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(54) **METHOD AND SYSTEM FOR PRODUCING HYDROCARBON FLUID THROUGH A WELL WITH A SENSOR ASSEMBLY OUTSIDE THE WELL CASING**

(76) Inventors: **Michael Anthony Addis**, Rijswijk (NL); **William Birch**, Aberdeenshire (GB); **Johannis Josephus Den Boer**, Rijswijk (NL); **Stephen Ainsleigh Rice**, Rijswijk (NL)

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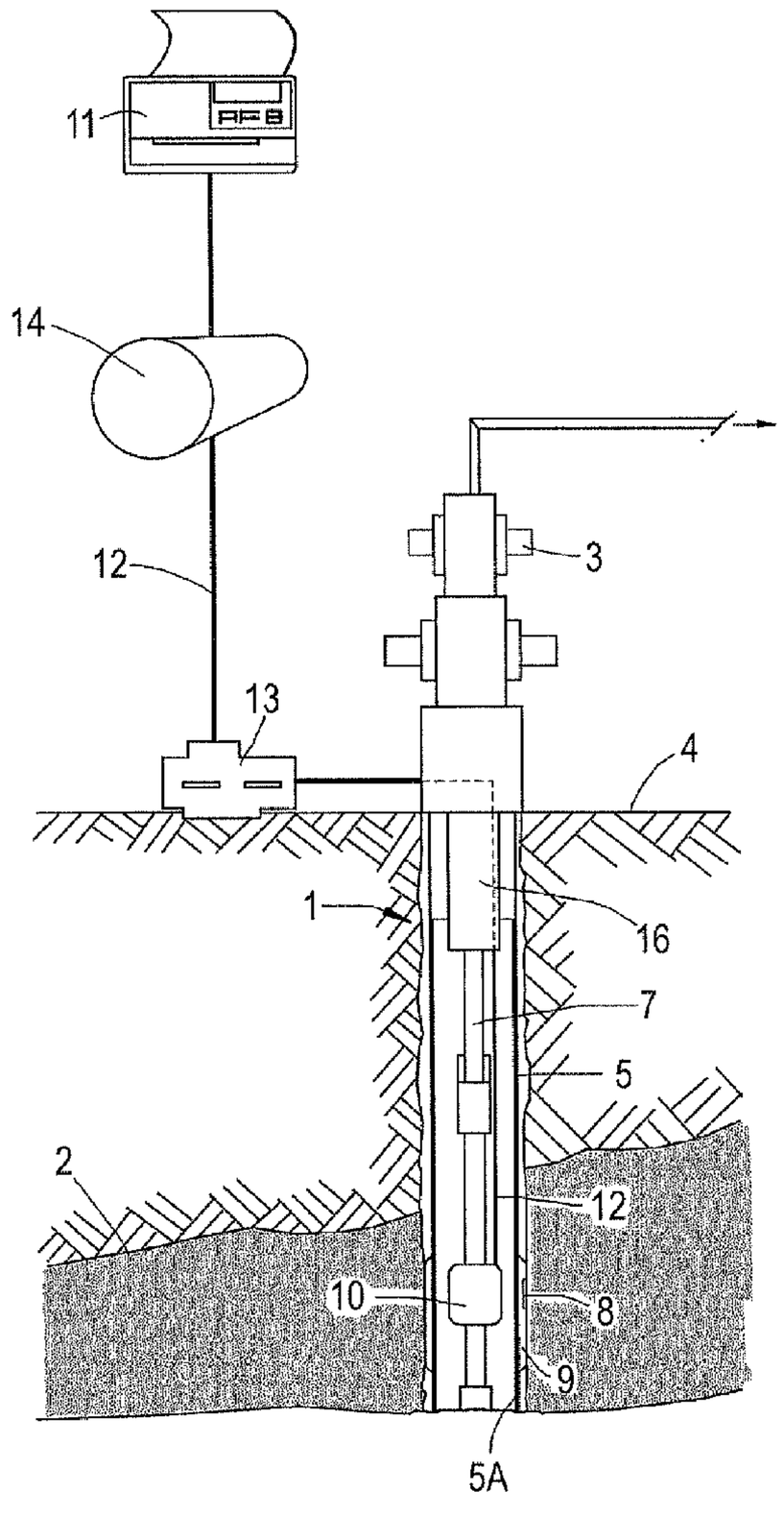
(57) **ABSTRACT**

