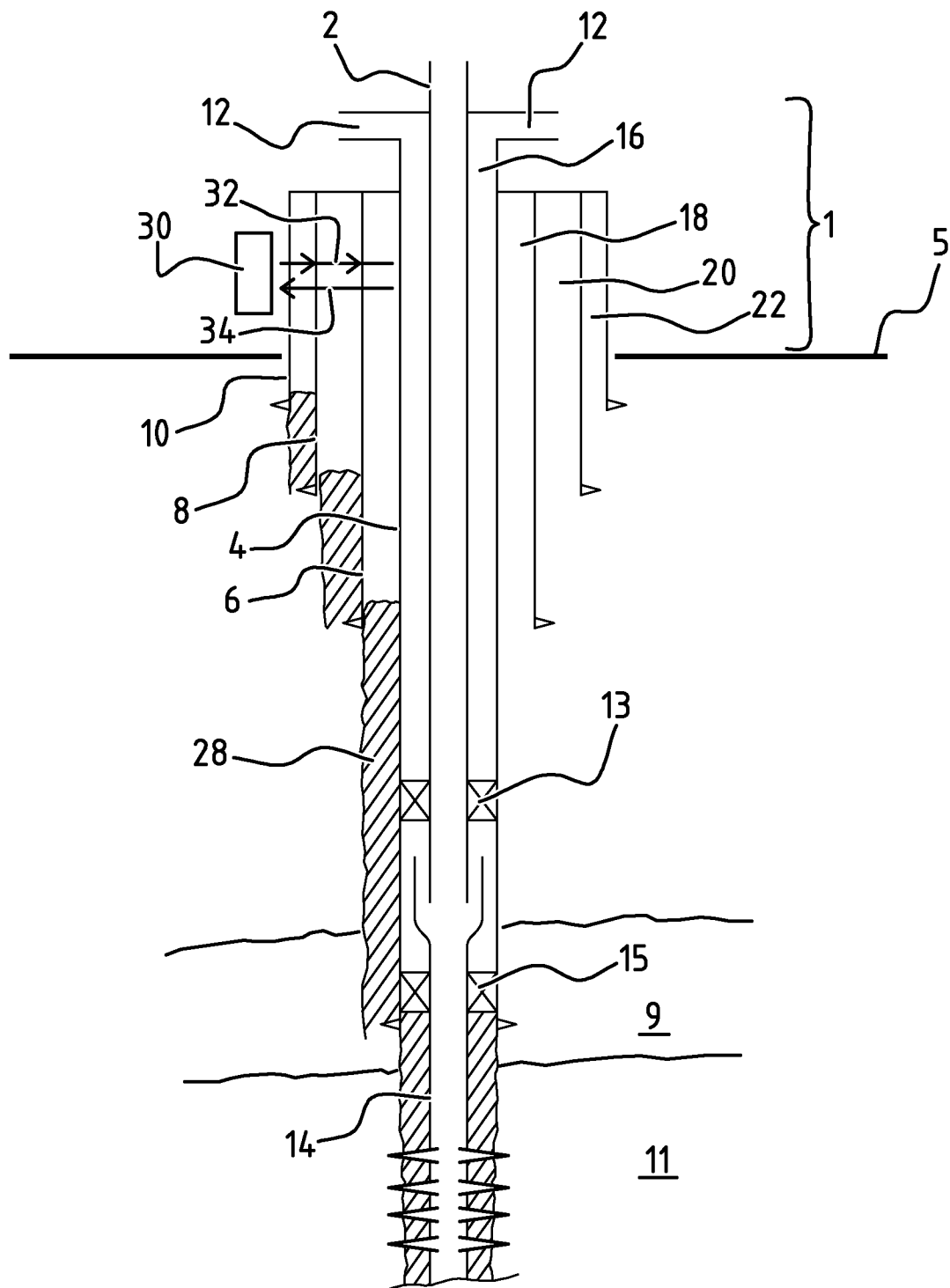
Knowing whether there is gas in any of the annuli in the subsea wellhead 1 before
10 any P&A operations of the well, may be useful information to make P&A decisions, such as how the well will be best abandoned in a cost effective and still reliable manner, and what type of vessel needs to be brought to the site to perform the abandonment. As an example: in cases where zonal isolation over the caprock, in this case cement sheath 28, is hydraulically connected to the B-annulus 18 in the wellhead 1, the presence of gas in that
15 annulus can be an indication that the zonal isolation is not effective, and that gas has leaked from the reservoir to the wellhead 1. Vice versa, in case no gas is found in the B annulus 18, it is a strong indication that the zonal isolation (cement sheath 28) in the caprock is actually sealing, since no gas has apparently leaked from the reservoir to the wellhead 1 over the course of possibly many years of production. If the latter is the case, one might decide to
20 abandon the well by only putting a permanent seal in the production tubing 2, and the A annulus 16, with the seal to be placed at the depth of the caprock 9. In such a case the production tubing can be left in place and there is no need to use a drill ship to pull the tubing. Instead, a lower cost well intervention type vessel can be used.

