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(54) Title **Device and method for monitoring of annulus volume in a pipe**

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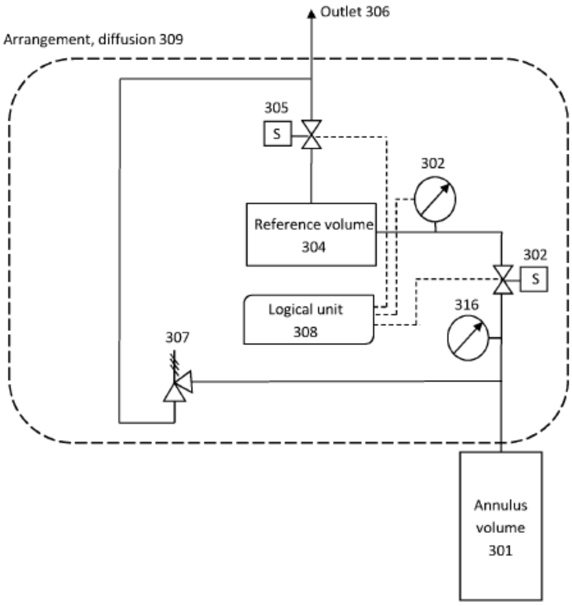
(57) Abstract

The present invention is related to integrity monitoring of an annulus volume in a pipe. More specifically, the invention is related to an arrangement and a method for determination of annulus free volume of a pipe. The monitoring can as an example be performed by use of a logical unit which controls the annulus testing by use of diffusion or gas feed, and also give input to calculation of the pipe's remaining lifetime. Further, the arrangement can as an example save and present results, allow for user specified settings and set off alarms if critical values are detected.



DEVICE AND METHOD FOR MONITORING OF ANNULUS VOLUME IN A PIPE

TECHNICAL AREA

The present invention is related to an arrangement and a method for annulus volume integrity monitoring. More specifically the invention relates to an arrangement and method for determination of annulus free volume of a flexible riser. The monitoring can be performed by use of a logical unit which runs the annulus testing with diffusion or gas feed.

INVENTION BACKGROUND

Monitoring and integrity evaluation are performed to control and map the condition and quality of the annulus volume in as an example a pipe, typically a flexible riser. Annulus testing for calculation of annulus free volume is a significant part of the pipe integrity evaluation. As shown in figure 1, the annulus volume 102 in a flexible pipe is defined as the area between the outer sheath 101 and the pressure barrier 103.

Based on such an annulus test, the fluid content in annulus can be evaluated by comparing the measured annulus free volume and knowledge of the total annulus volume. The annulus volume in a flexible pipe is expected to remain dry or experience a slow filling during time due to among other factors diffusion through the pipe pressure barrier. Annulus testing of flexible risers is per today typically performed annually at offshore installations in the Norwegian continental shelf. Figure 2 shows an example sketch of an offshore installation which comprises a flexible pipe 201, a platform 202 and a test location 203. The annulus testing of the flexible pipe 201 is typically performed at test location 203.

Results from manual annulus tests are typically input for calculation of the pipe’s remaining lifetime. As an example, the annulus volume can be fluid filled due to damaged outer sheath. The deterioration and therefore the remaining pipe lifetime with fluid filled annulus, is typically calculated based on the time of execution of the latest annulus test. If latest test was performed one year ago, one year of the remaining lifetime must be subtracted, by assuming that the damage appeared shortly after the previous test. Large expenses are therefore likely to occur by not being able to operate the pipe up to one more year or due to short time for planning when a flexible pipe needs to be replaced. The long time intervals between each annulus test is therefore a problem today. Especially some pipes require tight follow-up.

As per today the annulus testing is performed manually, which requires key personal offshore to perform the testing. Thus, the testing is dependent on human variations and factors, which can result in tests not being performed or not to be performed when scheduled. Additionally, human factors can cause separate parameter basis for separate tests. It can also be mentioned that for some pipes ventilating of annulus is performed directly in to the open, which cause danger for corrosion due to oxygen access.

Publication US 2011/0229271 A1 describes a device and method for venting gas from an annulus region of a flexible pipe. The method includes, inter alia, the steps of depressurizing a drilling area of the flexible pipe and, via at least one fluid connection, venting the gas from the annulus region to the drilling area.

SUMMARY OF THE INVENTION

According to the present invention, the above mentioned problems are solved by an arrangement and method for determination of a pipe’s annulus free volume and monitoring of the annulus volume state.

The mentioned monitoring can comprise initiation of pressure build up by adjusting the operational pressure to a predefined high pressure limit, keep the pressure for a given time period for the pressure to be stabilized, decide whether this high pressure is stabilized and perform at least one measurement of the pressure. If the pressure is found to be within a given accuracy compared to the predefined high pressure limit, the operation pressure can be adjusted to a predefined low pressure limit. Depressurization is obtained by emptying the reference volume at least one time.

Keep the pressure for a given period of time for the pressure to stabilize, decide whether the pressure is stabilized at the low pressure limit and perform at least on measurement of the pressure. If the pressure is found to be within a given accuracy compared to the predefined low pressure limit, the accumulated volume can be calculated based on data from the emptying of the at least one reference volume.

A first aspect of the invention is an arrangement for determination of a pipe’s annulus free volume, where the arrangement includes a reference volume, a valve connected to the annulus free volume and to the reference volume for depressurizing of the annulus volume to the reference volume, at least one valve connected to the reference volume and at least one outlet for depressurizing of the reference volume, and at least on pressure instrument for measurement of the annulus volume pressure, where the mentioned valves and the at least one pressure instrument is arranged to be read off and controlled for pressurizing and depressurizing, and where measurements of reference volume pressure and annulus volume pressure prior to and after depressurizing and the reference volume dimensions are used for calculation of the annulus free volume.

Calculation of the annulus free volume is performed by use of equations described below.

The arrangement can further comprise at least one logical unit for read off and control of the mentioned valves and the at least one pressure instrument during pressurizing and depressurizing. The logical unit is further arranged to use the pressure measurements in the reference volume and the annulus volume prior to and after depressurization and the reference volume dimension/size for calculation of the annulus free volume.

The arrangement can further comprise at least one gas container for pressurizing, one pressure regulator connected to the gas container to regulate the gas feed, and at least one valve to open and close for pressurization of the at least one annulus volume.

Further, the arrangement can comprise a pressure instrument connected to the gas container to gas container pressure measurement, and at least one pressure instrument connected to the pressure regulator for indication of the regulator settings. The mentioned pressure instruments are further connected to the logical unit for controlling and read off.
Additionally, the arrangement can comprise at least one pressure instrument for measurement of the reference volume pressure. The arrangement can comprise at least one pressure relief valve to control the deflation from the gas container, and eventually at least one pressure relief valve to control the deflation from the at least one annulus volume directly through the outlet. The gas feed is given from the mentioned external gas container or an internal gas container.

Another aspect of the invention is a method for determination of a annulus free volume in a pipe, where a pressure difference is established between the annulus volume and the reference volume, a number of depressurizations from the annulus volume to the reference volume, where the number is one or more, pressure is measured prior to and after the number of depressurizations. The annulus free volume is then calculated based on pressure measurements in the annulus volume prior to and after the number of depressurizations, together with pressure measurements for each depressurization in the reference volume and the reference volume dimension/size.