A method is disclosed for producing hydrocarbon fluids through a well having a well casing string with a casing section which is surrounded by an annular space which comprises a sensor assembly for measuring electromagnetic and/or other physical properties of solid and fluid materials within the annular space, in an underground formation surrounding the annular space and/or within the interior of the section of the casing string, wherein the sensor assembly is mounted on a body of swellable material, such as a swellable rubber or other elastomeric material, which is secured to the outer surface of said casing section and presses the sensor assembly against the inner surface of the surrounding underground formation after the casing string has been lowered into the wellbore.



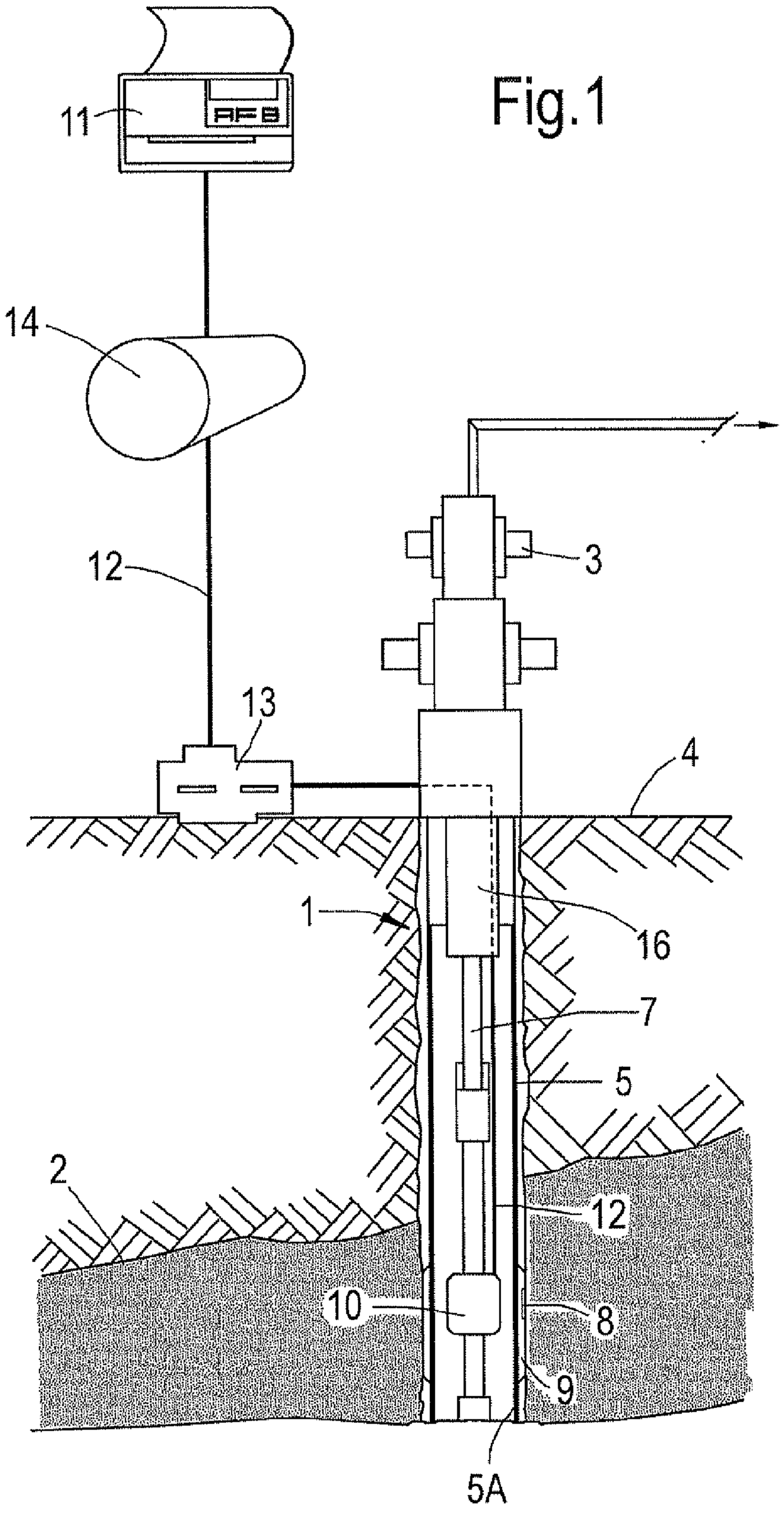


