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(54) **Method and electromagnetic device for causing a fluid flow through a subterranean permeable formation, and borehole provided with such a device**

(57) The invention relates to a method for causing a subterranean fluid flow through a permeable formation. The method comprises the steps of placing an electromagnetic device in a borehole that is situated in the earth's subsurface and comprises a tubing that reaches into the permeable formation. The method further com-

prises the step of activating the electromagnetic device to heat material in the permeable formation. Additionally, the step of placing the electromagnetic device in the borehole comprises arranging the device substantially outside the tubing of the borehole.

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## Description

**[0001]** In the process of oil exploration, oil is recovered from a permeable formation in the subsurface of the earth. A permeable formation is a subterranean medium through which a fluid, such as oil can flow. Examples of such permeable formations are soils, sands, shales of porous rocks and faults, and channels within non-porous rocks.

**[0002]** Different stages in the exploration of oil can be distinguished. In a primary stage, a flow of oil from the permeable formation via a borehole in an applicator well towards the earth's surface is generated by natural force, such as the internal pressure in the formation. In a secondary stage, such an oil flow is enhanced by injecting auxiliary energy in the subsurface, such as steam air or natural gas in order to displace the oil. During a tertiary stage of oil exploration more sophisticated methods are applied to improve oil production of the nearly exhausted field, such as miscible fluid displacement, microemulsion flooding, etc.

**[0003]** The invention relates to a method for causing a subterranean fluid flow through a permeable formation, comprising the steps of:

- placing an electromagnetic device in a borehole that is situated in the earth's subsurface and comprises a tubing that reaches into the permeable formation; and
- activating the electromagnetic device to heat material in the permeable formation.

**[0004]** Such a method is e.g. known from American patent publication US-A-6 189 611. By activating the electromagnetic device in US '611 the temperature of the material in the permeable formation, in particular oil, increases, so that its viscosity reduces and its permeability increases, thereby causing a subterranean fluid flow containing oil particles through the permeable formation. The subterranean fluid flow is directed away from the borehole to neighbouring boreholes to receive the partial oil stream.

**[0005]** It is noted that within this context the terms 'permeable' and 'permeability' relate to the hydraulic permeability.

**[0006]** According to the disclosure of US '611 the electromagnetic device is arranged in the tubing of the borehole, the tubing having walls that are transparent with respect to electromagnetic waves in order to transmit the electromagnetic energy towards the permeable formation. Another requirement is, that the walls of the tubing are able to sustain relatively high temperatures. In order to meet the above requirements, the walls are not constructed from a conventional steel material, but from e.g. fibreglass, polyvinyl chloride, ceramic or concrete.

**[0007]** A disadvantage of this type of materials is that they are rather uncommon for oil exploration techniques, especially under operational conditions well below the

earth's surface. Therefore, such materials cause extra costs, e.g. during the process of drilling the tubing of the borehole into the subsurface.

**[0008]** It is an object of the invention to provide a method for causing a subterranean fluid flow through a permeable formation, wherein the disadvantages identified above are reduced. In particular, the invention aims at obtaining a method for causing a subterranean fluid flow through a permeable formation, wherein the walls of the tubing can remain to be formed by standard tubes, while the principle of lossy propagation of electromagnetic fields into the permeable formation is maintained. Therefore, according to the invention, the step of placing the electromagnetic device in the borehole comprises arranging the device substantially outside the tubing of the borehole.

**[0009]** By arranging the electromagnetic device substantially outside the tubing of the borehole, electromagnetic waves directly propagate into the permeable formation, in the vicinity of the borehole, without passing a wall of the borehole. As a consequence, the walls of the tubing are not required to be formed by an electromagnetic transparent material, but can be constructed from conventional tubing material, such as steel.

