



(51) International Patent Classification:

E21B 43/12 (2006.01) *E21B 21/10* (2006.01)
E21B 34/08 (2006.01) *E21B 43/32* (2006.01)

(21) International Application Number:

PCT/NO2009/000394

(22) International Filing Date:

18 November 2009 (18.11.2009)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

2008 4858 18 November 2008 (18.11.2008) NO

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(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, 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, IS, JP, KE, KG, KM, 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, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

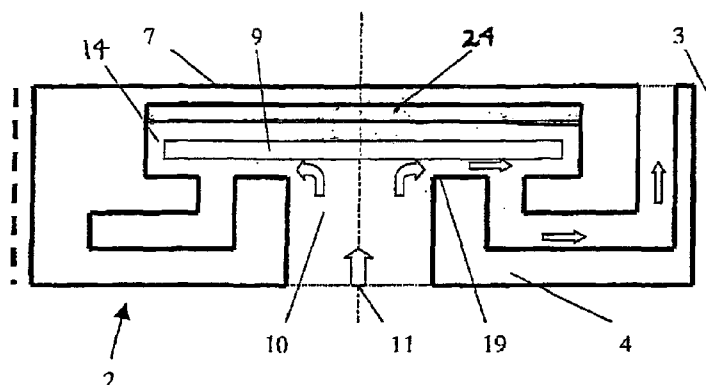
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT,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

Published:

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

(54) Title: A METHOD AND APPARATUS FOR CONTROLLING THE FLOW OF FLUID IN OIL AND/OR GAS PRODUCTION

Fig. 9



(57) Abstract: A method and apparatus is disclosed for controlling the flow of fluid in oil and/or gas production, involving a control device or an autonomous valve (2) operating by the Bernoulli principle and comprising a moveable disk or body (9) provided within a housing (4) for opening and closing said valve (2), involving use of a material (24) within the valve (2) that changes its properties as to shape and/or volume and/or elastic modulus when exposed to a chemical substance contained in the flow of fluid and thus altering said flow of fluid.

A METHOD AND APPARATUS FOR CONTROLLING THE FLOW OF FLUID IN OIL AND/OR GAS PRODUCTION

5 The present invention relates to a method and an apparatus for reversible temperature sensitive control of the flow of fluid in oil and/or gas production, involving an autonomous valve operating by the Bernoulli principle.

More particularly, the invention relates to a method and an apparatus as respectively
10 stated in the independent claims 1 and 11.

The present invention is based on a self adjusting or autonomous valve as disclosed in WO 2008/004875 A1 and operating by the Bernoulli principle, belonging to the applicant of the present invention.

15

Devices for recovering of oil and gas from long, horizontal and vertical wells are known from US patent publications Nos. 4,821,801, 4,858,691, 4,577,691 and GB patent publication No. 2169018. These known devices comprise a perforated drainage pipe with, for example, a filter for control of sand around the pipe. A considerable
20 disadvantage with the known devices for oil/and or gas production in highly permeable geological formations is that the pressure in the drainage pipe increases exponentially in the upstream direction as a result of the flow friction in the pipe. Because the differential pressure between the reservoir and the drainage pipe will decrease upstream as a result, the quantity of oil and/or gas flowing from the reservoir into the drainage
25 pipe will decrease correspondingly. The total oil and/or gas produced by this means will therefore be low. With thin oil zones and highly permeable geological formations, there is further a high risk that of coning, i. e. flow of unwanted water or gas into the drainage pipe downstream, where the velocity of the oil flow from the reservoir to the pipe is the greatest.

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From World Oil, vol. 212, N. 11 (11/91), pages 73 – 80, is previously known to divide a drainage pipe into sections with one or more inflow restriction devices such as sliding sleeves or throttling devices. However, this reference is mainly dealing with the use of inflow control to limit the inflow rate for up hole zones and thereby avoid or reduce
35 coning of water and or gas.

WO-A-9208875 describes a horizontal production pipe comprising a plurality of production sections connected by mixing chambers having a larger internal diameter than the production sections. The production sections comprise an external slotted liner which can be considered as performing a filtering action. However, the sequence of sections of different diameter creates flow turbulence and prevent the running of work-over tools.

When extracting oil and or gas from geological production formations, fluids of different qualities, i.e. oil, gas, water (and sand) is produced in different amounts and mixtures depending on the property or quality of the formation. None of the above-mentioned, known devices are able to distinguish between and control the inflow of oil, gas or water on the basis of their relative composition and/or quality.

With the autonomous valve as disclosed WO 20087004875 A1 is provided an inflow control device which is self adjusting or autonomous and can easily be fitted in the wall of a production pipe and which therefore provide for the use of work-over tools. The device is designed to “distinguish” between the oil and/or gas and/or water and is able to control the flow or inflow of oil or gas, depending on which of these fluids such flow control is required.

The device as disclosed in WO 20087004875 A1 is robust, can withstand large forces and high temperatures, prevents draw downs (differential pressure), needs no energy supply, can withstand sand production, is reliable, but is still simple and very cheap.

The device or valve as disclosed in WO 20087004875 A1 is possibly the best option today. Still there might be problems cutting off both water and gas in the same valve. It might also be a problem to cut of water in the case of low viscosity oil. In addition the present invention could provide a slower or even permanent change in the characteristic of the device or valve as disclosed in WO 20087004875 A1. Instability may be a potential problem with said device or valve due to the fast response of the body or disk and the long time constant to the inflow into the screens. Long time delays generally have potential for instability in regulation systems. With the prior art valve as disclosed in WO 20087004875 A1 there is also a lack of possibility to permanently seal off a section of the well if only water is produced.