The method can comprise steps for establishment of a predefined reference volume pressure prior to each depressurization, and reference volume pressure measurement after each depressurization.

Further, the pressure difference establishment can be performed by diffused gas or by applying gas from a gas container to the annulus volume.

The method can comprise steps to decide whether measured pressure in the annulus volume has reached the high pressure limit, followed by keeping this established pressure for a given period of time if necessary, and decide whether measured pressure in the annulus volume after the same period of time is within a given accuracy of the high pressure limit, further establishment of a pressure difference if this is not the case, and thereafter followed by the steps after the depressurizing as described above.

Further, the method can comprise decision of whether the measured pressure have reached the low pressure limit after depressurizing, followed by keeping this pressure for a given period of time if this is the case, decision of whether measured pressure in the annulus volume after this period of time is within a given accuracy to the low pressure limit, followed by further depressurizing if this is not the case, and thereafter followed by steps for calculation of annulus free volume.

Calculation of the annulus free volume can be performed by use of the following equations:

$$V = \frac{V_{out}}{(P_{a1} - P_{a2})}$$

$$V_{ut} = \sum_{i=1}^{i=n} V_{ref}\left(P_{ref1i} - P_{ref2i}\right)$$

Where:

- V is annulus free volume,
- V_{out} is accumulated volume during depressurization,
- V_{ref} is reference volume,
- P_{a1} is annulus pressure prior to the number of depressurizations (i = 1)
- P_{a2} is annulus pressure after the number of depressurizations (i = n)
- P_{ref1} is pressure in the reference volume prior to depressurization number i to the outlet,
- P_{ref2} is pressure in the reference volume after depressurization number i to the outlet, and

- n is the number of depressurization cycles.

The accumulated volume calculation can be performed by at least one logical unit based on data received when emptying at least one reference volume by use of a valve at least one time until a low pressure limit in the annulus volume is reached.

The pressure difference establishment can comprise pressurization performed by closing a valve if diffusion is used, or by adjustment of pressure regulator, and opening of the valve to the gas container and closing of the valve to the reference volume if the pressurization is performed by use of gas feed.

The method can comprise decision of whether the pressure is stabilized at the high pressure limit, by pressure measurement for diffused gas, or by closing of valve and pressure measurement if gas feed is used.

Emptying the reference volume can be performed at least one time by closing the valve in-between the annulus volume and the reference volume, and by opening the valve in-between the reference volume and the belonging outlet, until the low pressure limit in the annulus volume is reached.

Decision of whether or not the pressure is stabilized, can be performed by pressure measurement by use of a pressure instrument arranged at the annulus volume or at the reference volume.

The method can comprise volume calculations which allows for correction for diffusion and temperature differences, and control of one or more components of an arrangement as described above. The logical unit can perform such calculations and corrections.

The method can comprise the following features performed by the logical unit: control of at least one valve for pressurizing and depressurizing of at least one annulus volume, read off of at least one pressure instrument for pressure measurement of at least one reference volume, control of at least one valve for pressurizing and depressurizing of at least one reference volume, and read off of at least one pressure instrument for pressure measurement of at least one annulus volume.

Further, the following features of the method can be performed by a logical unit: read off of at least one pressure instrument for pressure measurement of at least one gas container, control of at least one pressure regulator for pressure adjustment of the gas feed from the gas container, read off of at least one pressure instrument to control the adjustments of the pressure regulator, and control of at least one valve for depressurizing of at least one gas container.

A third aspect of the invention is a method for monitoring of the annulus volume integrity comprising a method for calculation of annulus free volume as described above, where the method comprises one or more of the following steps: comparing the new annulus free volume to one or more previous calculated annulus free volumes, comparing accumulated volume per time to a normal condition, comparing accumulated volume per time to an historical trend, use of annulus free volume for calculation of pipe’s remaining lifetime, saving and presenting measured and calculated values, and triggering one or more alarms if critical values are found. The method can be performed continuously or at regular intervals.

FIGURE DESCRIPTION

Figure 1 shows the cross section of a flexible pipe.

Figure 2 shows an example of an offshore installation which comprises a flexible pipe.

Figure 3 shows an arrangement for monitoring of the integrity of at least one annulus volume based on diffused gas.

Figure 4 shows an arrangement for monitoring of the integrity of at least one annulus volume based on gas feed.

Figure 5 shows an example flow chart for the method of integrity monitoring of at least one annulus volume.

All figures are schematic and not in scale, and they are showing only the parts necessary to illustrate the invention, other parts are omitted or merely indicated.

INVENTION DESCRIPTION

The solution according to the present invention is achieved by a method and an arrangement in accordance to the characterizing parts of the independent claims.

The present invention is related to an arrangement and a method for monitoring of the annulus volume integrity. More specific, the invention relates to an arrangement and a method for determination of an annulus free volume in a pipe. As an example the monitoring can be performed by use of an logical unit which controls the annulus testing by diffusion or gas feed, and, based on the test results, calculates the annulus free volume. The test results can as an example be input to calculation of the pipe remaining lifetime.

The annulus testing can in a first embodiment comprise use of diffused gas and in a second embodiment comprise use of gas feed. By use of diffused gas, the mentioned monitoring is performed by waiting for a natural pressurization of the annulus volume. This is well suited for high diffusion pipes. However, for flexible pipes with low or no diffusion, gas feed is typically used. The advantage of gas feed, as an example nitrogen, is that the annulus testing will typically be less time consuming. The advantage of use of diffused gas is that the arrangement or product consist of fewer components and is thus less exposed to errors and more automotive.

In a first embodiment, i.e. the test setup for annulus testing by use of diffused gas, the arrangement typically comprises, not limited by, the components inside box 309 in figure 3; at least one first valve 302, as an example an solenoid valve, connected to at least one annulus volume 301, at least one second pressure instrument 303 for pressure measurement of at least one reference volume container 304, also called reference volume, the at least one reference volume 304 connected to a second pressure instrument 303 and first valve 302, at least one valve 305 connected to the at least one reference volume 304 and at least one outlet 306, at least one second pressure relief valve 307 which for safety issues is directly connected from at the least one annulus volume 301 to the at least one outlet 306, at least one first pressure instrument 316 for pressure measurement of the annulus volume 301, and at least one logical unit 308 connected to, controlling and reading off the first pressure instrument 316, valve 302, the second pressure instrument 303 and the second valve 305. The arrangement 309 can, based on the above, monitor one or more annulus volumes 301 and figure 3 thus shows a monitoring system.

In the illustrated embodiment a pressure instrument 303, 316 is arranged at both the annulus volume 301 and at the reference volume 304. In another embodiment one single pressure instrument 303 or 316 can be used for measuring of the annulus volume or the reference volume.