**[0010]** Preferably, the tubing is provided with openings and corresponding valves for closing the openings, so that the fluid flow that increases due to the temperature rise caused by the electromagnetic device and containing the oil particles can be received in the same borehole wherein the electromagnetic device is provided. Advantageously, the same borehole can be used for production. Hence, in contrast to the arrangement disclosed in US '611, no neighbouring boreholes are required to receive the fluid flow, thereby saving costs. Further, exploring the oil via one borehole wherein the electromagnetic device is provided, is more attractive in terms of energy efficiency, since the thermal energy of the partial oil stream is optimally, locally utilized.

**[0011]** In addition, by heating material in the vicinity of the borehole, dissolved gas particles in the fluid flow vaporise, so that a partial pressure is generated causing a natural gas lift. The natural gas lift facilitates an upward stream of the flow through the borehole. Further, by heating water particles in the fluid flow above a boiling temperature, steam is generated in an advantageous manner, which steam naturally expands upwards through the tubing of the borehole, thereby rendering an artificial lift system comprising a pump for pumping the fluid flow towards the earth's surface less necessary or even superfluous.

**[0012]** By providing an electromagnetic device comprising a screw-shaped antenna, an antenna with a relatively large radiation surface is obtained which nevertheless has relatively compact dimensions, especially with respect to a diameter size. Further, the screw-shaped antenna can be arranged relatively easily in the permeable formation screwing the tube with the antenna into the soil. Alternatively, the antenna might be screwed

separately into the soil around the tubing. Advantageously, the screw-shaped antenna further merely needs a few electrical connections while an equivalent multiple number of antennas need a multiple number of connections. By reducing the electrical connections, operational costs are minimized as connecting electric elements substantially outside the tubing might not be trivial.

**[0013]** Further, the invention relates to a borehole.

**[0014]** Additionally, the invention relates to an electromagnetic device.

**[0015]** Other advantageous embodiments according to the invention are described in the following claims.

**[0016]** By way of example only, embodiments of the present invention will now be described with reference to the accompanying figures in which

Fig. 1 shows a schematic perspective view of a cross section of a first embodiment of a borehole according to the invention; and

Fig. 2 shows a schematic perspective view of a cross section of a second embodiment of a borehole according to the invention.

**[0017]** The figures are merely schematic views of preferred embodiments according to the invention. In the figures, the same reference numbers refer to equal or corresponding parts.

**[0018]** Figure 1 shows a schematic perspective view of a cross section of a first embodiment of a borehole 1 according to the invention. The borehole 1 is mainly annular shaped and comprises a primary casing 2 extending from the earth's surface 3 into the earth's subsurface 4. The borehole 1 also comprises a secondary casing 5 having a longitudinal axis A that substantially coincides with a longitudinal axis of the primary casing 2 and extends from a lower side of the primary casing 2 downwards. The outer perimeter of the secondary casing 5 is smaller than the inner diameter of the primary casing 2, so that segments of the secondary casing 5 during construction of the borehole 1 might move through the primary casing 2.

**[0019]** Further, the borehole 1 comprises a tubing 6 extending from a lower side of the secondary casing 5 downwards into a permeable formation 7 of the subsurface. The outer perimeter of the tubing 6 is smaller than the inner diameter of the secondary casing 5, thus enabling a relatively easy construction of the tubing 6 via the secondary casing 5. The tubing 6 is formed from conventional tubing material, such as steel. However, also other conventional tubings could be used.

**[0020]** The permeable formation 7 comprises e.g. a porous rock formation and/or channels within non-porous rocks. In the permeable formation 7 oil is present, e.g. in the form of droplets that are surrounded by water droplets.

**[0021]** In addition, the borehole 1 comprises an electromagnetic device for heating material that is present in the permeable formation. The electromagnetic device is

arranged substantially outside the tubing 6 and comprises at least one antenna that is connected to an electric source 9 via an electric cable 11. In the present embodiment, the antenna is implemented as a coil 8. However, other antenna types are also possible. When activated, the electric source 9 generates an electric current in the coil 8 so that electromagnetic waves 10 emanate into the permeable formation 7. Due to the electromagnetic waves, the temperature of material in the formation 7 increases, so that the flow resistance of the material decreases. As a consequence, the radius of the tubing 6 virtually increases, thereby improving the oil production of the borehole 1. In particular, a subterranean flow 14 of the material comprising oil is generated towards the tubing 6. In order to recover the oil, the tubing 6 is provided with openings 12 that can be opened or closed by means of corresponding valves 13. The subterranean flow 14 is directed to the openings 12 of the tubing 6 and is subsequently directed to the earth's surface 3 as indicated by flow arrows 15, e.g. by means of a pump system (not shown in the figure).