The method and apparatus according to the present invention is characterized by the features as stated in the characterizing portion of claim 1 and 11, respectively.

Preferred embodiments of the invention is stated in the dependent claims.

The present invention will be further described in the following by means of examples
5 and with reference to the drawings, where:

- Fig. 1 shows a schematic view of a production pipe with a control device according to WO 20087004875 A1,
- 10 Fig. 2 a) shows, in larger scale, a cross section of the control device according WO 20087004875 A1, b) shows the same device in a top view.
- Fig. 3 is a diagram showing the flow volume through a control device according to the invention vs. the differential pressure in comparison
15 with a fixed inflow device,
- Fig. 4 shows the device shown in Fig. 2, but with the indication of different pressure zones influencing the design of the device for different applications.
- 20 Fig. 5 shows a principal sketch of another embodiment of the control device according to WO 20087004875 A1,
- Fig. 6 shows a principal sketch of a third embodiment of the control device
25 according to WO 20087004875 A1,
- Fig. 7 shows a principal sketch of a fourth embodiment of the control device according to WO 20087004875 A1,
- 30 Fig. 8 shows a principal sketch of a fifth embodiment of WO 20087004875 A1 where the control device is an integral part of a flow arrangement,

Fig. 9 shows a principal sketch of a first embodiment according to the present invention, where swelling backing material is provided in the open space for the moveable disc or body of the autonomous valve of WO 20087004875 A1,

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Fig. 10 shows a principal sketch of a second embodiment according to the present invention, where swelling backing material is provided behind hard metal wedges oppositely arranged in the flow path exiting said open space, and

10

Fig. 11 shows a modification of the first embodiment of the invention, where a plurality of small channels are provided in the housing of said valve for pressure and fluid communication between a rear side of the swelling material and the surroundings of the valve.

15

Fig. 1 shows, as stated above, a section of a production pipe 1 in which a prototype of a control device 2, according to WO 20087004875 A1 is provided. The control device 2 is preferably of circular, relatively flat shape and may be provided with external threads 3 (see Fig. 2) to be screwed into a circular hole with corresponding internal threads in the pipe or an injector. By controlling the thickness, the device 2, may be adapted to the thickness of the pipe or injector and fit within its outer and inner periphery.

Fig. 2 a) and b) shows the prior control device 2 of WO 20087004875 A1 in larger scale. The device consists of a first disc-shaped housing body 4 with an outer cylindrical segment 5 and inner cylindrical segment 6 and with a central hole or aperture 10, and a second disc-shaped holder body 7 with an outer cylindrical segment 8, as well as a preferably flat disc or freely movable body 9 provided in an open space 14 formed between the first 4 and second 7 disc-shaped housing and holder bodies. The body 9 may for particular applications and adjustments depart from the flat shape and have a partly conical or semicircular shape (for instance towards the aperture 10.) As can be seen from the figure, the cylindrical segment 8 of the second disc-shaped holder body 7 fits within and protrudes in the opposite direction of the outer cylindrical segment 5 of the first disc-shaped housing body 4 thereby forming a flow path as shown by the arrows 11, where the fluid enters the control device through the central hole or aperture

25

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(inlet) 10 and flows towards and radially along the disc 9 before flowing through the annular opening 12 formed between the cylindrical segments 8 and 6 and further out through the annular opening 13 formed between the cylindrical segments 8 and 5. The two disc-shaped housing and holder bodies 4, 7 are attached to one another by a screw connection, welding or other means (not further shown in the figures) at a connection area 15 as shown in Fig 2b).

The present invention exploits the effect of Bernoulli teaching that the sum of static pressure, dynamic pressure and friction is constant along a flow line:

10

$$p_{\text{static}} + \frac{1}{2} \rho v^2 + \Delta p_{\text{friction}}$$

When subjecting the disc 9 to a fluid flow, which is the case with the present invention, the pressure difference over the disc 9 can be expressed as follows:

15

$$\Delta p_{\text{over}} = [p_{\text{over}(p_4)} - p_{\text{under}(f(p_1, p_2, p_3))}] = \frac{1}{2} \rho v^2$$

Due to lower viscosity, a fluid such as gas will “make the turn later” and follow further along the disc towards its outer end (indicated by reference number 14). This makes a higher stagnation pressure in the area 16 at the end of the disc 9, which in turn makes a higher pressure over the disc. And the disc 9, which is freely movable within the space between the disc-shaped bodies 4, 7, will move downwards and thereby narrow the flow path between the disc 9 and inner cylindrical segment 6. Thus, the disc 9 moves downwards or up-wards depending on the viscosity of the fluid flowing through, whereby this principle can be used to control (close/open) the flow of fluid through of the device.

Further, the pressure drop through a traditional inflow control device (ICD) with fixed geometry will be proportional to the dynamic pressure:

$$\Delta p = K \cdot \frac{1}{2} \rho v^2$$

where the constant, K is mainly a function of the geometry and less dependent on the Reynolds number. In the control device according to the present invention the flow area will decrease when the differential pressure increases, such that the volume flow
5 through the control device will not, or nearly not, increase when the pressure drop increases. A comparison between a control device according to the present invention with movable disc and a control device with fixed flow-through opening is shown in Fig. 3, and as can be seen from the figure, the flow-through volume for the present invention is constant above a given differential pressure.

10 This represents a major advantage with the present invention as it can be used to ensure the same volume flowing through each section for the entire horizontal well, which is not possible with fixed inflow control devices.