The person skilled in the art will understand that the present invention can be carried
25 out in many various ways without departing from the scope of the appended claims.

CLAIMS

1. A method of ascertaining integrity of a downhole zonal isolation in at least one annulus formed between two wellbore tubulars of a sub-sea wellbore, whereby one of the two wellbore tubulars is arranged within the other thereby defining said at least one annulus, the method comprising:
 - 5 - directing ultrasonic waves at the at least two wellbore tubulars and said annulus in a direction at least transverse to the wellbore tubulars and at an inspection location above the downhole zonal isolation;
 - detecting reflections caused by the ultrasonic waves from surfaces of at least the wellbore tubulars;
 - 10 - inferring from the detected reflections whether the annulus at the inspection location is filled with a liquid or a gas.
2. The method of claim 1, wherein at the inspection location the wellbore tubulars are arranged concentric to each other.
3. The method of claim 1 or 2, wherein the inspection location is at a subsea wellhead.
- 15 4. The method of any one of claims 1 to 3, wherein the inspection location is above a seabed.
5. The method of any one of claims 1 to 4, wherein said inferring whether the annulus at the inspection location is filled with a liquid or a gas is based on travel times of the ultrasonic waves within the annulus.
- 20 6. The method of any one of claims 1 to 5, wherein the ultrasonic waves are directed radially inward at the at least two wellbore tubulars.
7. The method of any one of claims 1 to 5, wherein the ultrasonic waves are directed radially outward at the at least two wellbore tubulars.
8. The method of any one of the preceding claims, wherein the ultrasonic waves have a
25 frequency of equal to or higher than 150 kHz.

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**FIG. 1**

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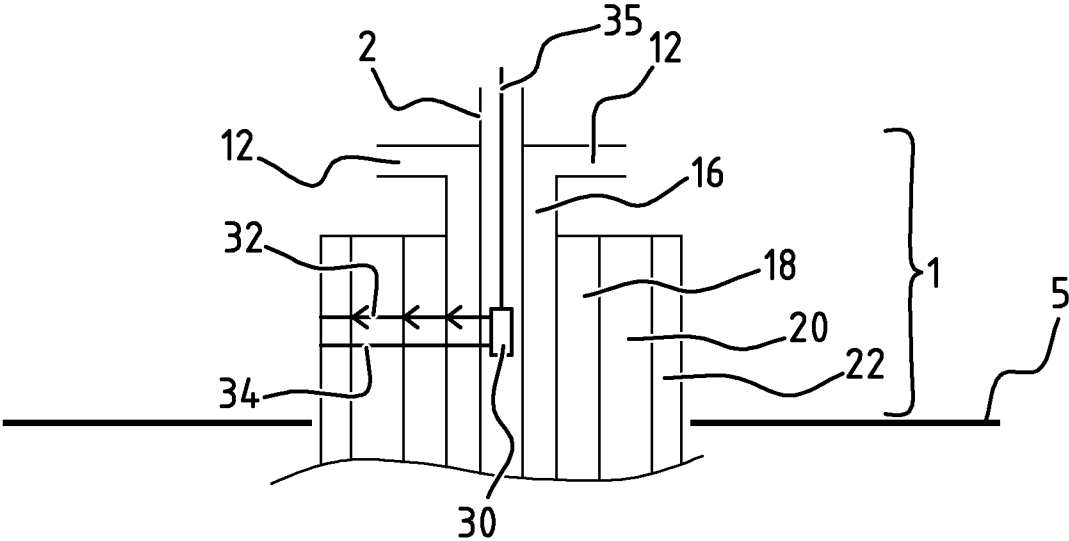


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER INV. E21B47/107 ADD.		
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		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2017/087331 A1 (CONOCOPHILLIPS CO [US]) 26 May 2017 (2017-05-26) the whole document -----	1-8
A	WO 2020/193710 A1 (ARDYNE HOLDINGS LTD [GB]) 1 October 2020 (2020-10-01) the whole document -----	1-8
A	US 2016/245946 A1 (KALYANRAMAN RAM SUNDER [US] ET AL) 25 August 2016 (2016-08-25) the whole document -----	1-8
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Date of the actual completion of the international search 22 December 2021		Date of mailing of the international search report 12/01/2022
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Ott, Stéphane

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2021/082657

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2017087331 A1	26-05-2017	GB 2560464 A US 2017145782 A1 WO 2017087331 A1	12-09-2018 25-05-2017 26-05-2017
WO 2020193710 A1	01-10-2020	GB 2582745 A NO 20211140 A1 WO 2020193710 A1	07-10-2020 23-09-2021 01-10-2020
US 2016245946 A1	25-08-2016	NONE	