In a second embodiment, test setup for annulus testing by use of gas feed, the arrangement typically comprises, not limited by, the components inside box 409 in figure 4. In addition to the components described in the first embodiment, this arrangement can comprise at least one gas container 410, where gas container 410 can be located internally or externally the arrangement 409, i.e. the product. Figure 4 show a gas container 410 as an external gas container. More specifically, the mentioned arrangement comprises at least one third pressure instrument 411 connected to at least one gas container 410, used to measure the remaining gas in the gas container 410, at least one pressure regulator 412, two-stages or more accurate regulator, connected to at least one gas container 410, at least one fist pressure release valve 413 connected to pressure regulator 412, at least one fourth pressure instrument 414, for read off of the pressure regulator 412 settings, at least one third valve 415 connected to a pressure regulator 412 and thus the gas container 410, used for pressurizing, at least one first pressure instrument 416 for pressure measurement of the annulus volume 401, at least one first valve 402 connected to at least one annulus volume 401, at least one second pressure instrument 403 for pressure measurements of the reference volume 404, at least one second valve 405 connected to at least one reference volume 404 and at least one outlet 406, at least one second pressure relief valve 407 directly connected from the annulus volume 401 to at least one outlet 406 for safety, and finally, at least one logical unit 408 connected to, controlling and reading off the first valve 402, the second pressure instrument 403, the second valve 405, the first pressure instrument 416, the third pressure instrument 411, pressure regulator 412, the fourth pressure instrument 414 and the third valve 415. Additionally, the third valve 415 is connected to the annulus volume 401. The arrangement 409 can be used for monitoring of one or more annulus volumes 401 and thus figure 4 shows a monitoring system.

For both the above mentioned embodiments the logical unit 308, 408 contains software for controlling of, as an example, pressure instruments and valves. The arrangement 309, 409 is therefore able to measure annulus volume 301, 401 pressures, control valves for pressurizing and depressurizing, and also perform calculations. Further, the monitoring system is able to save and present results, use user specified settings, give one or more alarms if values outside the normal range is seen and issue the results to external systems.

The pressure instruments 304, 404, 316, 416 can measure pressure both in the annulus volume 301, 401 and in the reference volume 304, 404, when the first valve 302, 402 in-between the mentioned volumes is open.

The pressure difference between the annulus volume 301, 401 and the reference volume 304, 404 can as an example be obtained by an annulus pressure above atmospheric pressure and then typically with atmospheric pressure in the reference volume and the outlet 306, 406, or by vacuum at the outlet and thus in the reference volume 304, 404.

Typically, a relatively small reference volume 304, 404 will be used, it could be one or more magnitudes smaller than the annulus volume 301, 401, and emptied several times. However, the invention is also applicable for a relatively large reference volume 304, 404, which can be same size or even larger than the annulus volume 301, 401, and emptied few times.

In another embodiment of the present invention the arrangement 309, 409 can, in-between the annulus testing, be used for diffusion flow rate measurement of the annulus volume 301, 401. The diffusion flow rate can also be utilized for calibration of the calculated annulus volume.

In an even further embodiment of the present invention, the arrangement 309, 409 can be a part of a larger monitoring system, used for continuous or regular integrity monitoring of the annulus volume, and in an even further embodiment the mentioned monitoring system can be part of a control system for control of one or more flows and gas or fluid pressures in annulus volumes in, as an example, pipes.

In a preferable embodiment of the present invention the arrangement 309, 409 is controlled by use of a logical unit 308, 408. However, it is possible in some embodiments to control the arrangement components manually.

At least one annulus test is performed when monitoring the annulus volume integrity. As an example, the annulus testing can comprise steps like shown in figure 5. In the first step, the arrangement is set to perform an annulus test, i.e. the arrangement is set to annulus testing mode 501. In the next step the arrangement is initiating a pressurization 502. If necessary, the pressure is kept for a given period of time until it is stabilized 503. Thereafter, the arrangement is performing a pressure measurement to check whether the high pressure limit is reached. If not, a new pressurization is performed 502. If the high pressure limit is reached, the process continues to step 504. Thereafter a depressurization is performed 505. If necessary, the pressure is kept for period of time until it is stabilized 506. The arrangement is thereafter performing a new pressure measurement to check whether the low pressure limit is reached. If not, a new depressurization is performed 505. If the low pressure limit is reached, the process continues to step 507. Thereafter annulus volume calculations are performed 508. The annulus testing is in this example ended by setting the arrangement back to standard mode 509.

With reference to the annulus test example above, it is emphasized that in other embodiments a standard mode is not needed. The purpose of the steps related to keeping the pressure at a high and low pressure limit is to increase the accuracy and is not needed in other embodiments.

An example embodiment of the method for monitoring of the annulus integrity is described more in detail in the following. The steps comprise pressurization both by use of diffusion and gas feed.

The method steps can as an example be:

1) Initiate pressurization for pressure build up to a predefined high pressure limit, by use of diffusion or gas feed. Often a minimum pressurization period is used.
    - Diffusion: first valve 302 open and second valve 305 closed
    - Gas feed: first valve 402 and third valve 415 open and second valve 405 closed, the pressure regulator 412 is set to the high pressure limit
2) When the annulus pressure reaches the high pressure limit, keep this pressure for a given period of time.
    - Diffusion: time period zero
    - Gas feed: third valve 415 closed, arrangement need to keep the pressure for a given period of time for the pressure to stabilize
3) Pressure measurement after stabilizing. If the measured pressure is within a given accuracy to the high pressure limit, as an example 90 to 110 % of the high pressure limit, continue to next step. If not, perform a new pressurization (i.e. start at step 1)).
    - Diffusion: second pressure instrument 303 is used for pressure measurement

- Gas feed: first valve 402 open, second valve 405 and third valve 415 closed, second pressure instrument 403 is used for pressure measurement

4) Initiate depressurization to a predefined low pressure limit. Flow measurement cycles will then be run by the arrangement to meet the new operational settings. Accumulated volume is calculated by the arrangement by emptying the annulus volume through the reference volume multiple times to meet the low pressure limit.
    - Diffusion: first valve 302 open, second valve 305 closed, thereafter emptying reference volume by closing first valve 302 and opening second valve 305. Repeat this step until the low pressure limit is reached
    - Gas feed: third valve 405 and 415 closed, first valve 402 open, thereafter emptying reference volume by closing first valve 402 and opening second valve 405. Repeat this step until the low pressure limit is reached
5) When the pressure is within a given accuracy to the low pressure limit, as an example 90 to 110 % of the low pressure limit, the arrangement will keep the pressure for a given period of time for the pressure to stabilize.
    - Diffusion: time period zero
    - Gas feed: arrangement need to keep the pressure a given period of time for the pressure to stabilize
6) Pressure measurement after stabilizing. If the pressure is measured to be within a given accuracy to the low pressure limit, continue to next step. If not, perform a new depressurization (i.e. start at step 4)).
    - Diffusion: second pressure instrument 303 is used for pressure measurement
    - Gas feed: second pressure instrument 403 is used for pressure measurement
7) When measurements are ended, the annulus free volume is calculated by the logical unit 308, 408.
8) Test ended.

In the present invention the annulus free volume is calculated by use of the following equations.

Volume calculations are performed based on the (combined) ideal gas equation:

$$\frac{PV}{T} = C$$

Where P is absolute pressure, V is volume, T is absolute temperature (Kelvin) and C is a constant.

The calculation of annulus free volume can be based on the following equations:

$$V = \frac{V_{out}}{(P_{a1} - P_{a2})}$$

$$V_{ut} = \sum_{i=1}^{i=n} V_{ref}\left(P_{ref1i} - P_{ref2i}\right)$$

Where:

- V is annulus free volume,
- V_{out} is accumulated volume during depressurization,
- V_{ref} is reference volume,
- P_{a1} is annulus pressure prior to the number of depressurizations (i = 1)
- P_{a2} is annulus pressure after the number of depressurizations (i = n)
- P_{ref1} is pressure in the reference volume prior to depressurization number i to the outlet,
- P_{ref2} is pressure in the reference volume after depressurization number i to the outlet, and
- n is the number of depressurization cycles.