When producing oil and gas the control device according to the invention may have two
15 different applications: Using it as inflow control device to reduce inflow of water, or using it to reduce inflow of gas at gas break through situations. When designing the control device according to the invention for the different application such as water or gas, as mentioned above, the different areas and pressure zones, as shown in Fig. 4, will have impact on the efficiency and flow through properties of the device. Referring to
20 Fig. 4, the different area/pressure zones may be divided into:

- A_1 , P_1 is the inflow area and pressure respectively. The force ($P_1 \cdot A_1$) generated by this pressure will strive to open the control device (move the disc or body 9 upwards).
- A_2 , P_2 is the area and pressure in the zone where the velocity will be largest and hence
25 represents a dynamic pressure source. The resulting force of the dynamic pressure will strive to close the control device (move the disc or body 9 downwards as the flow velocity increases).
- A_3 , P_3 is the area and pressure at the outlet. This should be the same as the well pressure (inlet pressure).
- 30 - A_4 , P_4 is the area and pressure (stagnation pressure) behind the movable disc or body 9. The stagnation pressure, at position 16 (Fig. 2), creates the pressure and the force

behind the body. This will strive to close the control device (move the body downwards).

Fluids with different viscosities will provide different forces in each zone depending on the design of these zones. In order to optimize the efficiency and flow through properties of the control device, the design of the areas will be different for different applications, e.g. gas/oil or oil/water flow. Hence, for each application the areas needs to be carefully balanced and optimally designed taking into account the properties and physical conditions (viscosity, temperature, pressure etc.) for each design situation.

10

Fig. 5 shows a principal sketch of another embodiment of the control device according to WO 20087004875 A1, which is of a more simple design than the version shown in Fig. 2. The control device 2 consists, as with the version shown in Fig. 2, of a first disc-shaped housing body 4 with an outer cylindrical segment 5 and with a central hole or aperture 10, and a second disc-shaped holder body 17 attached to the segment 5 of the housing body 4, as well as a preferably flat disc 9 provided in an open space 14 formed between the first and second disc-shaped housing and holder bodies 4, 17. However, since the second disc-shaped holder body 17 is inwardly open (through a hole or holes 23, etc.) and is now only holding the disc in place, and since the cylindrical segment 5 is shorter with a different flow path than what is shown in Fig.2, there is no build up of stagnation pressure (P_4) on the back side of the disc 9 as explained above in conjunction with Fig. 4. With this solution without stagnation pressure the building thickness for the device is lower and may withstand a larger amount of particles contained in the fluid.

Fig. 6 shows a third embodiment according to WO 20087004875 A1 where the design is the same as with the example shown in Fig. 2, but where a spring element 18, in the form of a spiral or other suitable spring device, is provided on either side of the disc and connects the disc with the holder 7, 22, recess 21 or housing 4.

The spring element 18 is used to balance and control the inflow area between the disc 9 and the inlet 10, or rather the surrounding edge or seat 19 of the inlet 10. Thus, depending on the spring constant and thereby the spring force, the opening between the

disc 9 and edge 19 will be larger or smaller, and with a suitable selected spring constant, depending on the inflow and pressure conditions at the selected place where the control device is provided, constant mass flow through the device may be obtained.

- 5 Fig. 7 shows a fourth embodiment according to WO 20087004875 A1, where the design is the same as with the example in Fig. 6 above, but where the disc 9 is, on the side facing the inlet opening 10, provided with a thermally responsive device such as bi-metallic element 20.
- 10 When producing oil and/or gas the conditions may rapidly change from a situation where only or mostly oil is produced to a situation where only or mostly gas is produced (gas breakthrough or gas coning). With for instance a pressure drop of 16 bar from 100 bar the temperature drop would correspond to approximately 20 °C. By providing the disc 9 with a thermally responsive element such as a bi-metallic element as shown in
- 15 Fig. 7, the disc will bend upwards or be moved upwards by the element 20 abutting the holder shaped body 7 and thereby narrowing the opening between the disc and the inlet 10 or fully closing said inlet.

The above examples of a control device as shown in Figs. 1 and 2 and 4 - 7 are all

20 related to solutions where the control device as such is a separate unit or device to be provided in conjunction with a fluid flow situation or arrangement such as the wall of a production pipe in connection with the production of oil and gas. However, the control device may, as shown in Fig. 8, be an integral part of the fluid flow arrangement, whereby the movable body 9 may be provided in a recess 21 facing the outlet of an

25 aperture or hole 10 of for instance a wall of a pipe 1 as shown in Fig. 1 instead of being provided in a separate housing body 4. Further, the movable body 9 may be held in place in the recess by means of a holder device such as inwardly protruding spikes, a circular ring 22 or the like being connected to the outer opening of the recess by means of screwing, welding or the like.

30

Embodiments of the present invention are shown in Figs. 9 - 11, in which a material 24 is arranged within the device or autonomous valve 2 as described above, said material

24 changing its properties (volume and/or elastic modulus) under the presence of a given chemical substance or fluid, e.g. water.

More specifically Figs. 9 – 11 show two different embodiments in which a swelling material 24 is respectively arranged in the open space 14 for the moveable disc or body 9 (Figs. 9 and 11) or is alternatively provided behind hard metal wedges 25 oppositely arranged in the flow path exiting said open space 14 (Fig. 10). In Fig. 11 there is shown a variant or development of the embodiment as shown in Fig. 9, and in which a plurality of small channels 26 provides pressure and fluid communication between a rear or attachment side 27 of the swelling material 24 and the surroundings of the valve 2. One reason with said fluid and pressure communication is that the swelling backing material 24 might need backing pressure in case of a large pressure differential and/or a long travel. Another reason is that the swelling rate will possibly increase if the swelling material 24 is exposed to said chemical substance (e.g. water) also from the rear side 27.

