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(54) **Electro-kinetic treatment of a subsurface pore fluid**

(57) A method for electro-kinetic treatment of a pore fluid comprising hydrocarbon fluid, such as natural gas (CH₄), non-hydrocarbon fluid, such as water, and dissolved charged species, such as ions, and/or other components, such as CO₂ and/or H₂S, in a subsurface formation, the method comprising the steps of:
- transmitting an electric field through the subsurface for-

mation by at least two electrodes (+ and -) traversing the formation; and
- inducing at least one of the charged species and/or other components to flow through the formation under the influence of the electric field, thereby upgrading the hydrocarbon fluid by at least one electro-kinetic effect of the electric field.

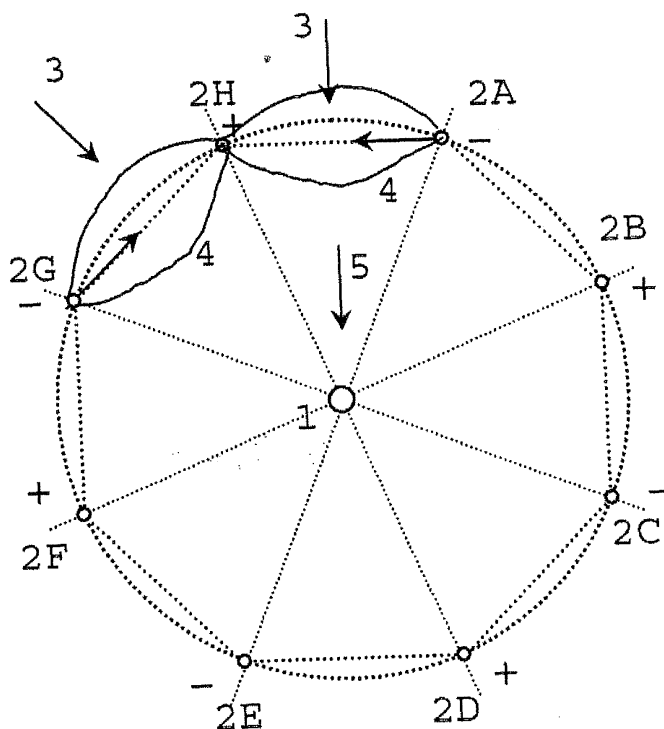


Figure 1

Description

BACKGROUND OF THE INVENTION

[0001] The invention relates to a method for electro-kinetic treatment of a subsurface pore fluid.

[0002] US patent 5,676,819 discloses an in-situ electro-kinetic method for removal of cationic heavy metal contamination from soil, utilizing gas phase manipulation to inhibit biodegradation of a chelating agent that is used in an electro-kinetic process to remove the contamination. The method includes implanting spaced electrodes in the contaminated soil and applying a direct current across said electrodes to cause electro-kinetic remediation. Thus, US patent 5,676,819 relates to electro-kinetic soil decontamination techniques.

[0003] The technical challenges to produce hydrocarbons from the subsurface are getting tougher in time. Therefore, the need for unconventional driving forces to influence the flow, transport and transfer of different phases and masses, in the subsurface, is on the rise.

[0004] Sour gas production is an important challenge for the oil and gas industry because of costly treatment, the production of huge amount of elemental sulphur as a treatment by-product, corrosive effects and environmental impacts. A new direction while dealing with this problem is to find a method to keep the sour elements of the gas, such as H_2S and CO_2 , in the subsurface formation and not to produce said sour components along with the natural gas to the surface. This treatment method may be called subsurface sour gas desulphurization.

[0005] An object of the present invention is to provide an electro-kinetic treatment process for in-situ upgrading of hydrocarbons produced from a subsurface formation.