**[0022]** In the embodiment as shown in Figure 1, the electromagnetic device comprises a multiple number of coils 8a-8c which are arranged substantially outside the tubing 6 at different heights between the openings 12 and corresponding valves 13 that are provided in the tubing 6. By applying a multiple number of coils 8a-8c, more electromagnetic energy can be directed towards the permeable formation 7 without increasing the size of an individual coil. The individual coils 8a-8c are substantially annular shaped and are connected to the electric cable 11. Further, by arranging the multiple number of coils 8a-8c at different heights between the openings 12 and the corresponding valves 13, the increase of flow resistance due to the presence of the tubing 6 and its attributes is minimal. The coils 8a-8c are provided with a protection layer for protecting against aggressive materials.

**[0023]** The electric source 9 is at least partially arranged on the earth's surface 3, so that electronic elements of the electric source 9 are relatively easily accessible, e.g. for inspection and/or repair activities. Other parts of the electric source could be installed downhole, close to the electromagnetic device.

**[0024]** Figure 2 shows a schematic perspective view of a cross section of a second embodiment of a borehole 1 according to the invention. Instead of using a multiple number of antennas that are mainly annular shaped, the electromagnetic device comprises a screw-shaped antenna 8d that is substantially arranged outside the tubing 6. Again the antenna 8d is implemented as a coil. By applying a screw-shaped coil 8d, multiple connections with individual coils are avoided, while nevertheless a relatively high electromagnetic power can be directed into the permeable formation. Optionally, a multiple number of screw-shaped coils can be applied to further increase the electromagnetic power of the electromagnetic device.

**[0025]** The coils are arranged on and/or near the outer

wall of the tubing 6.

**[0026]** Advantageously, the electromagnetic device is activated by means of an electromagnetic harmonic signal. Thereby, the dynamic electromagnetic signals might then be converted by the material in the permeable formation into heat due to the lossy propagation of EM waves. By adjusting the main frequency of the harmonic signal, specific material in the vicinity of the formation might be impinged.

**[0027]** As a first example, the frequency of the harmonic signal is adjusted to heat water, e.g. by applying a main frequency in the range extending from circa 10 MHz to circa 3 GHz. By heating water particles surrounding an oil droplet, also the oil droplet itself is heated, so that the oil permeability diminishes and the flow resistance reduces, as described above. Extra degassing of dissolved particles in the material flow causes a gas lift effect. Further, by heating water particles, steam might be obtained. Due to the expansion effect of the gas and the steam, the flow in the openings 12 or above in the tubing 6 towards the earth's surface 3 increases. In some cases, an artificial lift system, comprising a pump installation for maintaining the flow, might therefore be superfluous.

**[0028]** As a second example, the frequency of the harmonic signal is adjusted to heat in the formation 7 material comprising OH-groups. Thereby the process of forming paraffin-type material near the openings 12 in the tubing 6 is counteracted. Otherwise, paraffin-type material, such as tallow, might form in the tubing 6 as a loss of pressure might locally occur in the tubing 6. A paraffin-type formation in the tubing 6 is unattractive as it causes an increase in the flow resistance and might even block the subterranean flow 14 from the permeable formation 7. By heating material comprising OH-groups according to the invention, the occurrence of such paraffin-type material in the tubing 6 is avoided.

**[0029]** It is noted that in adjusting the main frequency of the harmonic signal, account must be taken for values of further parameters, such as the electrical conductivity due to the salt concentration of the water in the formation 7.

