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(54) Title: DISTRIBUTED INFLOW CONTROL FOR LONG HORIZONTAL WELLS

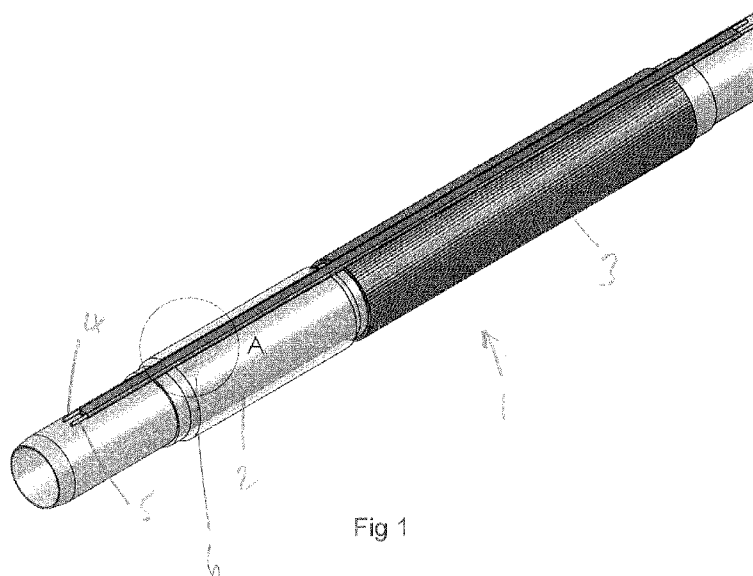


Fig 1

(57) Abstract: An apparatus for controlling the flow of fluids into a hydrocarbon well, comprising a section of production pipe (1) having a conduit communicating between the exterior and interior thereof, a valve (6) for controlling fluid inflow through the conduit and a source of heat arranged to heat the production pipe, valve and/or fluids flowing through the conduit, wherein the valve is a temperature-dependent valve. The valve opening depends upon: the level of added heat; the thermal properties of the fluid mix present; and/or flow rate.

Distributed inflow control for long horizontal wells

5 The present invention relates to a method and apparatus for selectively controlling the inflow of fluids into the production pipe of a hydrocarbon well, and in particular, but not exclusively, to horizontal oil wells.

10 In a horizontal well, as in other wells, there are provided sections of tubular production pipe connected together. These are provided with screens through which fluids flow into the well whilst excluding solid debris. The fluids include oil, water and gas.

After the well has been producing for some time, some zones in the well start to produce unwanted fluids, water and/or gas. Since the mobility of these fluids is most often much higher than that of oil, the production of oil suffers as a result of this.

15 However, whilst it is known to divide up a well into sections and selectively produce from only some of them, there is no satisfactory technology that allows, interactively (from topside), control of the inflows of the different fluids along the length of a well and this leads to reduced oil recovery from the reservoir. Accordingly, it is desirable to be able to control the relative flows of these in order to maximise oil production

20 Oil recovery can be increased by use of ICD (Inflow Control Devices) or AICD (Automated Inflow Control Devices) including the applicant's own technology, such as that disclosed in WO 2008/004875. This provides an inflow valve which may be mounted in the wall of a section of production pipe and which opens and closes depending on the viscosity of the fluid. Thus, it may be used to favour the flow of oil (more viscous) into the pipe over water (less viscous).

In addition, it is possible to divide the well up into sections and choose which section to produce from, but the challenge here is that operators do not have reliable reservoir knowledge to work with.

30 According to the present invention, there is provided an apparatus for controlling the flow of fluids into a hydrocarbon well, comprising a section of production pipe having a conduit communicating between the exterior and interior thereof, a valve for controlling fluid inflow through the conduit and a source of heat arranged to heat the production pipe, valve and/or fluids flowing through the conduit, wherein the valve is a temperature-dependent valve.

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Since the fluids flowing through the conduit will absorb heat (whether directly or indirectly by conduction via the pipe) from the source of heat, they will act as a coolant to the apparatus. Furthermore, as oil, water and gas have significantly different thermal capacities, they will provide cooling to a different degree, with the result that, for a given mass-flow rate, temperature will depend on the composition of the fluid. Accordingly, the operation of the temperature-dependent valve will depend upon fluid composition.