The main inventive idea is thus to use a material that changes its properties (volume and/or elastic modulus) under the presence of a given chemical substance. The material should be integrated in the valve or control device 2 to modify the inflow characteristics over time that the viscosity discrimination might not work very well for, in particular the presence of water.

The shut off mechanism can thus be based on two principles:

- Modifying the backing of the disc or body 9 so that e.g. a maximum opening is reduced under the influence of water (cfr. Figs. 9 and 11).
- Modify the flow characteristics at a pressure reference location (cfr. Fig. 10).

There is a material that changes property in a sheltered area of the valve or control device 2. The simplest example is a polymer that swells under the influence of water. Such polymers can e.g. double their volume when exposed to water. The process takes time as the water needs to diffuse into the polymer. The increased volume behind the disc or body 9 expels flow from the flow channel and hence modifies the valve or control device 2. In the case of much water the swelling backing material 24 can fill the complete space behind the disc or body 9 and hence permanently nearly block the valve 2.

In the second principle, by introducing said oppositely arranged wedges 25, the edge geometry and hence the reference pressure transmitted to the open space or cavity 14

behind the disc or body 9 is modified. In principle this can also be a jaw (not shown) that cuts off flow. The purpose of the wedge is to use a hard material with high erosion resistance that is directly exposed to the flow while the volume changing material is protected in a sheltered area. As apparent for the artisan in elucidation of this disclosure,
5 many realizations of this principle is possible.

It should be noted that the second principle can be configured to reverse the effect of the valve or control device 2 leaving the edge area the high velocity area which might be advantageous for specific applications.

10

Some important characteristics are as follows:

- Possibility to shut off both on basis of viscosity and chemical composition.
- Potential for slow varying shut off in addition to rapid reaction as in WO 20087004875 A1. (Stability).
- 15 • The use of a material 14 that changes shape, volume or elastic property under a chemical influence to alter the geometry of the control device or valve 2.
- Changing the flow velocity over or adjacent to the body or disc 9 and hence the Bernoulli force based on chemical sensitivity.
- The possibility to completely cut off the production by choking the complete
20 channel that is the origin of the Bernoulli effect.
- The mechanism for this altering need not be coupled to the viscosity and hence separate choking criteria can be built into the control device or valve 2 e.g. both low viscosity and water (using a material that swells under the presence of water and not in the presence of hydrocarbons).
- 25 • Potential for chemical selectivity (it is possible that a backing material might be made sensitive e.g. to ions in the formation water).
- Modifying maximum channel dimensions available for the flow (without exposing the backing material 24 to high velocity flow and erosion).
- It is believed that the control device or valve 2 with this modification will be
30 even more selective and utilize the best of two otherwise competing technologies in a compact unit not substantially more complicated than the valve 2 without said modification.

The present invention is only restricted by the appended claims, and not by the
35 embodiments as described above. In the context of the present invention the term "oil and/or gas production" includes any process related to exploration or exploitation of oil and/or gas (e.g. installation, injection of steam, etc.) and is thus not restricted to a production mode.

40

C l a i m s

1.
5 A method for controlling the flow of fluid in oil and/or gas production, involving a control device or an autonomous valve (2) operating by the Bernoulli principle and comprising a moveable disk or body (9) provided within a housing (4) for opening and closing said valve (2), c h a r a c t e r i z e d by involving use of a material (24) within the valve (2) that changes its properties as to shape and/or volume and/or elastic
10 modulus when exposed to a chemical substance contained in the flow of fluid and thus altering said flow of fluid.
2.
The method in accordance with claim 1, c h a r a c t e r i z e d by using a swelling
15 material (24).
3.
The method in accordance with claim 2, c h a r a c t e r i z e d by using a reversible swelling material (24).
20
4.
The method in accordance with any of the preceding claims, c h a r a c t e r i z e d by said material (24) substantially completely blocking or shutting off the flow of fluid through the valve (2) by direct action or by acting on a separate member (25).
25
5.
The method in accordance with any of the preceding claims, c h a r a c t e r i z e d by said chemical substance being water.
- 30 6.
The method in accordance with any of the preceding claims, c h a r a c t e r i z e d by modifying a backing of the disc or body (9) with said material (24).
7.
35 The method in accordance with claim 6, c h a r a c t e r i z e d by modifying maximum channel dimensions available for the flow without exposing the backing material (24) to high velocity flow and erosion.

8.

The method in accordance with any of the preceding claims, characterized by modifying flow characteristics at a pressure reference location within said valve (2).

5

9.

The method in accordance with any of the preceding claims, characterized by changing the flow velocity over or adjacent to the body or disc (9) and hence the Bernoulli force based on chemical sensitivity.

10

10.

The method in accordance with any of the preceding claims, characterized by providing pressure and fluid communication between a rear side (27) of the material (24) and the surroundings of the valve (2).

15

11.

An apparatus for controlling the flow of fluid in oil and/or gas production, comprising a control device or an autonomous valve (2) operating by the Bernoulli principle and comprising a moveable disk or body (9) provided within a housing (4) for opening and closing the valve (2), characterized by further comprising a material (24) arranged within said valve (2) having shape and/or volume and/or elastic modulus changing properties by exposure to a chemical substance contained in the flow of fluid.

20

12.