**[0030]** Further, it is noted that the power of the electromagnetic device can be adjusted, e.g. to a power in the range extending from circa 1 kW to circa 100 MW, to heat the material in the permeable formation 7 to a substantially predetermined temperature, so that a downhole refining process might be obtained. Clearly, also other power values might be applied, e.g. several tens or several hundreds of MW.

**[0031]** The invention is not restricted to the embodiments described herein. It will be understood that many variants are possible. Instead of using a primary and a secondary casing, also a single casing might be employed. Also other electromagnetic device types might be used, e.g. having rectangular-shaped antennas or strips.

**[0032]** Further, features of the different embodiments might be exchanged. As an example, also the screw-

shaped coil of Figure 2 might be provided with a protection layer for protecting against aggressive materials.

**[0033]** In addition, multiple boreholes according to the invention might be employed to recover oil from the permeable formation.

**[0034]** As the person skilled in the art knows, also curved boreholes might be used for exploring oil from the subsurface. Therefore, the specific form of the borehole according to the invention is not necessarily without a curvature.

**[0035]** Other such variants will be obvious for the person skilled in the art and are considered to lie within the scope of the invention as formulated in the following claims.

## Claims

1. A method for causing a subterranean fluid flow through a permeable formation, comprising the steps of:

- placing an electromagnetic device in a borehole that is situated in the earth's subsurface and comprises a tubing that reaches into the permeable formation; and
- activating the electromagnetic device to heat material in the permeable formation,

wherein the step of placing the electromagnetic device in the borehole comprises arranging the device substantially outside the tubing.

2. A method according to claim 1, wherein the electromagnetic device is activated by means of a harmonic signal.

3. A method according to claim 2, wherein the frequency of the harmonic signal is adjusted to heat material in the vicinity of the borehole.

4. A method according to claim 2, wherein the harmonic frequency is adjusted to heat material containing OH-groups.

5. A method according to any previous claim, wherein the harmonic frequency is adjusted in dependence of the electric conductivity in the permeable formation.

6. A method according to any previous claim, wherein the power of the electromagnetic device is adjusted to heat the material in the permeable formation to a substantially predetermined temperature.

7. A borehole that is situated in the earth's subsurface and comprises a tubing that reaches into a permeable formation, wherein an electromagnetic device

is placed in the borehole to heat material in the permeable formation for causing a subterranean fluid flow through the permeable formation, and wherein the electromagnetic device is substantially arranged outside the tubing.