SUMMARY OF THE INVENTION

[0006] The invention therefore provides a method for electro-kinetic treatment of a pore fluid comprising hydrocarbon fluid, non-hydrocarbon fluid (e.g. water) and dissolved charged species (e.g. ions) and/or other components in a subsurface formation, the method comprising the steps of:

- transmitting an electric field through the subsurface formation by at least two electrodes traversing the formation; and
- inducing at least one of the charged species and/or other components to flow through the formation under the influence of the electric field, thereby upgrading the hydrocarbon fluid by at least one electro-kinetic effect of the electric field.

The charged species may comprise ions dissolved in water, such as dissociated $NaCl$, H_2S and/or CO_2 , and in such case the method may comprise the steps of:

- providing a production well for the production of the

hydrocarbon fluid from the subsurface formation;

- providing two or more treatment bores at a first distance from the well;
- introducing at least one electrode in each of the treatment bores;
- establishing the electric field between the electrodes in adjacent treatment bores, wherein due to electro-kinetic effects water will flow along the electric field between the electrodes in the adjacent treatment bores, thereby creating a water curtain between the electrodes in the adjacent treatment bores;
- inducing the hydrocarbon fluid to flow towards the production well and through the water curtain,

wherein a mass transfer of the sour components is induced between the pore fluid and the water curtain, thus resulting in a treated hydrocarbon fluid comprising a smaller amount of sour components than initially found in the pore fluid.

[0007] The electro-kinetic effects may comprise Electro-Migration (EM), Electro-Phoresis (EP) and/or Electro-Osmosis (EO).

[0008] Water may be present in, or injected into, the pores of the formation and the electro-kinetic effects comprise Electro-Osmosis (EO), whereby the water is induced to migrate towards one of the electrodes.

[0009] The hydrocarbon fluid may be a sour gas comprising hydrogen sulfide. Using the method of the invention the hydrogen sulfide is dissolved in the flux of pore water that is forming the EO water curtain, thereby upgrading the sour gas by desulphurization and sweetening.

[0010] Water may be introduced into the formation through a borehole comprising or located in the vicinity of one of the electrodes where the introduced water is induced to flow by Electro-Osmotic (EO) effects towards the other electrode carrying opposite charge.

[0011] The sour gas may comprise Hydrogen Sulfide (H_2S) and the injected water may comprise a H_2S scavenger and/or a H_2S oxidizing agent, which oxidizes the H_2S in-situ biologically by catalysis in the presence of micro-organisms, i.e. bio-catalyses.

[0012] The sour gas stream may be induced to flow through the formation in a direction substantially orthogonal to a plane defined by the electrodes and the gas may be produced through a substantially vertical gas production wells. The production well is surrounded by an array of electrodes and the water is flowing, by EO forces, among them forming a water curtain around the production well.

[0013] These and other features, embodiments and advantages of the method according to the invention are described in the accompanying claims, abstract and the following detailed description of non-limiting embodiments depicted in the accompanying drawings, in which description reference numerals are used which refer to corresponding reference numerals that are depicted in the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

Figure 1 shows a plan view of a gas production well according to the present invention which is surrounded by a number of electro-kinetic gas treatment bores which comprise electrodes.

DETAILED DESCRIPTION OF THE DEPICTED EMBODIMENTS

[0015] The electric potential gradient deployment seems to have the prospect to play a role in influencing the flow and transport of fluids and masses in the subsurface. Upon applying an electric potential gradient between electrodes, installed in the subsurface, it will induce the following electro-kinetic effects in one or more of the pore fluids: a) Electro-Migration (EM): where ions fluxes are moving towards electrodes that carry opposite charges; b) Electro-Phoresis (EP): where charged particles are moving towards the electrodes that carry opposite charges; and c) Electro-Osmosis (EO): where net pore fluid, e.g. water, flux moves towards either electrodes depending on the charges of the soil grains. There are several likely scenarios for the electric potential gradient implementation in the subsurface where one or more of the electro-kinetic effects can be utilized.