Thus, typically, the valve's opening depends upon the level of added heat, the thermal properties of the fluid mix present and/or flow rate. The valve may be binary (open/closed) in operation, but preferably its degree of opening is variable and most preferably variable in dependence on these parameters.

Since a practical well comprises very many pipe sections, by means of the present invention, it is possible to control inflow to each joint (i.e. section of pipe) in, for example, a long horizontal well. Furthermore, the degree of heating supplied by the heat source is preferably variable so that control may be based on an adjustable amount of heat from a heating cable and the fluid properties in each section/joint.

Being able to manipulate inflow at joint level from topside real-time makes it possible to increase oil production and recovery.

The heating source is therefore preferably an electrical heater, such as a resistive heating cable, since this provides a convenient and controllable source of heat that may readily be controlled from the surface.

The invention may also provide data concerning fluid properties along the length of horizontal well using temperature measurements. For example, an optical fibre may be used to measure the temperature versus distance. Since the temperature is dependent on the operation of the inflow control (i.e. the valve), it provides an indication of fluid composition at the location in question.

The system may be tuned to allow desired fluid inflows at each location. For example, it will typically be desired to favour inflow of oil. Since oil has a thermal capacity that is significantly higher than gas, but lower than water, an intermediate valve temperature should preferably result in maximum inflow through the conduit (i.e. the valve being fully open). Likewise, fluid inflow should preferably be minimised when temperature is lowest in order to exclude water and may also be minimised when it is highest, to exclude gas. Of course, in a real-world situation, mixtures of fluids will normally be present and the apparatus may be arranged to

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favour richer oil mixtures. The valves will typically open and close gradually via a continuous range of intermediate positions corresponding to different mixtures of fluids.

5 The heat source (such as the electrical heating cable) may be arranged on the outer surface of the pipe section to heat fluids prior to their reaching the valve. For example, it may be located on or adjacent a screen of the type conventionally used to exclude debris from a production pipe. However, it is also possible to arrange it to directly heat the valve so that fluid is heated as it passed therethrough or otherwise in contact therewith. In each case, the overall effect is similar in that
10 fluids with higher thermal capacities such as water will have a greater cooling effect and hence result in a lower temperature of the valve.

The valve may be any suitable temperature-dependent valve which can be arranged to open and close at suitable temperatures (bearing in mind that the degree of heating may be varied as appropriate too). In one preferred form, a
15 separate temperature-dependent actuator is provided to move a valve member between open and closed positions. For example, the valve may be arranged to slide in order to open or close aperture(s) in a housing. It is particularly preferred to provide a plurality of apertures in the housing to allow for the valve to open at different temperatures. Most preferably, the valve is arranged to be closed at its
20 lowest temperature setting consistent with heating being provided (e.g. when water is present) and/or to be closed at its higher temperature setting, e.g. when gas is present and/or to be open in an intermediate setting when oil is present.

The invention also extends to a corresponding method and so, according to another aspect there is provided a method of controlling the flow of fluids into a
25 hydrocarbon well, comprising providing a section of production pipe having a conduit communicating between the exterior and interior thereof, a valve for controlling fluid inflow through the conduit and a source of heat arranged to heat the production pipe, valve and/or fluids flowing through the conduit, wherein the valve is a temperature-dependent valve which opens and closes the conduit depending on
30 the temperature of the fluid and controlling the flow of fluid into the well by means of the valve.

The method preferably further comprises the use of the preferred forms of the apparatus as discussed above.

35 An embodiment of the invention will now be described, by way of example only, and with reference to the accompanying drawings:-

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Figure 1 is a perspective view of a section of production pipe of a hydrocarbon well having inflow control according to an embodiment of the invention;

Figure 2 is an enlarged detail of portion A of Figure 1 showing the location of
5 a heat-operated inflow valve;

Figure 3 is a perspective view of the inflow valve;

Figure 4 comprises a series of plan and sectional views of the inflow valve (individually referred to below as Figure 4 - top/bottom, left/right and plan/section) showing different operating modes of the valve.