Fig.1

Fig.2

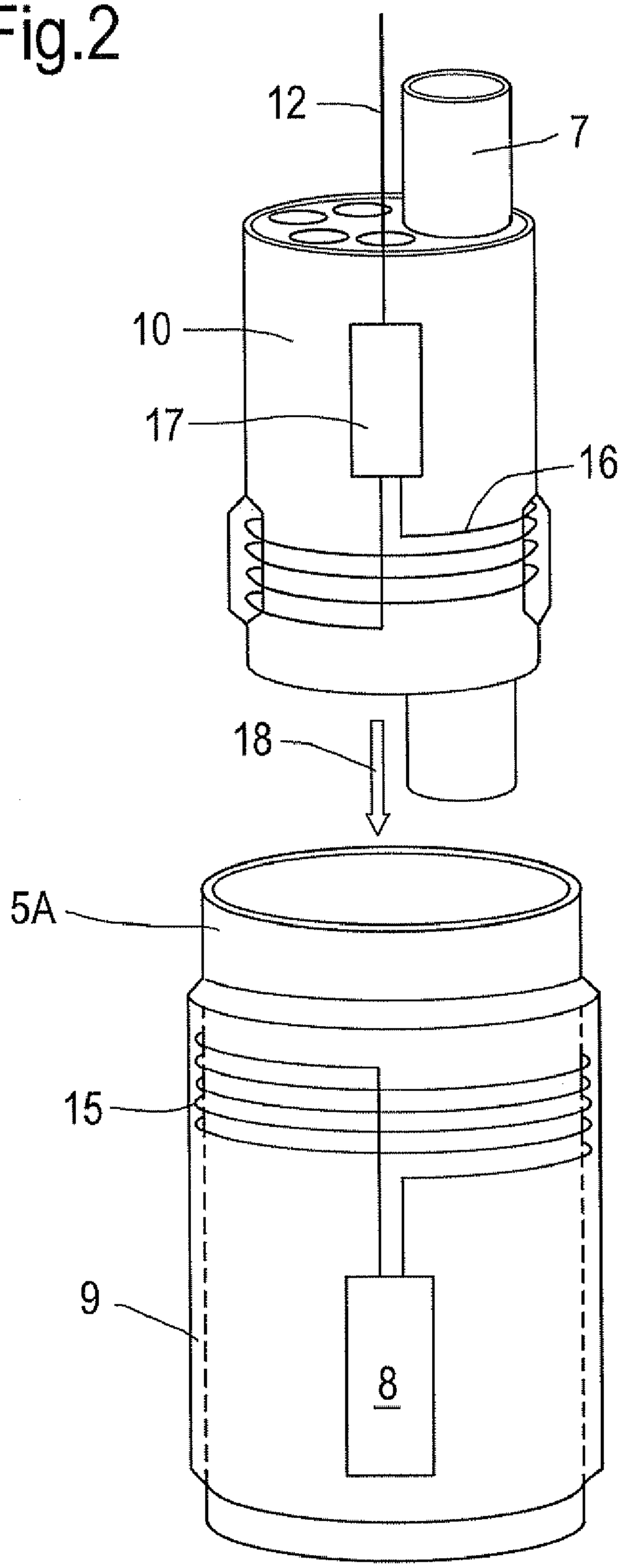
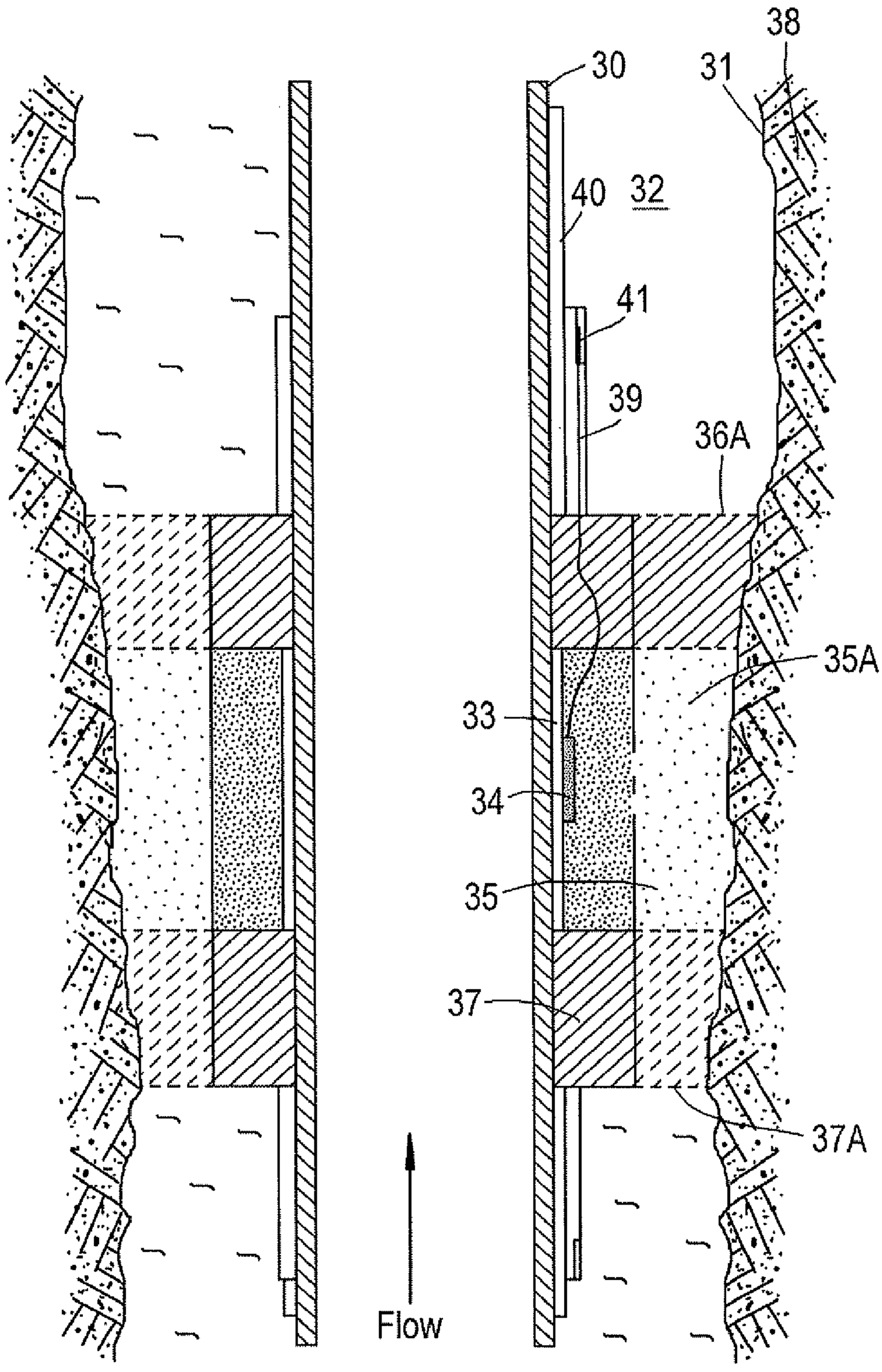


Fig.3



METHOD AND SYSTEM FOR PRODUCING HYDROCARBON FLUID THROUGH A WELL WITH A SENSOR ASSEMBLY OUTSIDE THE WELL CASING

BACKGROUND OF THE INVENTION

[0001] The invention relates to a method and system for producing hydrocarbon fluid through a well with a sensor assembly outside the well casing.