The equations above are based on a case where the temperature is assumed to be constant and equal inside and outside the annulus volume 301, 401.

As earlier mentioned, the accumulated volume can be calculated by emptying the reference volume 304, 404 repeatedly until a low pressure limit in the annulus volume 301, 401 is reached.

The reference volume pressure after emptying can as an example be equal to atmospheric pressure or be vacuum.

The annulus test results are typically used as input for calculation of the pipe's remaining lifetime. As an example, this could be a pipe where the annulus is fluid filled due to outer sheath damage.

It can further be mentioned that the present invention is a one way system, which ensures no oxygen into the annulus volume.

Even though the present invention is described with a reference to mentioned embodiments, a specialist will understand that more modifications are possible with no deviation from the invention as it is defined in the following claims.

CLAIMS

1. An arrangement for determination of annulus free volume (301, 401) in a pipe, **characterized in that** the arrangement comprises the following:
   - a reference volume (304, 404),
   - at least one first valve (302, 402) connected to the annulus volume (301, 401) and the reference volume (304, 404) for depressurization of the free annulus volume (301, 401) to the reference volume (304, 404),
   - at least one second valve (305, 405) connected to the reference volume (304, 404) and at least one outlet (306, 406) for depressurization of the reference volume (304, 404),
   - at least one first pressure instrument (316, 416, 303, 403) for pressure measurement of the annulus free volume (301, 401) in the pipe and at least a second pressure instrument (303,403) for measuring pressure in the reference volume (304, 404), and
   - at least one logical unit (308, 408) for read off and control of the mentioned valves (302, 402, 305, 405) and the at least one first and second pressure instrument (303, 403, 316, 416) for pressurization and depressurization, where the logical unit (308, 408) further is arranged to use the pressure measurements in the reference volume (304, 404) and the annulus volume (301, 401) in the pipe prior to and after depressurization and the dimension of the reference volume (304, 404) for calculation of the annulus free volume .

2. Arrangement according to claim 1, where the calculation of the annulus free volume is performed by the following equations

$$V = \frac{V_{out}}{(P_{a1} - P_{a2})}$$

$$V_{ut} = \sum_{i=1}^{i=n} V_{ref}\left(P_{ref1i} - P_{ref2\,i}\right)$$

where:

- V is annulus free volume,
- V_{out} is accumulated volume during depressurization,
- V_{ref} is reference volume,
- P_{a1} is annulus pressure prior to the number of depressurizations (i = 1)
- P_{a2} is annulus pressure after the number of depressurizations (i = n)
- P_{ref1} is pressure in the reference volume prior to depressurization number i to the outlet,
- P_{ref2} is pressure in the reference volume after depressurization number i to the outlet, and
- n is the number of depressurization cycles.

3. Arrangement according to claims 1 or 2, wherein the mentioned valves (302, 402, 305, 405) are solenoid valves.

4. Arrangement according to claims 1 – 3, where the arrangement further comprises:
   - at least one gas container (410) for gas feed for pressurization,
   - a pressure regulator (412) connected to the gas container (410) for pressure regulation of the gas feed, and
   - at least one third valve (415) to open and close for pressurization of the at least one annulus volume (401).

5. Arrangement according to claim 4, where the arrangement further comprises:
   - a third pressure instrument (411) connected to the gas container (410) to measure the pressure in this gas container,
   - at least one fourth pressure instrument (414) connected to the pressure regulator (412) to indicate the regulator settings,

where the mentioned pressure instruments (411, 414) are further connected to the logical unit (408) for control and read off.

6. Arrangement according to claims 4 or 5, where the arrangement comprises:
   - at least one first pressure relief valve (413) for regulation of gas from the gas container (410).

7. Arrangement according to claims 1 - 6, where the arrangement comprises:
   - at least one second pressure relief valve (307, 407) for regulation of gas from the at least one annulus volume (301, 401) to at least one outlet (306, 406).

8. Arrangement according to claims 4 - 7, where gas feed is from the mentioned gas container (410) or an internal gas container.

9. A method for determination of annulus free volume (301, 401) in a pipe with an arrangement according to any of the previous claims , c h a r a c t h e r i z e d b y the step of:
   - establishing a pressure difference between the annulus free volume (301, 401) in the pipe and the reference volume (304, 404),
   - performing a number of depressurizations from the annulus free volume (301, 401) in the pipe to the reference volume (304, 404), where the number of depressurizations is one or more,
   - measuring the pressure in the reference volume prior to and after the number of depressurizations,
   - measuring the annulus free volume pressure in the pipe prior to and after the number of depressurizations, and
   - calculating the annulus free volume in the pipe based on the measured pressure in the annulus volume (301, 401) prior to and after the number of depressurizations, pressure in the reference volume (304, 404) prior to and after each of the number of depressurizations and the reference volume dimension/size.

10. Method according to claim 9, where the method further comprises:
    - establishing a predefined pressure in the reference volume prior to each of the number of depressurizations, and
    - measuring pressure in the reference volume after each of the number of depressurizations.

11. Method according to claims 9 or 10, where the pressure difference establishment comprises gas diffusion to the annulus free volume in the pipe for pressurization.

12. Method according to claims 9 or 10, where the pressure difference establishment comprise gas feed from a gas container to the annulus free volume for pressurization.

13. Method according to claims 9 or 10, where the pressure difference establishment comprises reduction of the pressure in the reference volume.

14. Method according to claims 9 -13, where the method comprises:
    - after establishment of the pressure difference, deciding of whether the measured pressure in the annulus free volume has reached a high pressure limit, followed by keeping this pressure for a given period of time if this is the case, and
    - decision of whether the measured pressure in the annulus volume after the given period of time is within a given accuracy level of the high pressure limit, if not, followed by further pressurization, and further depressurization from the annulus free volume if the pressure is stabilized.

15. Method according to claims 9-14, where the method comprises:
    - after depressurization, decision of whether the measured pressure in the annulus volume has reached a low pressure limit, followed by keeping this pressure for a given period of time when this is the case,

- after the given period of time, decision of whether measured pressure in the annulus volume is within a given accuracy to the low pressure limit, if not, followed by further depressurization, and further calculating the annulus free volume in the pipe if the pressure is stabilized.

16. Method according to claims 9-15, where the calculation of the annulus free volume is performed by use of the following equations:

$$V = \frac{V_{out}}{(P_{a1} - P_{a2})}$$

$$V_{ut} = \sum_{i=1}^{i=n} V_{ref}\left(P_{ref1i} - P_{ref2\,i}\right)$$

where:

- V is annulus free volume,
- V_{out} is accumulated volume during depressurization,
- V_{ref} is reference volume,
- P_{a1} is annulus pressure prior to the number of depressurizations (i = 1)
- P_{a2} is annulus pressure after the number of depressurizations (i = n)
- P_{ref1} is pressure in the reference volume prior to depressurization number i to the outlet,
- P_{ref2} is pressure in the reference volume after depressurization number i to the outlet, and
- n is the number of depressurization cycles.