10 A section of production pipe 1 according to the illustrated embodiment of the invention is shown in Figure 1. This is one of numerous sections of production pipe connected end-to-end forming a horizontal oil well. The pipe comprises a main tubular body ending up in an inflow chamber 2 surrounded by a screen 3 which allows fluids to flow into the inflow chamber whilst excluding solid debris.

15 A pair of cables 4, 5 run along the pipe 1 outside the screen 3 within grooves. Cable 4 is an electrical resistive heating wire and cable 5 is a fibre optic DTS temperature sensor which outputs (via suitable control apparatus at the surface of a type known in the art) temperature data corresponding to points along its length.

20 Located within the wall of inflow chamber 2 is an inflow valve, the location of which is best seen from Figure 2, which is an enlargement of region A of Figure 1. It is arranged in the wall of inflow chamber 2 such that fluid passing through the screen 3 must flow through it in order to enter the production pipe 1.

The inflow valve 6 is temperature dependent and its structure is shown in
25 Figure 3. It has a valve body 7 in the form of a disc which is received in a correspondingly-shaped opening in inflow chamber 2. In addition, there is a sliding valve 8 connected to a heat-activated actuator 9 by bracket 13.

The valve body 7 has an elongate slot 10 formed in its upper surface which receives slider 11 of valve 8 such that slider 8 can reciprocate within the slot 10 as
30 it is moved by actuator 9. This is a linear actuator which extends when heated, with greater heat resulting in greater extension.

An aperture 12 is formed in slider 8 which may be aligned with one of a pair of apertures 14, 15 formed in valve body 7 (see Figure 4). Thus, depending on the position of the slider 11, a flow path may be created via aperture 12 and either

- 5 -

aperture 14 or 15 (i.e. "open"), or flow may be blocked (i.e. "closed"). Note that both apertures 14 and 15 lead into the inner production pipe.

Figure 4 illustrates four possible operating conditions of the valve 6. In each case, a plan view and a sectional view is provided so that the flow paths may be seen. In Figure 4 – Top Left, aperture 12 is aligned with aperture 14 so the valve is open. Similarly, in Figure 4 Top Right, it is aligned with aperture 15 and hence it is also open. However, in Figure 4 Bottom Left, aperture 12 is intermediate apertures 14 and 15, and in Figure 4 Bottom Right, it is to the right (as shown) of aperture 15, so in both of these cases the valve is closed.

Since the extension of heat activated actuator 9 is temperature dependent, it will be appreciated that operating condition of the valve depends upon the temperature of the actuator. This property is used to control the flow of fluids into the production pipe 1 as will be discussed below.

The invention can control inflow to each joint in a long horizontal well based on an adjustable amount of heat from a heating cable and the fluid properties in each point/joint.

As noted above, cable 4 is a resistive heating cable. This provides a heat source along the screen of a horizontal oil well so that the inflowing fluids and/or the pipe section 1 (including the valve) are heated. However, in addition to the amount of heat supplied, the temperature will depend upon the local fluid properties and flow rate. Since a fluid having a higher specific thermal capacity will require more heat to raise its temperature by a given amount, when such a fluid is present, the temperature will be lower. Likewise, other factors being equal, a higher inflow rate will result in a lower temperature because a given mass of the fluid is exposed to the source of heat for a shorter time.

These characteristics are exploited to favour the inflow of oil and influence the function by adjusting the power on the heat cable.

In addition fiber optic cable 5 is included to measure the operation of the valves by measuring their temperature since their condition at a given temperature is known and predetermined.

For the reasons discussed above, the temperature of oil, water and gases will be different as long as the heat source is constant. This is due to huge differences in heat capacities. This relationship is exploited in the invention. The typical heat capacities of typical fluids in a well are:-

- 6 -

Water: 4200 kJ/Kg*K

Oil: 2000 kJ/kg*K

Gases: 1-10 kJ/kg*K

- 5 In addition, the typical overall heat transfer coefficients involved are as follows, from hot surface to:-

Water/oil: 1000-4000 W/m²K

Gases at high pressure: 150-500 W/m²K

10

From the heat capacities and heat transfer coefficients, it can be seen that water will be the coldest fluid and gases the warmest.