The apparatus in accordance with claim 11, characterized by said body (9) facing the outlet of an aperture or hole (10) in the centre of a recess (21) or housing body (4) and being held in place in the recess (21) or housing body (4) by means of a holder device or arrangement (7, 22), thereby forming a flow path (11) where the fluid enters the valve (2) through the central aperture or inlet (10) flowing towards and along the body (9) and out of the recess or housing (21, 4).

30

13.

The apparatus in accordance with claims 11 or 12, characterized in that said material (24) is a swelling material, and preferably a reversible swelling material.

35

14.

The apparatus in accordance with any of claims 11 to 13, characterized in that said material (24) is arranged in an open space (14) within which the moveable disc or body (9) is provided.

5

15.

The apparatus in accordance with any of claims 11 or 13, characterized in that said material (24) is provided behind hard metal wedges (25) which are oppositely arranged in the flow path (11), for cooperatively and variably restricting said flow path (11).

10

16.

The apparatus in accordance with any of claims 11 to 15, characterized in that a plurality of pressure and fluid communication channels (26) are provided between a rear side (27) of the material (24) and the surroundings of the valve (2).

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Fig. 1

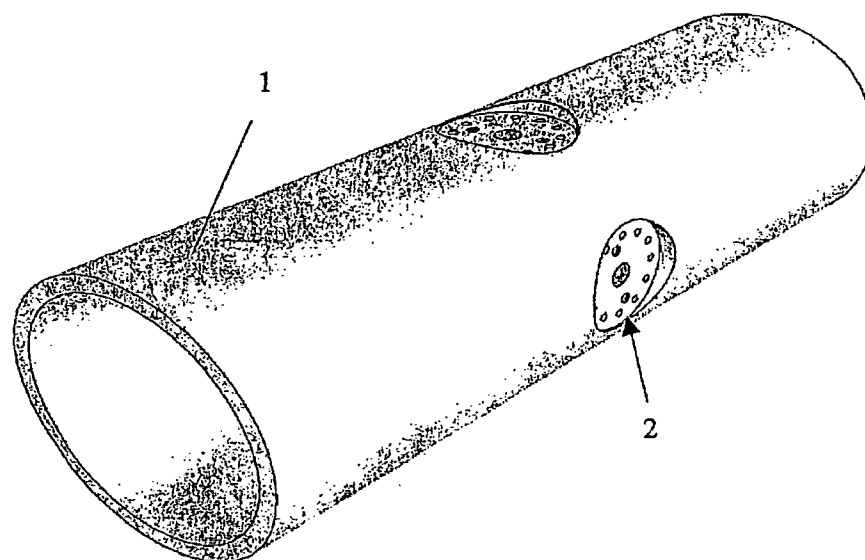


Fig. 2 a)

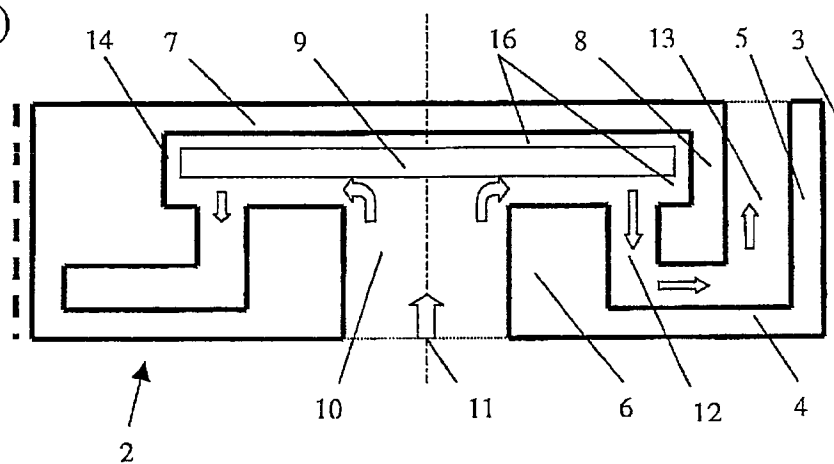


Fig. 2 b)