17. Method according to one of the claims 9-16, where the accumulated volume calculation is performed by at least one logical unit (308, 408) based on data received from emptying the reference volume (304, 404) via a second valve (305, 405) at least one time until the low pressure limit in the annulus free volume in the pipe is reached.

18. Method according to any one of claims 9-17, where the pressure difference establishment comprises pressurization performed by either;
    - i) opening at least one first valve (302) in pressure communication with the annulus free volume in the pipe and closing at least one second valve (305) in pressure communication with the reference volume for use of diffused gas, or
    - ii) adjusting a pressure regulator, opening of a third valve in pressure communication with a gas container and the annulus free volume in the pipe and closing the at least one second valve in pressure communication with the reference volume if the pressure difference is established using a gas feed from the gas container.

19. Method according to one of the claims 14-18, where the time period is zero for use of diffusion, or the pressure is kept for a period of time until the pressure is stabilized if gas feed from a gas container (410) is used.

20. Method according to one of the claims 14-19, where it is decided that the pressure is stabilized at a predefined high pressure limit, performing a pressure measurement by use of a second pressure instrument (303) if diffused gas is utilized, or by closing valve (415) and measuring pressure by use of pressure instrument (403) if gas feed is utilized.

21. Method according to one of the claims 14-20, where emptying of the reference volume (304, 404) is performed at least one time by closing the at least one first valve (302, 402) and opening the at least one second valve (305, 405) until the low pressure limit in the annulus free volume (301, 401) in the pipe is reached.

22. Method according to one of the claims 14-21, where it is decided that the pressure is stabilized at the predefined low

pressure limit, performing pressure measurement by use of pressure instrument (303, 403, 316, 416).

23. Method according to claim 19, comprising one or more of the following steps:
- calculations corrected for diffusion,
- calculations corrected for temperature differences, and
- control of one or more components of the arrangement (309, 409) according to one of the claims 1 – 8.

24. Method according to one of the claims 9-23, where the following features are performed by a logical unit (308, 408):
- control at least one first valve (302, 402) for pressurization and depressurization of the annulus free volume (301, 401),
- read off at least one second pressure instrument (303, 403) for pressure measurement of the reference volume,
- control at least one second valve (305, 405) for pressurization and depressurization of the reference volume (304, 404), and
- read off at least one pressure instrument (303, 403, 316, 416) for pressure measurement of the annulus free volume (301, 401).

25. Method according to one of the claims 9-24, where the following features are performed by a logical unit (308, 408):
- read off at least one third pressure instrument (411) for pressure measurement of at least one gas container (410),
- control at least one pressure regulator (412) for regulation of pressure of the gas feed from the gas container (410),
- read off at least one fourth pressure instrument (414) to check the settings of the pressure regulator (412), and
- control at least one third valve (415) for pressurization and depressurization of at least one gas container (410).

26. Method for monitoring of the annulus volume integrity according to claims 9-25, where the method further comprises one or more of the following steps:

- compare calculated annulus free volume to one or more previous calculated annulus free volumes for integrity evaluation,
- compare accumulated volume per time to a normal condition,
- compare accumulated volume per time to an historical trend,
- use calculated annulus free volume for calculation of pipe’s remaining lifetime,
- save and present measured and calculated values, and
- trigger one or more alarms if critical values are found.

27. Method according to claim 26, where the method can be performed continuously or at regular intervals.

PATENTKRAV

1. En anordning for bestemmelse av et ledig annulusvolum (301, 401) i et rør, karakterisert ved at anordningen omfatter følgende:
- et referansevolum (304, 404),
- minst en første ventil (302, 402) koplet til det ledige annulusvolumet (301, 401) og til referansevolumet (304, 404) for trykkavlastning av det ledige annulusvolumet (301, 401) til referansevolumet (304, 404),
- minst en andre ventil (305, 405) koplet til referansevolumet (304, 404) og til minst et utløp (306, 406) for trykkavlastning av referansevolumet (304, 404),
- minst en første trykkmåler (316, 416, 303, 403) for måling av trykk i det ledige annulusvolumet (301, 401) i røret og minst en andre trykkmåler (303,403) for måling av trykk i referansevolumet (304,404), og
- minst en logisk enhet (308, 408) for avlesning og styring av de nevnte ventiler (302, 402, 305, 405) og den minst ene første og andre trykkmåler (303, 403, 316, 416) for trykkoppbygging og trykkavlastning, hvori den logiske enheten (308, 408) videre anvendes for å benytte trykkmålingene i referansevolumet (304, 404) og annulusvolumet (301, 401) i røret før og etter trykkavlastning og størrelsen av referansevolumet (304, 404), for beregning av det ledige annulusvolumet (301, 401).

2. Anordning ifølge krav 1, der beregningen av det ledige annulusvolumet utføres med følgende likninger:

$$V = \frac{V_{ut}}{(P_{a1} - P_{a2})}$$

$$V_{ut} = \sum_{i=1}^{i=n} V_{ref}\left(P_{ref1i} - P_{ref2i}\right)$$

der
- V er ledig annulusvolum,
- V_{ut} er akkumulert volum ved trykkavlastning,
- V_{ref} er referansevolumet,
- P_{a1} er annulustrykk før antallet trykkavlastninger (i = 1),
- P_{a2} er annulustrykk etter antallet trykkavlastninger (i = n),
- P_{ref1i} er trykk i referansevolum før trykkavlastning nummer i til utløpet,
- P_{ref2i} er trykk i referansevolum etter trykkavlastning nummer i til utløpet, og
- n er antall sykler av trykkavlastning.

3. Anordning ifølge krav 1 eller 2, der de nevnte ventilene (302, 402, 305, 405) er solenoid-ventiler.

4. Anordning ifølge ethvert av kravene 1 -3, der anordningen videre omfatter:
   - minst en gassbeholder (410) for tilførsel av gass for trykkoppbygging,
   - en trykkregulator (412) som er koblet til gassbeholderen (410) for å regulere trykket på tilført gass, og
   - minst en tredje ventil (415) for å åpne og lukke for trykkoppbygging i minst det ene annulusvolumet (401).

5. Anordning ifølge krav 4, der anordningen videre omfatter:
   - en tredje trykkmåler (411) som er koblet til gassbeholderen (410) for å måle trykket i denne gassbeholderen,
   - minst en fjerde trykkmåler (414) koplet til trykkregulatoren (412) for å indikere regulatorinnstillingene,

   der de nevnte trykkmålerne (411, 414) videre er koplet til den logiske enheten (408) for styring og avlesning.

6. Anordning ifølge krav 4 eller 5, der anordningen omfatter:
   - minst en første overtrykksventil (413) for å regulere utslipp fra gassbeholderen (410).

7. Anordning ifølge krav 1 - 6, der anordningen omfatter:
   - minst en andre overtrykksventil (307, 407) for å regulere utslipp av gass fra det minst ene annulusvolumet (301, 401) til minst ett utløp (306, 406).