- Accordingly, with reference again to Figure 4, it may be seen that the valve is open when no heat is applied (i.e. it fails open) as shown Top Left. When heat is applied, the valve is open at the fairly high temperature – Top Right - that will occur when oil is flowing. However, it will be closed when water flows – Bottom Left - because water's high thermal capacity takes away most of the heat and when temperature is high – Bottom Right – when gas flows and little heat is absorbed by it. The valve will close gradually as the temperature increases or decreases and will thus allow oil with a certain water cut or a certain amount of gases to pass through.

20

The fiber optic cable 4 that measures temperature will give information of fluid composition entering the well along its length based on the corresponding valve positions.

- This technology may also be combined with modern ICD/AICD inflow controls. Today, ICD /AICD completions are designed for maximum production to be able to reach a high first period production rate. This is a compromise that makes the lower production in mid and late time suffer due to low pressure over the ICD/AICD's. Combining the two technologies may allow ICD or AICD design to be optimized for mid or late life and the heat actuated valves could be used to achieve max production in an early phase. ICD/AICD performs much better in choking back water/gas if the pressure drop is larger but this is currently not prioritized due to low net value.

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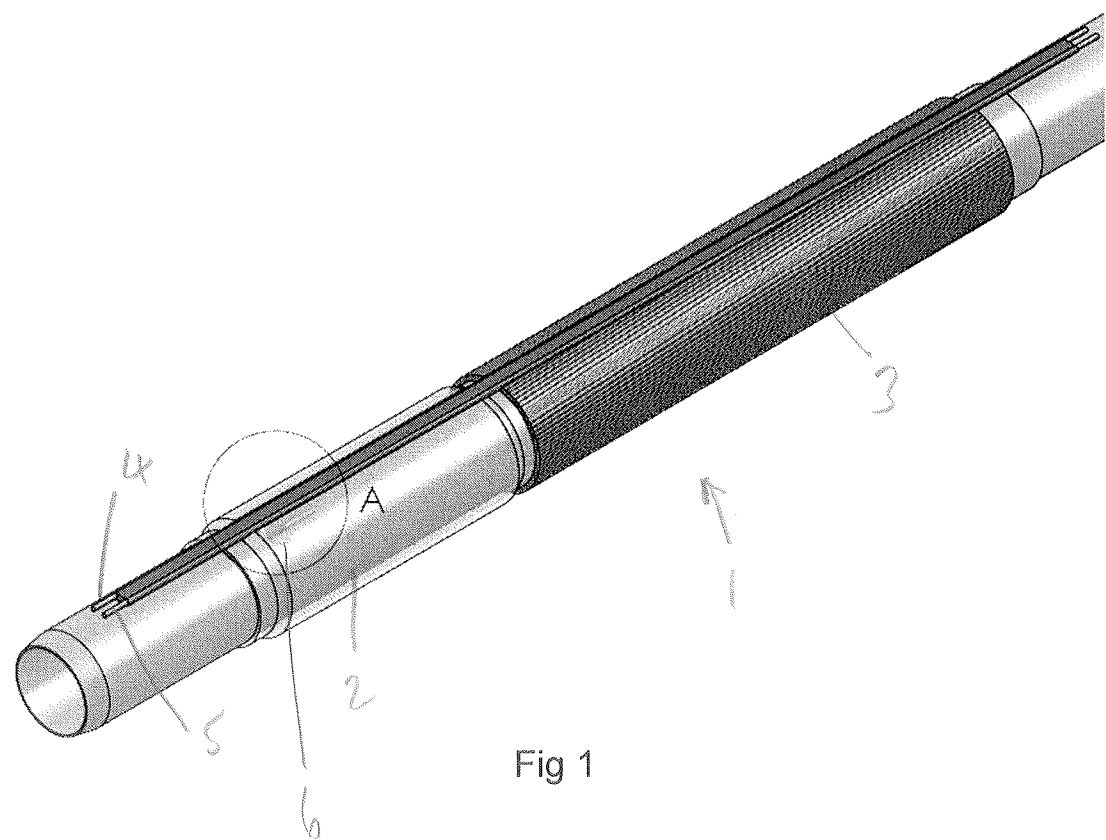
Claims