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8. A borehole according to claim 7, wherein the borehole comprises an outer casing that is situated in the earth's subsurface having a longitudinal axis that substantially coincides with a longitudinal axis of the tubing, wherein the tubing extends from a lower side of the casing and wherein an outer perimeter of the tubing is smaller than an inner wall perimeter of the casing.  
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9. A borehole according to claim 7 or 8, wherein openings and corresponding valves are provided in the tubing.
10. A borehole according to any of previous claims 7-9, wherein the electromagnetic device comprises at least one antenna being connected to an electric source.  
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11. A borehole according to any of previous claims 7-10, wherein the antenna is screw-shaped.  
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12. A borehole according to any of previous claims 7-11, wherein the electromagnetic device comprises a multiple number of antennas which are arranged at different heights between the openings and corresponding valves that are provided in the tubing.  
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13. A borehole according to any of previous claims 7-12, wherein the outer perimeter of a antenna is smaller than the inner wall perimeter of the casing.  
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14. A borehole according to any of previous claims 7-13, wherein the electric source is at least partly arranged on the earth's surface.  
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15. An electromagnetic device that is arranged for heating material in a permeable formation for causing a subterranean fluid flow through the permeable formation, wherein the electromagnetic device further is arranged for placing substantially outside a tubing of a borehole that is situated in the earth's subsurface.  
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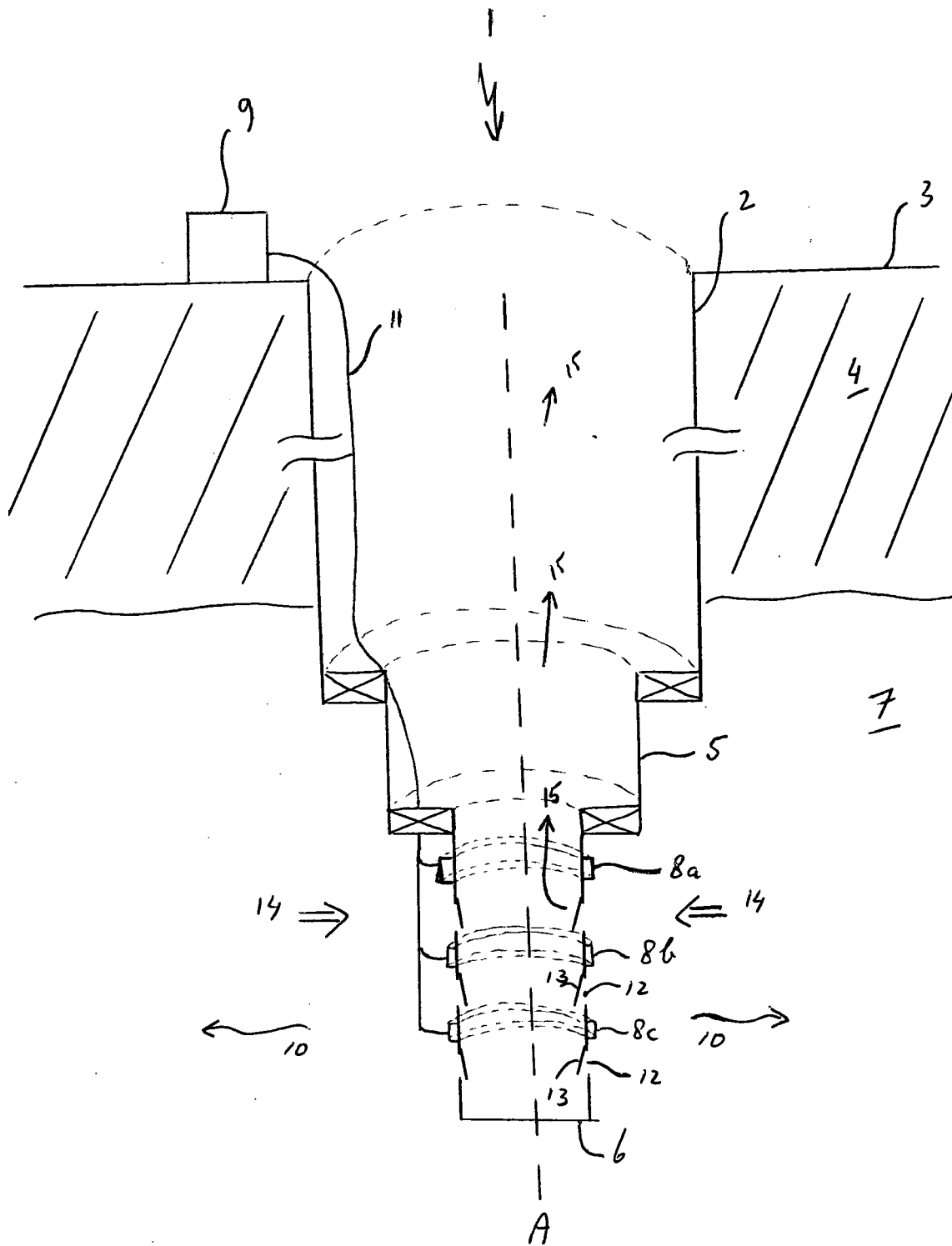