[0002] Such a method and system are known from International patent application WO 03/029614, which discloses a system for measuring pore pressure in a formation surrounding a well casing by a pressure sensor which is embedded in a cement sheath surrounding a steel well casing, and which sheath is fractured by a perforating gun to provide an open fluid channel between the sensor and the pores of the surrounding formation.

[0003] A limitation of the known system is that it is difficult to provide electrical power to the sensor and to transmit data from the sensor to surface and that the steel casing inhibits collection of electromagnetic data about several properties of fluid and solid materials in the surrounding formation.

[0004] It is an object of the present invention to provide a method and system, which alleviate these limitations.

SUMMARY OF THE INVENTION

[0005] In accordance with the invention there is provided a method of producing hydrocarbon fluids through a well having a well casing string with a casing section which is surrounded by an annular space which comprises a sensor assembly for measuring electromagnetic and/or other physical properties of solid and fluid materials within the annular space, in an underground formation surrounding the annular space and/or within the interior of the casing section, wherein the sensor assembly is mounted on or in the vicinity of a body of swellable material, which body is secured to the outer surface of the section of the casing string and is configured to swell against the inner surface of the underground formation surrounding the wellbore after the casing string has been lowered into the wellbore;

and the sensor assembly is configured to measure one or more of the following properties:

[0006] the pore pressure in pores of the formation adjacent to the annular space;

[0007] the chemical composition of fluid in the pores of the formation adjacent to the annular space;

[0008] the electrical resistivity and/or conductivity of the solid and fluid materials in the formation surrounding the annular space;

[0009] the streaming and spontaneous potentials of the solid and fluid materials in the formation surrounding the annular space;

[0010] the dielectric constant of the solid and fluid materials in the formation surrounding the annular space;

[0011] changes in a cement lining arranged in the annular space, including migration of any chemical contaminants through the cement lining;

[0012] properties of a fluid flowing through the interior of the non-magnetic section of the casing string;

[0013] deformation and/or tilting of the well casing string;

[0014] deformation, such as compaction and expansion, of the formation surrounding the annular space;

[0015] stress in any solid materials in the annular space and the formation surrounding the annular space; and

[0016] acoustic rock reflections.

[0017] The sensor assembly may be connected to an electrical and/or fiber optical data transmission conduit within the casing string by a wireless data and/or power transmission link, which transmits data and/or power through the wall of a non-magnetic or weakly magnetic casing section.

[0018] The wireless data and/or power transmission link may comprise at least one pair of substantially coaxial inductive couplers which each comprise a coiled electrical cable.

In accordance with the invention there is furthermore provided a system for producing hydrocarbon fluids through a well having a well casing string with a casing section which is surrounded by an annular space which comprises a sensor assembly for measuring electromagnetic and/or other physical properties of solid and fluid materials within the annular space, in an underground formation surrounding the annular space and/or within the interior of the casing section, wherein the sensor assembly is mounted on a body of swellable material, which body is secured to the outer surface of the section of the casing string and is configured to swell and press the sensor to the inner surface of the underground formation surrounding the wellbore after the casing string has been lowered into the wellbore.

[0019] These and other features, embodiments and advantages of the method and system according to the invention are described in the accompanying claims, abstract and the following detailed description of preferred embodiments disclosed in the accompanying drawings in which reference numerals are used which refer to corresponding reference numerals that are shown in the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. **1** is a schematic longitudinal sectional view of a well equipped with a sensor assembly according to the invention;

[0021] FIG. **2** is a schematic three-dimensional view of the inductive couplings on the production tubing and casing sections in the vicinity of the sensor assembly; and

[0022] FIG. **3** is a schematic longitudinal sectional view of a well equipped with a sensor assembly according to the invention.