8. Anordning ifølge krav 4-7, der gass tilføres fra nevnte gassbeholder (410) eller en intern gassbeholder.

9. Fremgangsmåte for bestemmelse av et ledig annulusvolum (301, 401) i et rør med en anordning ifølge ethvert av de foregående krav, k a r a k t e r i s e r t v e d de følgende trinn:

- etablering av en trykkdifferanse mellom det ledige annulusvolumet (301, 401) i røret og et referansevolum (304, 404),
- gjennomføring av et antall trykkavlastninger fra det ledige annulusvolumet (301, 401) i røret til referansevolumet (304, 404), der antallet trykkavlastninger er én eller flere,
- måling av trykk i referansevolumet før og etter antallet trykkavlastninger,
- måling av trykk i det ledige annulusvolumet i røret før og etter antallet trykkavlastninger, og
- beregning av det ledige annulusvolumet i røret basert på målingene av trykk i det ledige annulusvolumet (301, 401) før og etter antallet trykkavlastninger, trykk i referansevolumet (304, 404) før og etter hver av antallet trykkavlastninger og størrelsen av referansevolumet.

10. Fremgangsmåte ifølge krav 9, hvor fremgangsmåten videre omfatter:

- etablering av et bestemt trykk i referansevolumet før hver av antallet trykkavlastninger, og
- måling av trykk i referansevolumet etter hver av antallet trykkavlastninger.

11. Fremgangsmåte ifølge krav 9 eller 10, der etableringen av trykkdifferanse omfatter tilføring av gass ved diffusjon til det ledige annulusvolumet i røret for trykkoppbygging.

12. Fremgangsmåte ifølge krav 9 eller 10, der etableringen av trykkdifferanse omfatter tilføring av gass fra en gassbeholder til annulusvolumet for trykkoppbygging.

13. Fremgangsmåte ifølge krav 9 eller 10, der etableringen av trykkdifferanse omfatter reduksjon av trykket i referansevolumet.

14. Fremgangsmåte ifølge ethvert av kravene 9-13, der fremgangsmåten omfatter:

- etter etableringen av trykkdifferanse, bestemmelse av om målt trykk i annulusvolumet har nådd en høytrykksgrense, fulgt av holding av dette trykket i en gitt tidsperiode hvis dette er tilfelle, og
- bestemmelse av om målt trykk i annulusvolumet etter den gitte tidsperioden er innenfor et gitt nøyaktighetsområde rundt høytrykksgrensen, fulgt av videre

trykkoppbygging om dette ikke er tilfelle, og videre trykkavlastning fra annulusvolumet om trykket er stabilisert.

15. Fremgangsmåte ifølge ethvert av kravene 9-14, hvor fremgangsmåten omfatter:

- etter trykkavlastning, bestemmelse av om målt trykk i annulusvolumet har nådd en lavtrykksgrense, fulgt av holding av dette trykket i en gitt tidsperiode når dette er tilfelle,
- etter den gitte tidsperioden, bestemmelse av om målt trykk i annulusvolumet er innenfor en gitt nøyaktighet rundt lavtrykksgrensen, fulgt av videre trykkavlastning hvis dette ikke er tilfelle, og fulgt av beregning av det ledige annulusvolumet i røret om trykket er stabilisert.

16. Fremgangsmåte ifølge krav 9-15, der beregningen av det ledige annulusvolumet gjøres ved anvendelse av følgende ligninger:

$$V = \frac{V_{ut}}{(P_{a1} - P_{a2})}$$

$$V_{ut} = \sum_{i=1}^{i=n} V_{ref}\left(P_{ref1i} - P_{ref2i}\right)$$

der

- V er ledig annulusvolum,
- V_{ut} er akkumulert volum ved trykkavlastning,
- V_{ref} er referansevolum,
- P_{a1} er annulustrykk før antallet trykkavlastninger (i = 1),
- P_{a2} er annulustrykk etter antallet trykkavlastninger (i = n),
- P_{ref1i} er trykk i referansevolumet før trykkavlastning nummer i til utløpet,
- P_{ref2i} er trykk i referansevolumet etter trykkavlastning nummer i til utløpet, og
- n er antall sykler av trykkavlastning.

17. Fremgangsmåte ifølge ethvert av kravene 9-16, der beregningen av akkumulert volum utføres av minst en logisk enhet (308, 408) basert på data mottatt fra tømming av referansevolumet (304, 404) via en andre ventil ventil (305, 405) minst en gang inntil lavtrykksgrensen i det ledige annulusvolumet i røret er nådd.

18. Fremgangsmåte ifølge ethvert av kravene 9-17, der etableringen av en trykkforskjellen omfatter trykkoppbygging utført ved enten

(i) åpning av minst en første ventil (302) i trykkforbindelse med det ledige annulusvolumet i røret og lukke minst en andre ventil (305) i trykkforbindelse med referansevolumet for bruk av diffundert gass, eller

(ii) justering av trykkregulator, åpning av en tredje ventil i trykkforbindelse med en gassbeholder og det ledige annulusvolumet i røret og lukke den minst ene andre ventilen i trykkforbindelse med referansevolumet om trykkdifferansen er etablert ved bruk tilførsel av gass fra gassbeholderen.

19. Fremgangsmåte ifølge ethvert av kravene 14-18, der tidsperioden er lik null ved bruk av diffusjon, eller trykket holdes en gitt tidsperiode til trykket blir stabilisert om tilført gass fra en gassbeholder (410) benyttes.

20. Fremgangsmåte ifølge ethvert av kravene 14-19, der det bestemmes at trykket er stabilisert ved en gitt høytrykkgrense, utfører måling av trykket ved bruk av en andre trykkmåler (303) om diffundert gass benyttes, eller ved lukking av ventil (415) og måling av trykket ved bruk av trykkmåler (403) om tilført gass benyttes.

21. Fremgangsmåte ifølge ethvert av kravene 14-20, der tømming av referansevolumet (304, 404) utføres minst en gang ved lukking av den minst ene første ventilen (302, 402) og ved åpning av den minst ene andre ventilen (305, 405) inntil lavtrykksgrensen i det ledige annulusvolumet (301, 401) i røret er nådd.

22. Fremgangsmåte ifølge ethvert av kravene 14-21, der det bestemmes at trykket er stabilisert ved lavtrykkgrensen, utfører måling av trykket ved bruk av trykkmåler (303, 403, 316, 416).

23. Fremgangsmåte ifølge krav 19, omfattende ett eller flere av følgende trinn:

- beregninger korrigert for diffusjon,
- beregninger korrigert for temperaturforskjeller, og
- styring av en eller flere komponenter av anordningen (309, 409) ifølge ett av kravene 1 til 8.

24. Fremgangsmåte ifølge ethvert av kravene 9-23, der følgende trekk utføres av en logisk enhet (308, 408):

- styring av minst en første ventil (302, 402) for trykkoppbygging og trykkavlastning i det ledige annulusvolumet (301, 401),
- lesing av minst en andre trykkmåler (303, 403) for måling av trykket av referansevolumet,
- styring av minst en andre ventil (305, 405) for trykkoppbygging og trykkavlastning av referansevolumet (304, 404), og
- lesing av minst en trykkmåler (303, 403, 316, 416) for måling av trykket i det ledige annulusvolumet.

25. Fremgangsmåte ifølge ethvert av kravene 9-24, der følgende trekk utføres av en logisk enhet (308, 408):
- avlesning av minst en tredje trykkmåler (411) for måling av trykket ved minst en gassbeholder (410),
- styring av minst en trykkregulator (412) for å regulere trykket på tilført gass fra gassbeholder (410),
- avlesning av minst en fjerde trykkmåler (414) for å avlese innstillingene på trykkregulatoren (412), og
- styring av minst en tredje ventil (415) for trykkoppbygging og trykkavlastning av minst en gassbeholder (410).