[0016] Electro-Osmotic flow, synonymous with Electro-Osmosis, is the motion of liquid induced by an applied electric potential gradient across, for instance, a porous and permeable material, or any other fluid conduit. Because Electro-Osmotic velocities can be independent of conduit size, Electro-Osmotic flow is most important when the fluid conduit is relatively small. Electro-Osmotic flow can occur in natural unfiltered water, as well as buffered solutions.

[0017] Electro-Osmotic flow is caused by the Coulomb force induced by an electric field on net mobile electric charge in a solution. Because the chemical equilibrium between a solid surface and an electrolyte solution typically leads to the interface acquiring a net fixed electrical charge, a layer of mobile ions, known as an electrical double layer or Debye layer, forms in the region near the interface. Herein, the solid surface includes, for instance, sand or porous rock of a formation and the electrolyte solution includes water in the formation. When an electric field is applied to the fluid, the net charge in the electrical double layer is induced to move by the resulting Coulomb force. The water, in which the charged particles (e.g., ions) are moving, will move due to the friction forces induced by the moving charged particles. The resulting flow is termed Electro-Osmotic flow (Tikhomolova, K.P., Electro-Osmosis, Ellis Horwood series in physical chemistry, 1993).

[0018] A potential application for the electro-kinetics is in the subsurface desulphurization of sour gas that can be achieved by developing an EO water curtain around

the production well. The water curtain is realized by letting the liquid phase (relatively saline water) to flow between electrodes installed in the subsurface reservoir around the gas production well, utilizing the EO forces, as shown schematically in Figure 1.

[0019] Figure 1 shows a gas production well 1, which is surrounded by an array of, for instance, eight electro-kinetic gas treatment wells 2A to 2H. The wells 2A, 2C, 2E and 2G comprise negatively charged electrodes or cathodes (shown as -) and the wells 2B, 2D, 2F and 2H comprise positively charged electrodes or anodes (shown as +). The treatment wells 2A-2H may be small diameter, low cost wells, wherein the diameter is small and costs are low in comparison to the diameter and costs of the production well 1. The diameter of the treatment wells is preferably just large enough to enclose one or more electrodes. The depth of the treatment wells and the production well 1 preferably extend into the formation to reach the reservoir bottom (i.e., the bedrock).

[0020] When the electrodes are charged as indicated in Figure 1, i.e. intermittently positively and negatively charged with respect to each other, electric fields are established between adjacent electrodes. Due to electro-kinetic effects, water in the formation (i.e., initially found formation water and eventually the water supplied from the positive electrodes) will start to move along the electric fields, thus effectively creating a so-called EO water curtain 4 between the electrodes. While moving towards the production well 1, the gas flow 3 has to go through the EO water curtain 4. At the water curtain the sour hydrocarbon gas flow 3 will contact the water of the water curtain 4. The contact between and the mixing of gas and water favours mass transfer of the sour components (H_2S and/or CO_2) from the gas phase to the water phase. The sour components of the gas flow 3 dissolve and dissociate in the water of the water curtain, so that a treated gas flow 5 having a lower amount of sour components continues towards the production well 1. The water curtain thus sweetens the sour gas stream 3. The dissolved sour components (H_2S and/or CO_2) will be either reacting with a scavenger abiotically or biotically (i.e., catalyzed by the presence of micro-organism) in the water while the reaction products move towards the cathode carried with the water moving by EO or its dissociated species will be moving to either electrodes, depending on their charges, by EM. In both cases, the sour components mass transfer rate from gas to water will be enhanced since both mechanisms provide a sink-like effect for dissolved sour components or its dissociated species in the water phase.

[0021] Salinity of the formation water is an important factor in the design process, since a relatively high formation-water salinity can halt the Electro-Osmotic flow and/or short-circuit the electrodes. In that case, the Electro-Migration transport of dissolved ions, resulting from the dissociation of the sour components, will be the main transport mechanism and the dissociation rate will be the limiting factor for the mass transfer from gas to water.

[0022] When the formation water salinity is relatively

low, the design of the method of the invention starts by estimating the water saturation and salinity, followed by calculating the required steady state current, potential, energy and costs.