- 5 1. An apparatus for controlling the flow of fluids into a hydrocarbon well, comprising a section of production pipe having a conduit communicating between the exterior and interior thereof, a valve for controlling fluid inflow through the conduit and a source of heat arranged to heat the production pipe, valve and/or fluids flowing through the conduit, wherein the valve is a temperature-dependent valve.
- 10 2. An apparatus as claimed in claim 1, wherein the valve opening depends upon: the level of added heat; the thermal properties of the fluid mix present; and/or flow rate.
- 15 3. An apparatus as claimed in claim 1 or 2, wherein degree of heating from the source of heat is variable.
- 20 4. An apparatus as claimed in claim 1, 3 or 3, wherein the source of heat is an electrical heater.
- 25 5. An apparatus as claimed in claim 4, wherein the heater comprises an electrical resistance cable.
6. An apparatus as claimed in any preceding claim, further comprising a temperature sensor associated with the valve.
- 25 7. An apparatus as claimed in claim 6, wherein the temperature sensor comprises a fibre optic cable.
- 30 8. An apparatus as claimed in any preceding claim, wherein the valve is arranged to close when the fluid is water and/or mostly water.
9. An apparatus as claimed in any preceding claim, wherein the valve is arranged to close when the fluid is gas and/or mostly gas.
- 35 10. An apparatus as claimed in any preceding claim, wherein the valve is arranged to open when the fluid is oil and/or mostly oil.