26. Fremgangsmåte for monitorering av tilstand til et annulusvolum omfattende en ifølge ett av kravene 9-25, der fremgangsmåten videre omfatter ett eller flere av de følgende trinn:
- sammenlikning av beregnet ledig annulusvolum med ett eller flere tidligere beregnede ledige annulusvolumer for tilstandsvurdering,
- sammenlikning av akkumulert volum per tid med en normaltilstand,
- beregning av akkumulert volum per tid i forhold til en historisk trend,
- anvendelse av beregnet ledig annusvolum for å beregne gjenværende levetid til røret,
- lagring og presentasjon av målte og beregnede verdier, og
- utløsning av en eller flere alarmer om kritiske verdier registreres.

27. Fremgangsmåte ifølge krav 26, der fremgangsmåten kan utføres kontinuerlig eller med jevne intervaller.

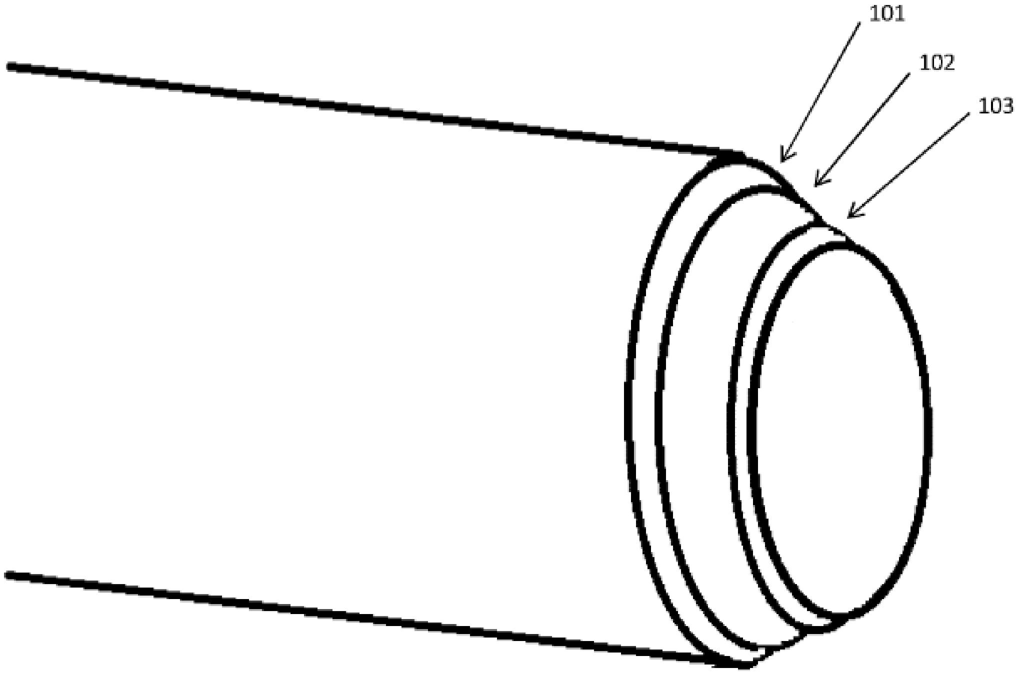


Fig. 1

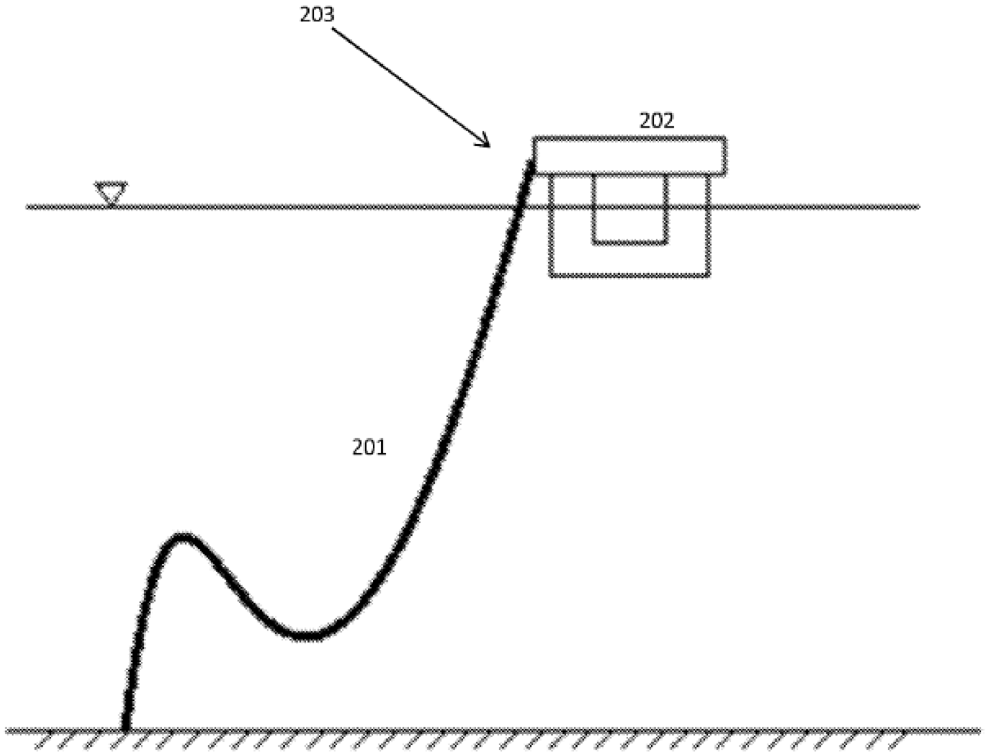


Fig. 2

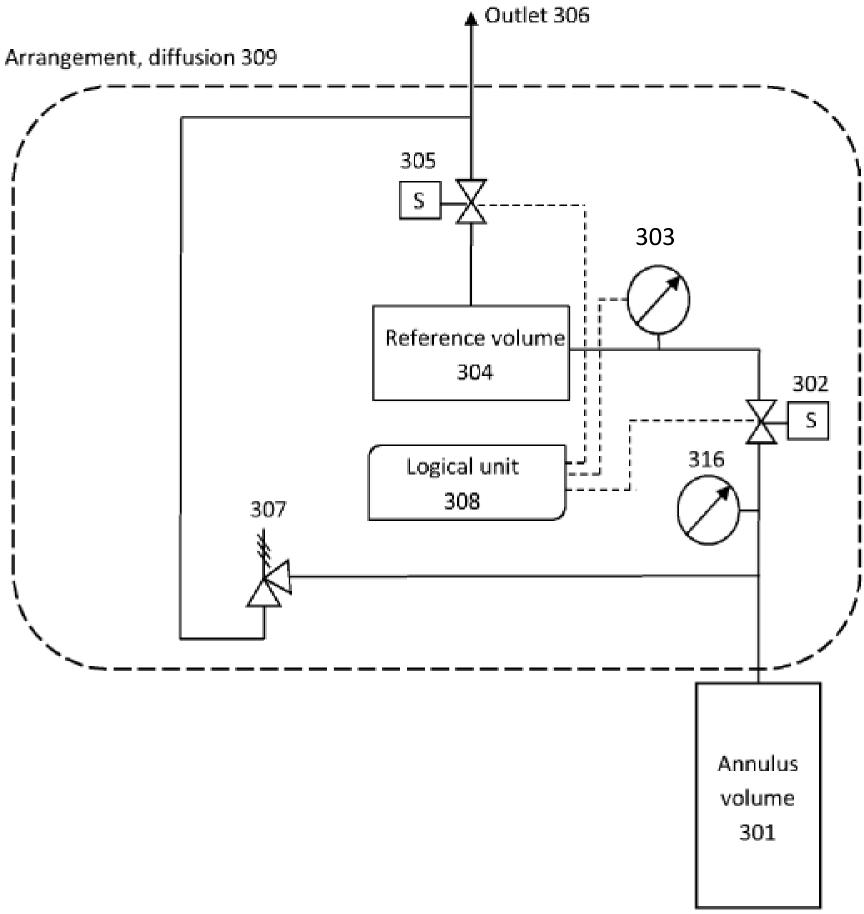

Outlet 306
Arrangement, diffusion 309
305
S
303
Reference volume
304
302
S
Logical unit
308
316
307
Annulus
volume
301

Fig. 3

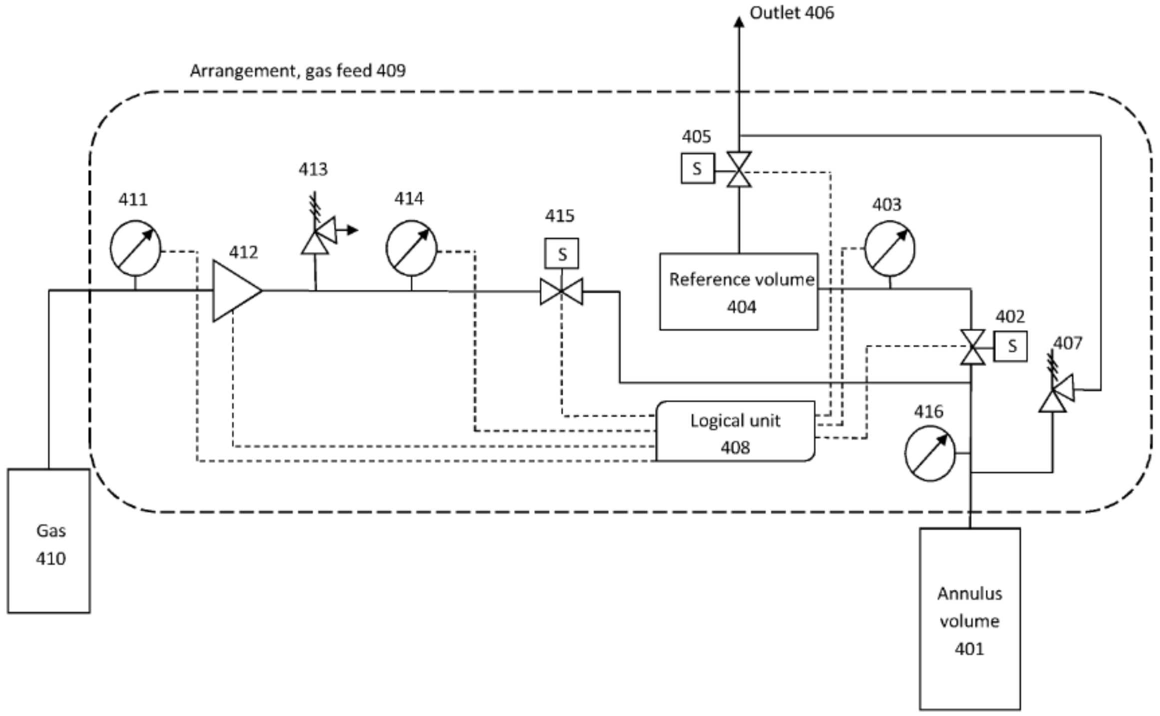

Outlet 406
Arrangement, gas feed 409
405
S
411
413
414
415
S
403
412
Reference volume
404
402
S
407
Logical unit
408
416
Gas
410
Annulus
volume
401

Fig. 4

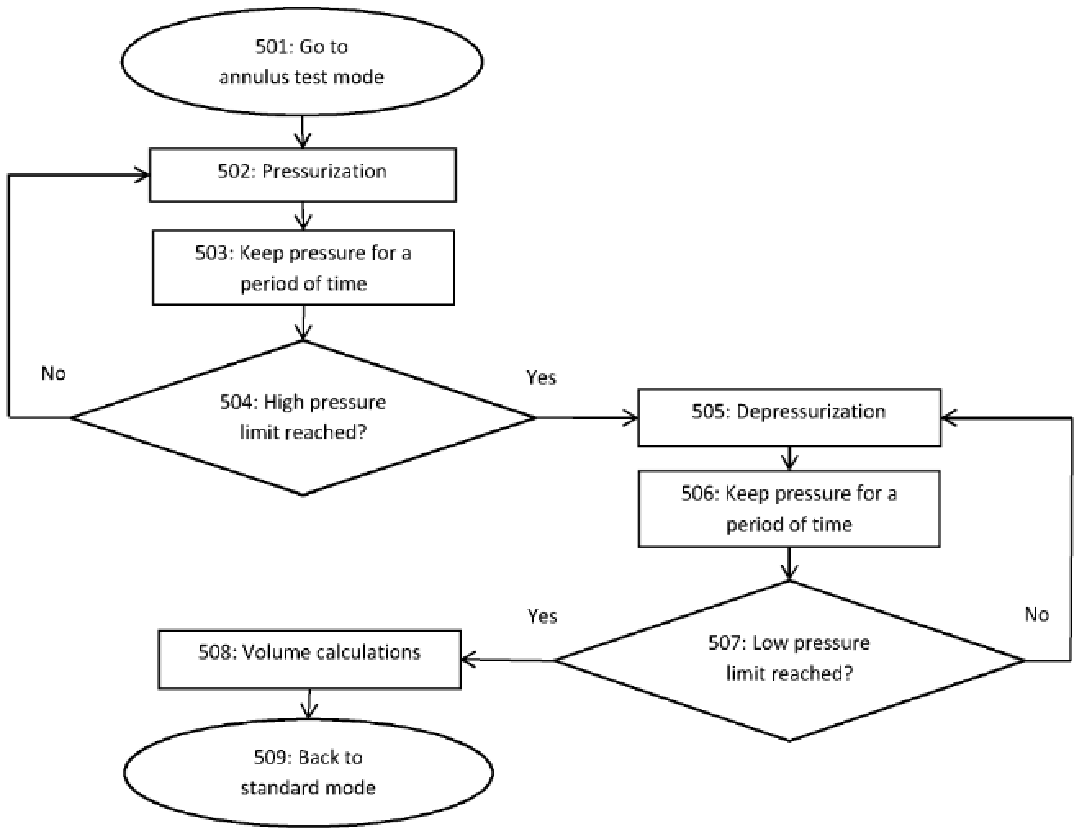

501: Go to annulus test mode
502: Pressurization
503: Keep pressure for a period of time
No
504: High pressure limit reached?
Yes
505: Depressurization
506: Keep pressure for a period of time
Yes
No
507: Low pressure limit reached?
508: Volume calculations
509: Back to standard mode

Fig. 5