[0023] In fact, many reservoirs contain water having a relatively high salinity that will lead to a lower value of the Zeta potential and consequently a smaller Electro-Osmotic permeability value and a higher value of the sub-surface conductivity. The combination of these values will result in higher costs for sweetening the hydrocarbons. In such cases, initial injection of relatively sweet water in the vicinity of the electrodes to dilute the salinity of the formation-water is needed. The water is, for instance, injected via the two or more treatment bores comprising the electrodes

[0024] The exemplary embodiment shown in Figure 1 has eight treatment bores, wherein four of them act as water sinks (cathodes) and the other four act as water sources (anodes).

[0025] Electro-Osmotic forces will drag water from the anodes (positively charged electrodes) to the cathodes (negatively charged electrodes) to form the water curtain 4 around the production well 1.

Utilizing the H_2S dissolution only (about 250 to 300 g/l under typical hydrocarbon reservoir conditions) while using partitioning coefficients under average reservoir conditions, one unit volume of (newly introduced) water could clean up (absorb the H_2S of) at least about 8 unit volumes of sour gas on average. The dissociated ions (e.g. H^+ and HS^-) after the H_2S dissolution will be removed by Electro-Migration (EM) towards the electrodes, decreasing the water resistance to H_2S mass transfer towards water and allowing more dissolution to take place thus increasing the water capacity to absorb more H_2S from the gas. I.e. the EM will act as a sink for the H_2S . If we take into account the Electro-Migration (EM) sink-like effect, i.e. ion movements due to an electric potential gradient, in addition to H_2S dissolution in water, a sweetening ratio of about 1:10 could be obtained since the mobility of the ions is, at least, one order of magnitude higher than the water mobility (permeability) by EO [Virkyte, J., Sillanpaa, M., Latostenmaa, P., 2002, Electrokinetic soil remediation-critical overview, Sci. Total Environ. 289, 97-121.].

[0026] In a practical embodiment for the production of gaseous hydrocarbons from a formation, the electrodes of the treatment bores 2A-2H may be arranged at a substantially similar first distance d_1 with respect to the production well 1. The treatment bores may be arranged at a substantially regular mutual spacing d_2 . The first distance is for instance in the range of 30 m to 80 m, for instance about 50 m. The mutual spacing may be in the range of 20 m to 60 m, for instance about 40 m. The electric field needed to establish a water curtain 4 suitable to lower the amount of sour components in the stream 3 of pore fluid may be in the range of 0.5 to 10 V/cm, for instance about 3 to 5 V/cm. Electric current may be in the range of 1 to 10 kAmps, for instance 1.1 to 3.5 kAmps.

In an average sour gas reservoir, the electric power needed to sweeten one m^3 of gas may be ranging from a fraction of to several kW.hr/ m^3 depending on the reservoir characteristics.

[0027] Calculations indicate that, with a proper design of the treatment process, it is possible to develop an EO water curtain 4 around the production well 1 that can mix with the sour gas favouring its sweetening economically. Economically herein may indicate that the costs related to the water curtain are comparable to or lower than the costs related to conventional gas treating above the surface. The method of the present invention may reduce the amount of sour components in the pore fluid by, for instance, 10% to 50% with respect to the initial amount. Treatment facilities at surface may still be required to reduce the amount of sour components further to predetermined specifications. But the method of the invention enables the use of facilities at surface having significantly reduced CAPEX, for instance, due to lower corrosion and reduced safety hazards.

[0028] Cost factors for establishing the water curtain include for instance the costs of drilling a number of treatment bores, introducing electrodes, consumed electrical power, pumping facilities to introduce water in the treatment bores and the water introduced in the treatment bores for the duration of the project.