DETAILED DESCRIPTION OF THE DEPICTED EMBODIMENTS

[0023] FIG. **1** shows a crude oil and/or natural gas production well **1**, which traverses a crude oil and/or natural gas containing formation **2**.

[0024] The well **1** comprises a wellhead **3** which is located at the earth surface **4** and from which a well casing **5** and a tubing hanger **6** are suspended, from which tubing hanger **6** a production tubing **7** is suspended within the well **1**.

[0025] A sensor assembly **8** is mounted in a support sleeve **9**, which is secured to the outer surface of a casing section **5**A of the well casing **5**, which support sleeve **9** substantially fills an annular space surrounding the well casing **5** within a region where the well **1** traverses the crude oil and/or natural gas containing formation **2**. A wireless power and/or signal transmission sleeve **10** is mounted on the outer surface of the production tubing **7** at the same depth as the support sleeve **9** and such that the sleeves **9** and **10** are substantially co-axial to each other.

[0026] The wireless power and/or signal transmission sleeve **10** is connected to a surface monitoring unit **11** via an electrical and/or fiber optical cable assembly **12** extending through the annulus between the production tubing **7** and well casing **5** and through the wellhead **3**. Optionally the cable assembly **12** may be equipped with a sensor interface unit **13** and a subsea control module **14** if the wellhead **3** is located at the sea bottom **4**. FIG. **2** shows in more detail and at a larger scale than in FIG. **1** that the support sleeve **9** is provided with an inductive coupler **15** which is connected to the sensor assembly **8** and that the wireless power and/or signal transmission sleeve **10** is provided with a second inductive coupler **16**, which is connected to the cable assembly **12** by a power and/or signal transmission, amplification and/or conversion module **17**. The tubing **7** is inserted into the non-magnetic casing section **5**A as illustrated by arrow **18** such that the inductive couplers **15** and **16** are arranged substantially coaxially to each other and form a wireless electrical power and/or signal transmission link which connects the sensor assembly **8** via the cable assembly **12** to the surface monitor unit **11**.

[0027] The presence of a non-magnetic casing section **5**A between the inductive couplers **15** and **16** enhances the wireless transmission of electrical power and/or signals between the sensor assembly **8** and the power and/or signal transmission, amplification and/or conversion module **17** so that the sensor assembly **8** may be equipped with a significant amount of sensors, such as sensors which are configured to measure:

[0028] the pore pressure in pores of the formation adjacent to the annular space;

[0029] the chemical composition of fluid in the pores of the formation adjacent to the annular space;

[0030] the electrical resistivity and/or conductivity of the solid and fluid materials in the formation surrounding the annular space;

[0031] the streaming and spontaneous potentials of the solid and fluid materials in the formation surrounding the annular space;

[0032] the dielectric constant of the solid and fluid materials in the formation surrounding the annular space

[0033] deformation and/or tilting of the well casing string;

[0034] deformation, such as compaction and expansion, of the formation surrounding the annular space;

[0035] stress in any solid materials in the annular space and the formation surrounding the annular space; and/or

[0036] acoustic rock reflections.

[0037] FIG. **3** shows a liner **30** arranged in a wellbore **31** wherein the annular space between the liner **30** and wellbore **31** is filled with cement **32** and a sensor assembly according to the invention. The assembly comprises a support sleeve **33**, a pressure sensor **34** which is embedded in an intermediate permeable swellable elastomeric sleeve **35**, and an upper and a lower swellable elastomeric sleeve **36** and **37** are arranged above and below the intermediate permeable elastomeric sleeve **35**.

The upper, lower and intermediate sleeves **35-37** are configured to swell against the wellbore **31** such that they have the swollen shape as indicated by dotted lines **35**A-**37**A after the cement slurry **32** has been injected and before the cement slurry **32** has been hardened.