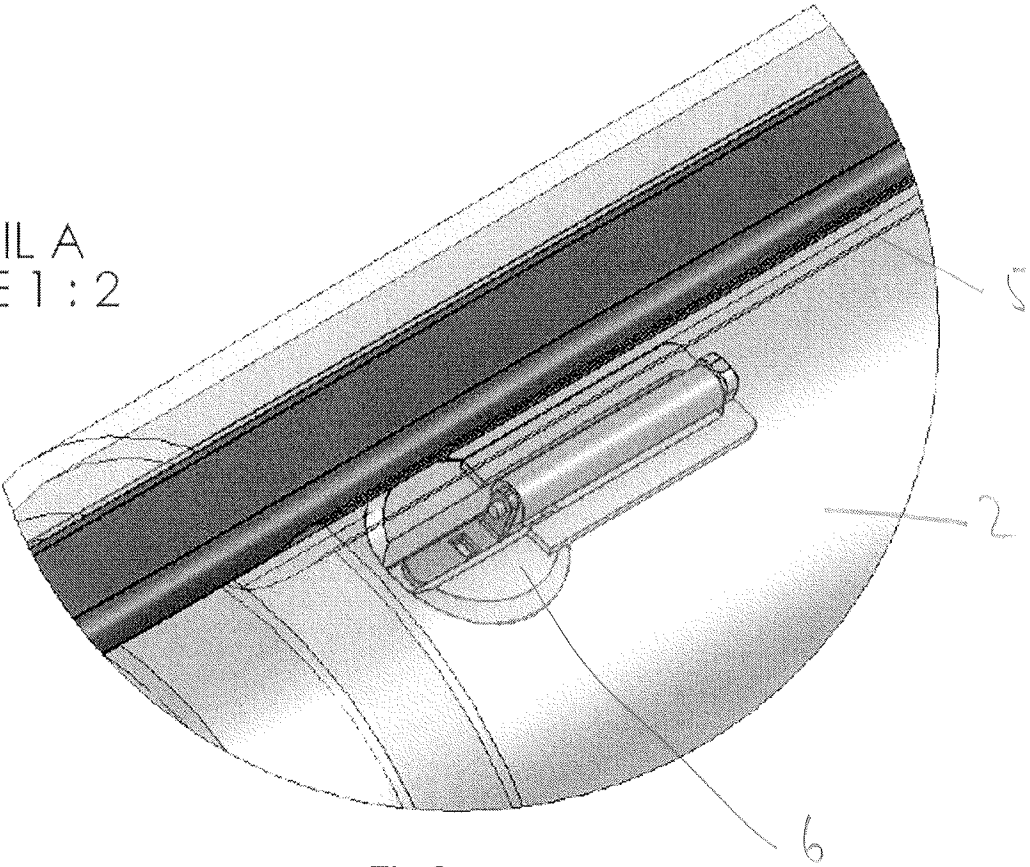
- 8 -

- 5 11. A method of controlling the flow of fluids into a hydrocarbon well, comprising providing a section of production pipe having a conduit communicating between the exterior and interior thereof, a valve for controlling fluid inflow through the conduit and a source of heat arranged to heat the production pipe, valve and/or fluids flowing through the conduit, wherein the valve is a temperature-dependent which opens and closes the conduit depending on the temperature of the fluid and controlling the flow of fluid into the well by means of the valve.
- 10 12. A method as claimed in claim 11 comprising the use of the apparatus of any of claims 1 to 10.