[0029] The method according to the invention may comprise the following steps:

- Relatively sweet water is being injected once, when needed, at the beginning of the treatment process from the treatment wells 2A-2H to dilute the salinity of the matrix water, i.e. the water which is initially found in the reservoir, in order to avoid short-circuiting between adjacent electrodes with opposite polarities + and -.
- Gas production is starting while the electric potential between electrodes + and - is applied to mobilize water by EO between the electrodes and develop the EO water curtain 4 between two or more of the treatment wells and at least partly around the production well 1.
- Depending on the sub-surface matrix (grains) charge type, water will be moving towards one of the electro-kinetic gas treatment wells 2A-2H. Here, it is assumed that the formation matrix is negatively charged thus the water EO net flux will be towards the treatment wells having a negatively charged electrode, i.e. a cathode.
- Initially, water may be kept inside the electro-kinetic gas treatment wells 2B, 2D, 2F and 2H under balance with the reservoir pressure. Subsequently, water is being supplied to the treatment wells having a positively charged electrode, i.e. an anode, to compensate for the water being dragged inside the sub-surface matrix by the EO flow towards the cathodes.
- On pore scale, the gas as a non-wetting phase will be mainly flowing in the middle of the bigger pores

while water as a wetting phase will be flowing in the smaller pores and nearby grains surfaces (Dake, L.P., Fundamentals of Reservoir Engineering, 1978, Elsevier.). By accomplishing this, the possible contact area between water and gas will increase, thus enhancing mass transfer of the sour components (H_2S and/or CO_2) from the gas to the water phase.

- The dissolved sour components, its dissociated species and reaction products will be moving to either electrode wells 2A-2H depending on their charge status and type by EO and/or by EM. A proper disposal methods for the water containing different species at each electrode well 2A-2H is designed, e.g., disposal by gravity (free fall) at the cathode or disposal to a different sub-surface layer at the anode.
- The treatment process can be optimized by the use of numerical simulations that utilizes real values for the different designing parameters measured before and during the treatment process.

[0030] The method according to the invention may be used for sour gas sweetening, wherein

- The sour gas content in the produced natural gas is reduced in situ (in the sub-surface), thereby minimizing the exposure to sour components leading to a considerable expenditure reduction on surface facilities and Health-Safety-Environmental (HSE) related issues.
- A water curtain surrounding the sour gas production well can be developed by applying an electrical potential gradient between pairs of electrodes in an array of electrodes where the water is flowing by Electro-Osmosis.
- Gas-water mixing is maximized by providing a considerable surface area between the two phases and introducing "new" water in the matrix between the electrodes (as explained earlier).
- With an appropriate engineering design and management of the treatment process and the reservoir electro-kinetic properties, e.g., electro-osmotic permeability and conductivity, the needed electric potentials, currents and energy can be optimized leading to even more economically sound treatment option.
- Submerged pumps may be used to periodically flush the water accumulated inside the electrodes, which includes diverse species, to the bottom of the reservoir or to another deeper or shallower formations.
- Abiotic (e.g., Scavengers) or biotic (e.g., bacteria) sour component scavengers can be added to the water moving between the electrodes and forming the EO water curtain 4 to increase the water capacity

in cleaning the sour gas and consequently minimize the needed volume of water and energy for the treatment process.

[0031] The method according to the invention may also be applied for other applications, such as:

- Installation of an array of electrodes around a gas production well to mobilize or remove water by electro-osmosis (EO) to avoid well impairment in hydrocarbon reservoirs.
- Mobilization of nano-particles, micro-organisms and/or surfactant monomers into certain zones and directions into the subsurface formation by electro-kinetic effects to enhance the hydrocarbon productivity, e.g. surfactant monomers drag into fractured carbonate reservoirs to change its wettability to water, or help in reservoir surveillance activities can be included in this patent.
- Production of gases, e.g. oxygen and hydrogen, nearby the electrodes by water electrolysis can be used in hydrocarbon productivity enhancement, e.g. stimulating biodegradation of bigger molecules into smaller ones in the case of oil-sand production. On the other hand, the H_2S gas can be oxidized by oxygen in the gas phase nearby the cathode electrodes.
- Any combination of part or all of the above applications.