Figure 1

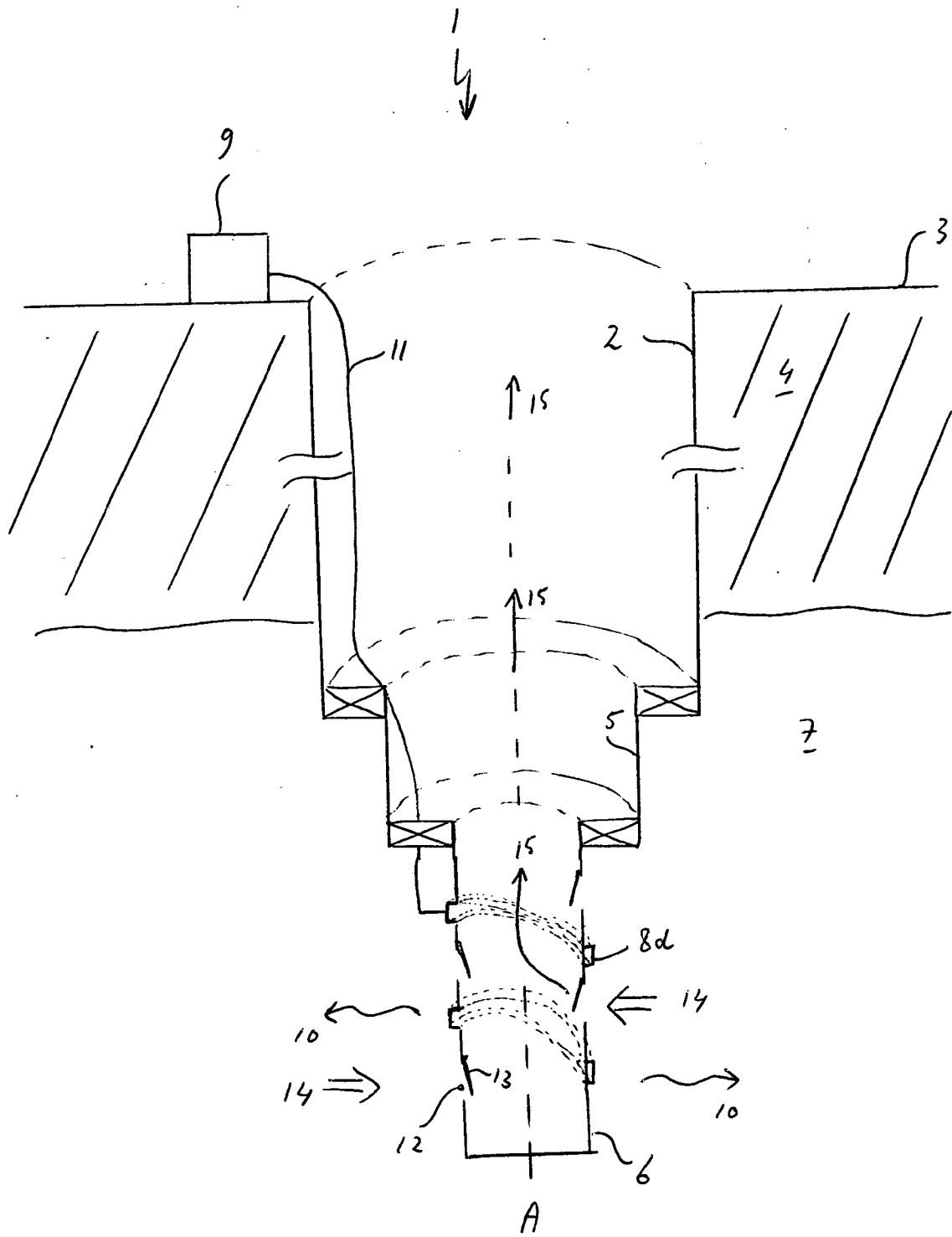


Figure 2



European Patent  
Office

# EUROPEAN SEARCH REPORT

Application Number  
EP 05 07 7227

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The present search report has been drawn up for all claims			
Place of search <b>Munich</b>		Date of completion of the search <b>16 February 2006</b>	Examiner <b>Bellingacci, F</b>
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

1  
EPO FORM 1503 03.82 (P04C01)



**ANNEX TO THE EUROPEAN SEARCH REPORT  
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EP 05 07 7227

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on  
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