The upper and lower sleeves **36** and **37** are impermeable and thereby seal off the intermediate sleeve **35** and the pressure sensor **34** embedded therein from the cement body **32**. The intermediate sleeve **35** has a permeability, preferably in the range of 1-10 mD, to allow the pressure sensor **34** to be in fluid contact with the fluid in the pores of the formation **38** surrounding the wellbore **31**. The pressure sensor **34** is provided with a signal and power supply cable **39**, which may be connected to an umbilical power and signal transmission cable assembly **40** by an inductive coupler **41** or another wireless or wired coupling assembly.

The pressure sensor **34** shown in FIG. **3** is adequately isolated from the cement **32** by the swellable sleeves **36**A and **37**A and is in fluid contact with the fluid in the pores of the surrounding formation **38** via the permeable sleeve **35**A which enables the pressure sensor **34** to accurately monitor the pore pressure of the fluid, such as crude oil, natural gas, oil shale and/or shale oil, in the pores of the formation **38** over a prolonged period of time.

1. A method of producing hydrocarbon fluids through a well having a well casing string with a casing section which is surrounded by an annular space which comprises:

a) providing in the well a sensor assembly for measuring electromagnetic and/or other physical properties of solid and fluid materials within the annular space, in an underground formation surrounding the annular space and/or within the interior of the casing section,

wherein the sensor assembly is mounted on or in the vicinity of a body of swellable material, which body is secured to the outer surface of the casing section and is configured to swell against the inner surface of the underground formation surrounding the wellbore after the casing string has been lowered into the wellbore;

and the sensor assembly is configured to measure one or more of the following properties:

the pore pressure in pores of the formation adjacent to the annular space;

the chemical composition of fluid in the pores of the formation adjacent to the annular space;

the electrical resistivity and/or conductivity of the solid and fluid materials in the formation surrounding the annular space;

the streaming and spontaneous potentials of the solid and fluid materials in the formation surrounding the annular space;

the dielectric constant of the solid and fluid materials in the formation surrounding the annular space;

changes in a cement lining arranged in the annular space, including migration of any chemical contaminants through the cement lining;

properties of a fluid flowing through the interior of the non-magnetic section of the casing string;

deformation and/or tilting of the well casing string;

deformation, such as compaction and expansion, of the formation surrounding the annular space;

stress in any solid materials in the annular space and the formation surrounding the annular space; and

acoustic rock reflections;

b) producing hydrocarbons from the well; and

c) using the sensor assembly to sense one or more of the properties.

2. The method of claim **1**, wherein the sensor assembly is connected to an electrical and/or fiber optical data transmission conduit within the casing string by a wireless data and/or

power transmission link, which transmits data and/or power through the wall of the non-magnetic section of the well casing string.

3. The method of claim **2**, wherein the wireless data and/or power transmission link comprises at least one pair of substantially coaxial inductive couplers which each comprise a coiled electrical cable.

4. The method of claim **1**, wherein the sensor assembly is mounted on a body of swellable elastomeric material.

5. A system for producing hydrocarbon fluids through a well having a well casing string with a casing section which is surrounded by an annular space which comprises a sensor assembly for measuring electromagnetic and/or other physical properties of solid and fluid materials within the annular space, in an underground formation surrounding the annular space and/or within the interior of the casing section,

wherein the sensor assembly is mounted on a body of swellable material, which body is secured to the outer surface of the casing section and presses the sensor against the inner surface of the underground formation surrounding the wellbore after the casing string has been lowered into the wellbore.

6. The system of claim **5**, wherein the sensor assembly is mounted on a body of swellable elastomeric material.

7. The system of claim **5**, wherein the casing section is made of a non-magnetic or weakly magnetic material.

8. The system of claim **7**, where the non-magnetic or weakly magnetic material is selected from the group of materials consisting of: non-metallic materials, Glassfiber Reinforced Plastic_(GRP); non-magnetic materials, aluminium, gold, titanium;_low curie temperature materials, inconel 718, monel K500; low magnetic permeability soft magnetic materials, and casing steel grades L80 and L80 13 Chrome, where the relative magnetic permeability μ_r is in the range from 50 to 200 and/or the bulk electrical resistivity is in the range from 30×10^{-8} to 120×10^{-8} Ωm.

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