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DETAIL A
SCALE 1 : 2



2/2

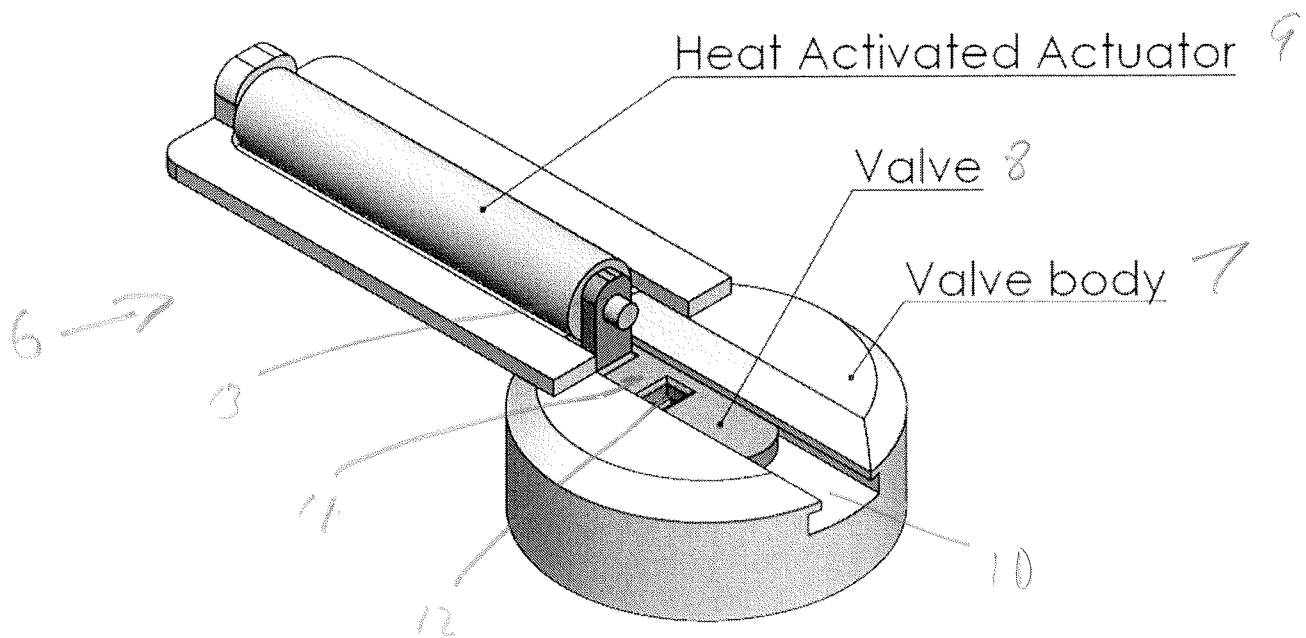


Fig 3

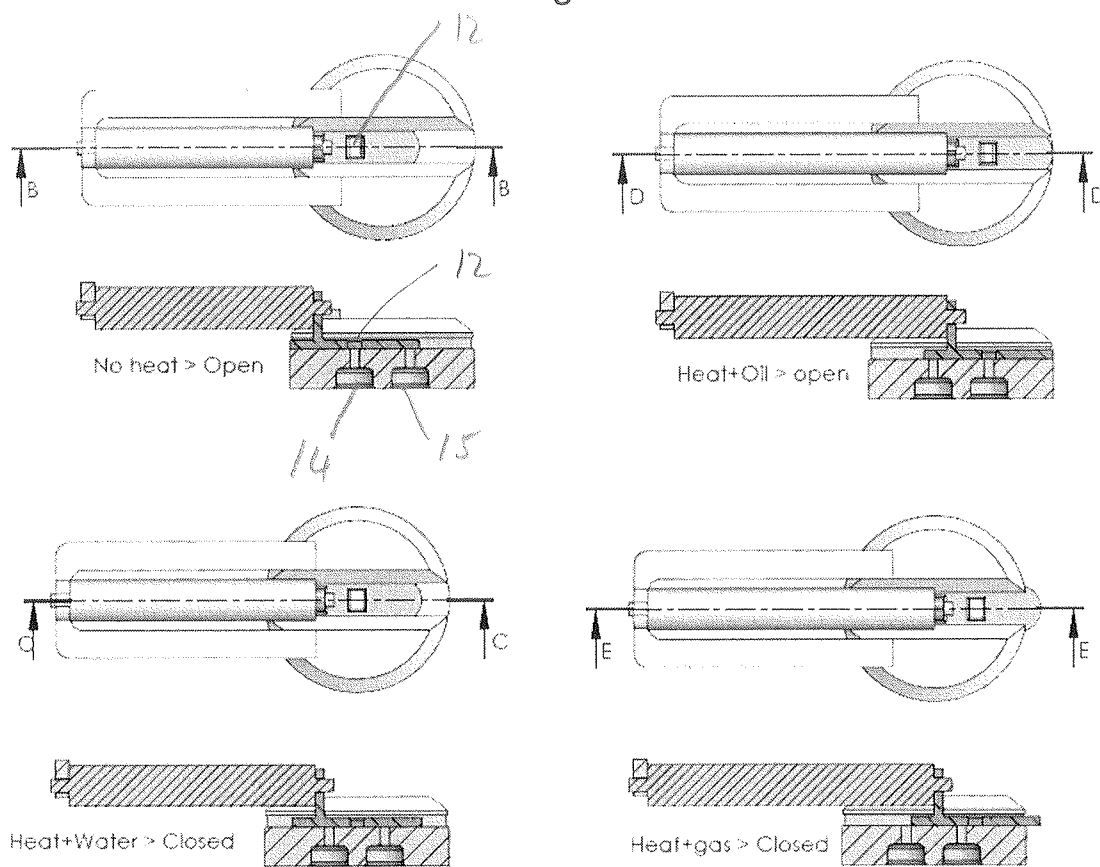


Fig 4

INTERNATIONAL SEARCH REPORT

International application No
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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)
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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.
X	WO 2005/103443 A1 (FREYER RUNE [NO]) 3 November 2005 (2005-11-03) page 3, paragraph 2-6 page 7, paragraph 5 figures 1-3	1-12
X	WO 2013/034185 A1 (STATOIL PETROLEUM AS [NO]; MATHIESEN VIDAR [NO]; AAKRE HAAVARD [NO]; W) 14 March 2013 (2013-03-14) page 10, lines 30-32 page 12, line 31 - page 13, line 22 figure 3A	1-3,8-12
X	US 2009/230335 A1 (OCALAN MURAT [US] ET AL) 17 September 2009 (2009-09-17) paragraphs [0038], [0039] figure 12	1-3,8-12
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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

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INTERNATIONAL SEARCH REPORT

International application No

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 760 832 A (MC GOWEN H ET AL) 25 September 1973 (1973-09-25) abstract -----	1-12

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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