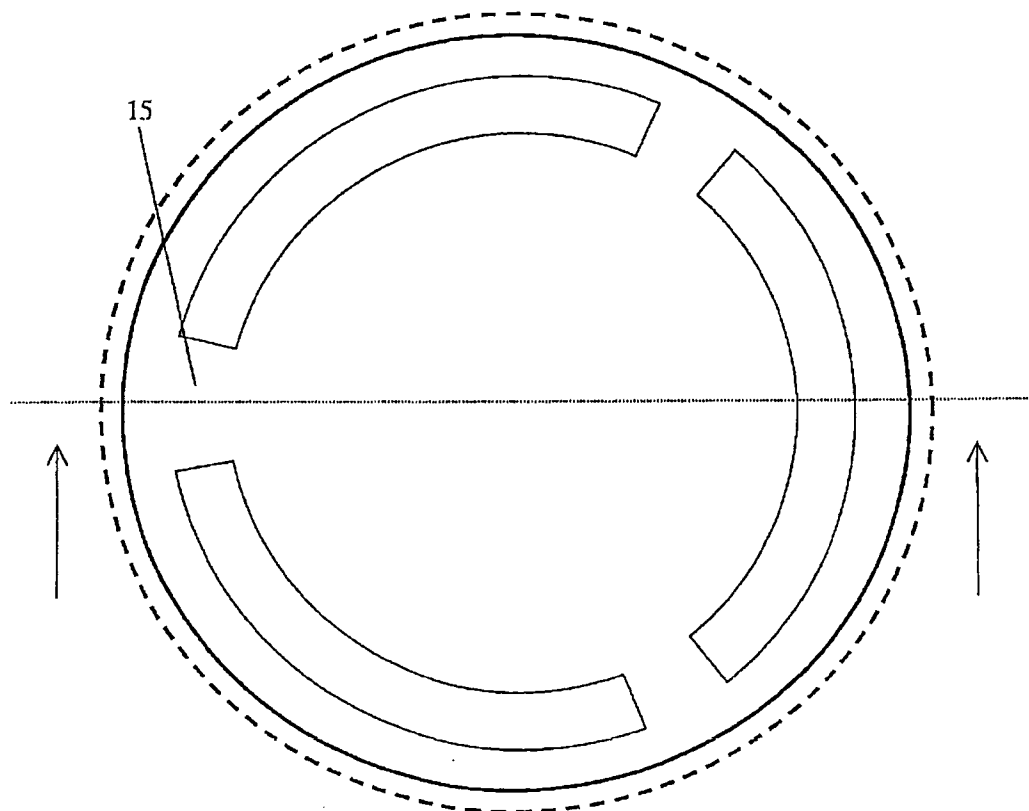


Fig. 3

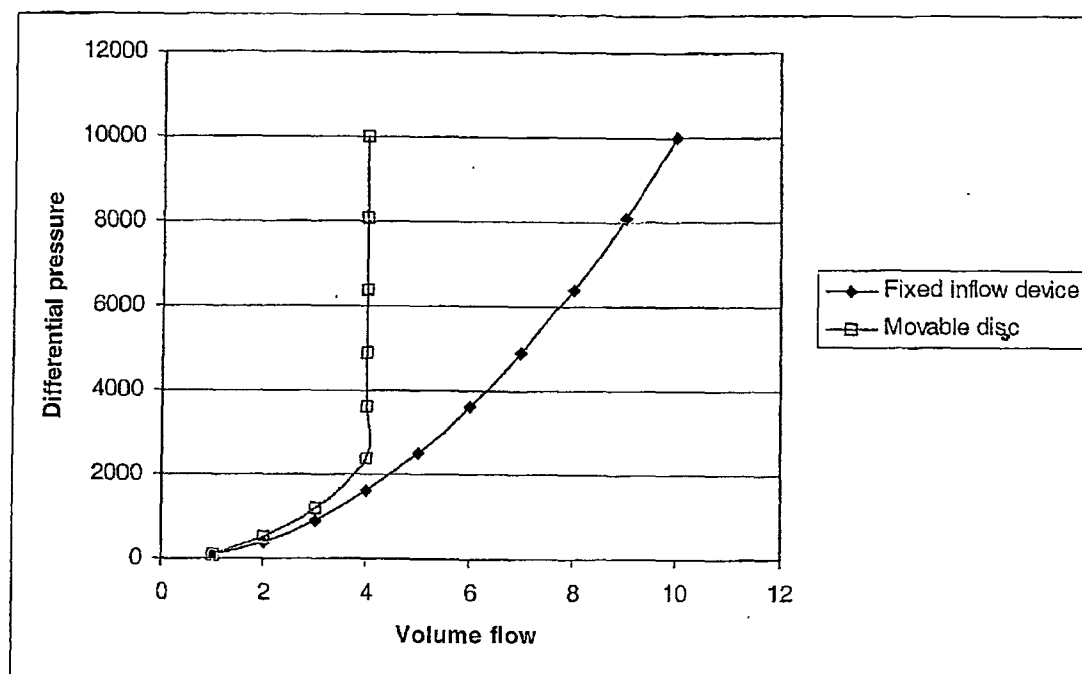


Fig. 4

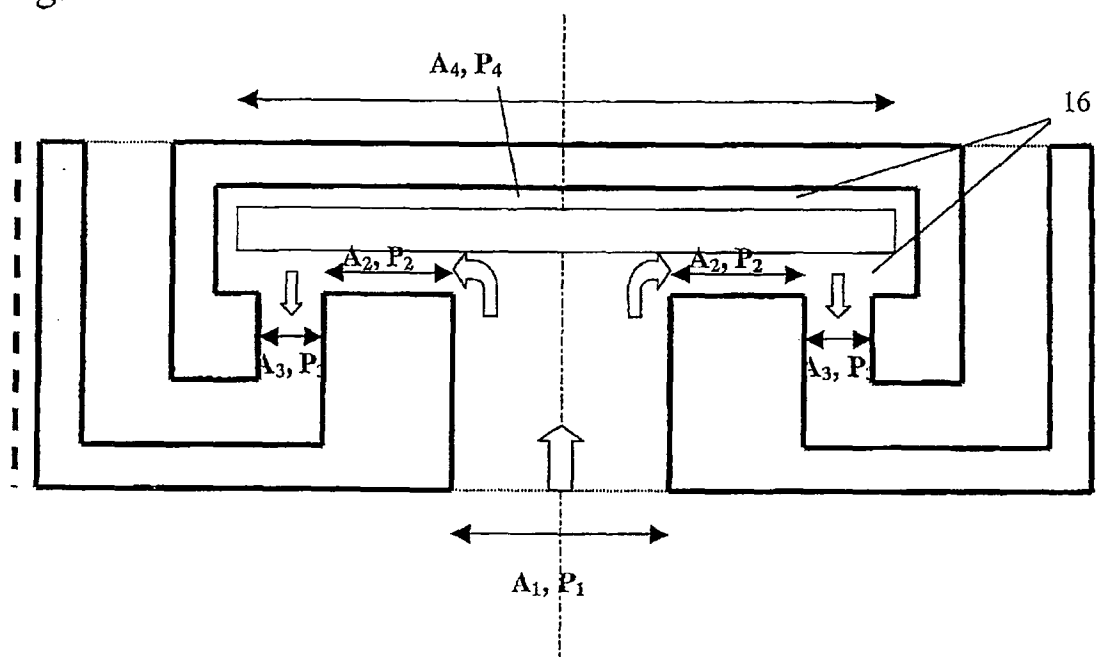


Fig. 5

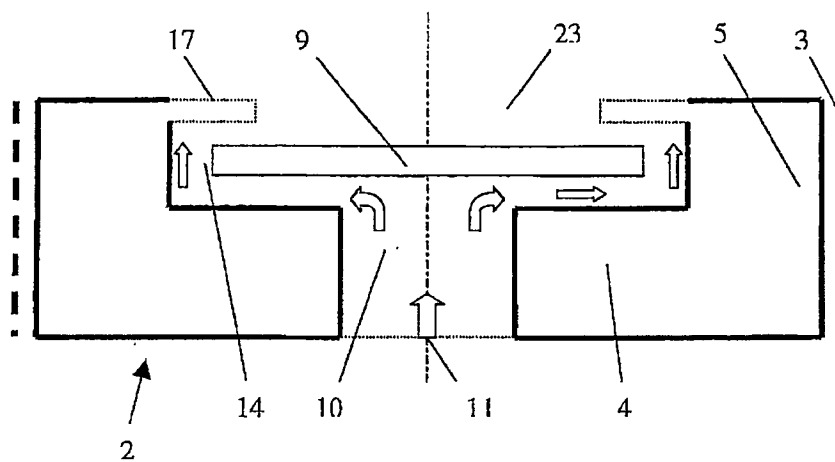


Fig. 6

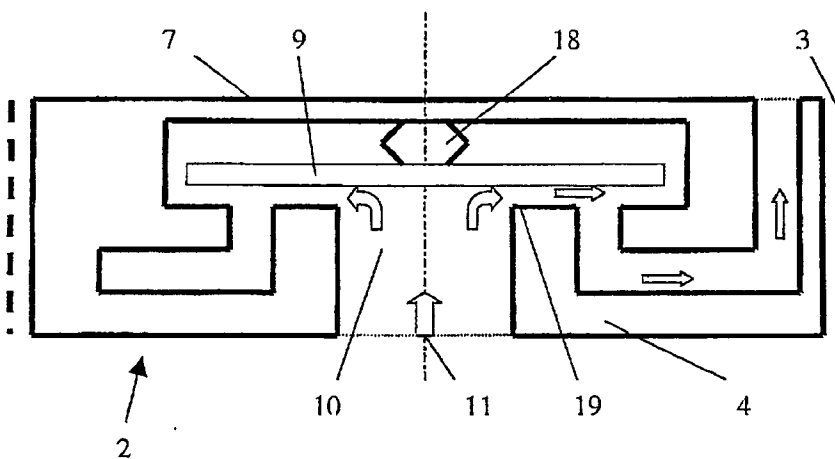


Fig. 7

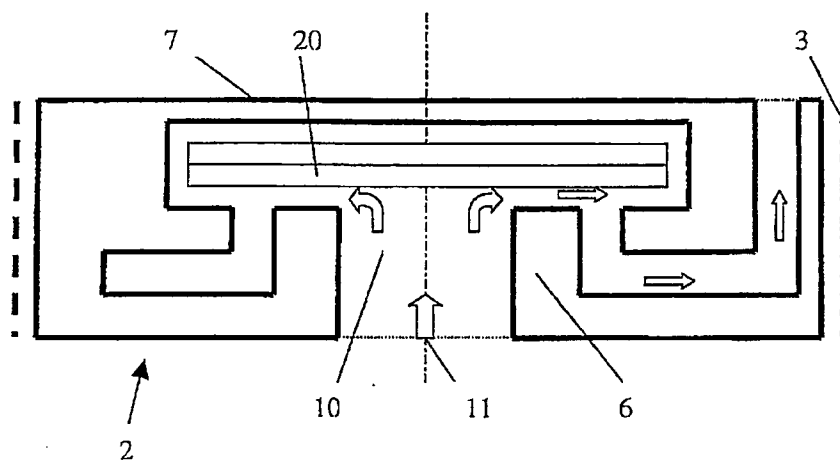


Fig. 8

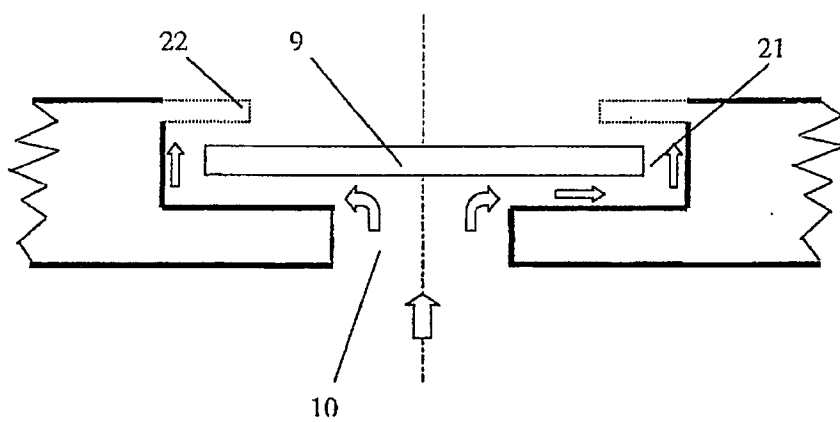


Fig. 9

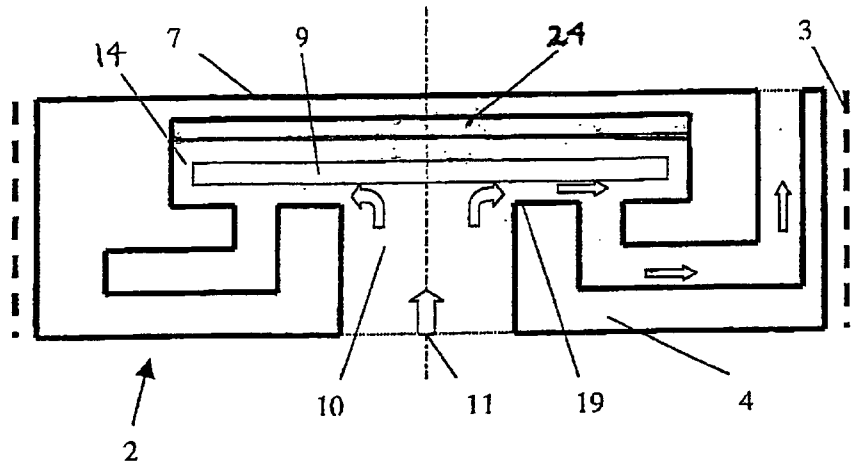


Fig. 11

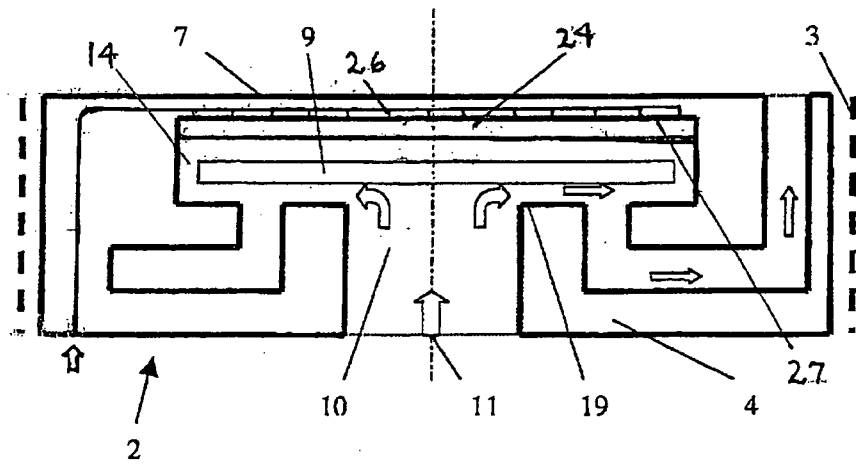
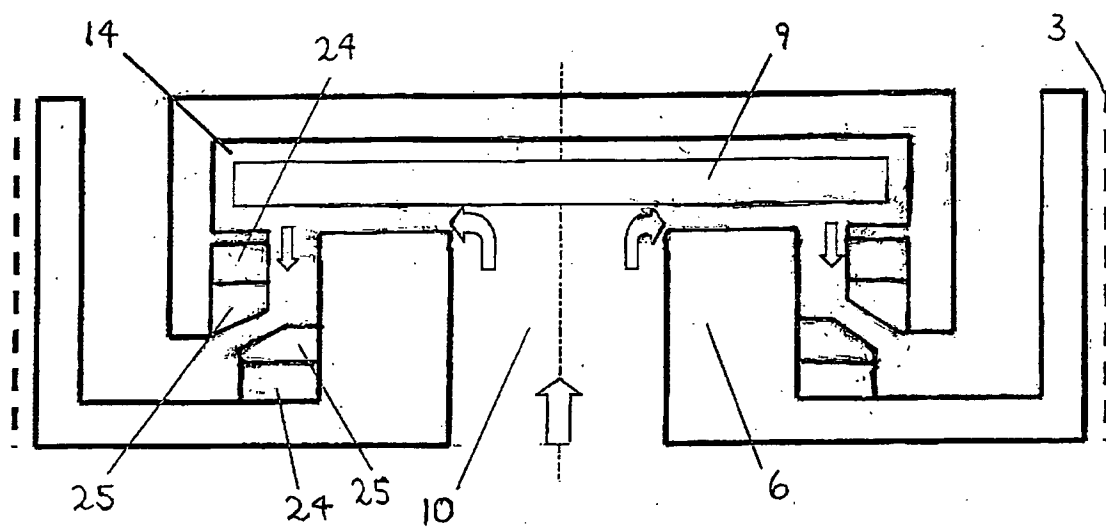


Fig. 10



INTERNATIONAL SEARCH REPORT

International application No

PCT/N02009/000394

A. CLASSIFICATION OF SUBJECT MATTER

INV. E21B43/12 E21B34/08 E21B21/10 E21B43/32

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 practical, 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.
Y	WO 2008/004875 A1 (NORSK HYDRO AS [NO]; AAKRE HAAVARD [NO]; MATHIESEN VIDAR [NO]) 10 January 2008 (2008-01-10) cited in the application the whole document	1-16
Y	US 2007/246225 A1 (HAILEY TRAVIS T JR [US] ET AL) 25 October 2007 (2007-10-25) paragraph [0038] - paragraph [0045] figures 3A,3B	1-16
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A	NO 326 258 B1 (IOR TECHNOLOGY AS [NO]) 27 October 2008 (2008-10-27) the whole document	1-16

☐ 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

18 February 2010

Date of mailing of the international search report

02/03/2010

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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