[0032] The method of the present invention is not limited to the above-described embodiments thereof, wherein many modifications are conceivable within the scope of the appended claims.

Claims

1. A method for electro-kinetic treatment of a pore fluid comprising hydrocarbon fluid, non-hydrocarbon fluid and dissolved charged species and/or other components in a subsurface formation, the method comprising the steps of:
 - transmitting an electric field through the subsurface formation by at least two electrodes traversing the formation; and
 - inducing at least one of the charged species and/or other components to flow through the formation under the influence of the electric field, thereby upgrading the hydrocarbon fluid by at least one electro-kinetic effect of the electric field.
2. The method of claim 1, wherein the non-hydrocarbon fluid comprises water, the charged species comprise ions dissolved in the water and the other components comprise sour components, such as disso-

ciated H₂S and/or CO₂, and the method comprises the steps of:

- providing a production well for the production of the hydrocarbon fluid from the subsurface formation; 5
 - providing two or more treatment bores at a selected distance from the production well;
 - introducing at least one electrode in each of the treatment bores; 10
 - establishing the electric field between the electrodes in adjacent treatment bores, wherein due to electro-kinetic effects at least a fraction of the water will flow, as a curtain of water, moving along the electric field between the electrodes in the adjacent treatment bores; and 15
 - inducing the hydrocarbon fluid to flow towards the production well and through the moving water curtain, wherein a mass transfer of the sour components is induced between the pore fluid and the curtain of moving water, thus resulting in a treated hydrocarbon fluid comprising a smaller amount of sour components than initially found in the pore fluid. 20
3. The method of claim 1 or 2, wherein the electro-kinetic effects comprise Electro-Migration (EM), Electro-Phoresis (EP) and/or Electro-Osmosis (EO). 25
 4. The method of claim 2, wherein the water is connate water initially present in, or injected through at least one of the treatment wellbores into, the pores of the formation and the electro-kinetic effects comprise Electro-Osmosis (EO), whereby the water is induced to flow towards one of the electrodes to form an EO water curtain between the electrodes. 30
 5. The method of any one of claim 1-4, wherein the hydrocarbon fluid comprises gaseous hydrocarbons. 40
 6. The method of claim 5, wherein the hydrocarbon fluid is a sour hydrocarbon gas comprising sour components, e.g., hydrogen sulfide (H₂S) and/or carbon dioxide (CO₂), wherein the sour components are dissolved in a flux of water created by the EO water curtain, thereby upgrading the sour gas by desulfurization and sweetening. 45
 7. The method of claim 4, wherein at least part of the water is introduced into the formation through one or more of the treatment bores and the introduced new water is induced to flow by Electro-Osmotic (EO) effects towards the electrode of one or more of the other treatment bores. 50
 8. The method of claim 7, wherein the sour gas comprises sour components and the introduced water 55
- comprises a scavenger or comprises an oxidizing agent, which scavenges and/or oxidizes the sour components in-situ in the presence of micro-organisms that act as a catalyzer.
9. The method of any of the previous claims, wherein the hydrocarbon fluid is induced to flow through the formation in a direction substantially orthogonal to a plane defined by the electrodes.
 10. The method of any of the previous claims, wherein the hydrocarbon fluid is produced through a substantially vertical gas production well, which is surrounded by an array of treatment bores comprising electrodes.
 11. The method of claim 10, wherein the array comprises an even number of electrodes and adjacent electrodes have opposite polarities.
 12. The method of claim 2, wherein the electrodes of the treatment bores are arranged at a substantially similar distance from the production well and at a substantially regular mutual spacing.
 13. The method of claim 12, wherein the distance is in the range of 30 m to 80 m, for instance about 50 m.
 14. The method of claim 12, wherein the mutual spacing is in the range of 20 m to 60 m, for instance about 40 m.
 15. The method of any one of claims 1-14, wherein the electric field has a strength in the range from 0.5 to 10 V/cm, for instance between 3 and 5 V/cm.

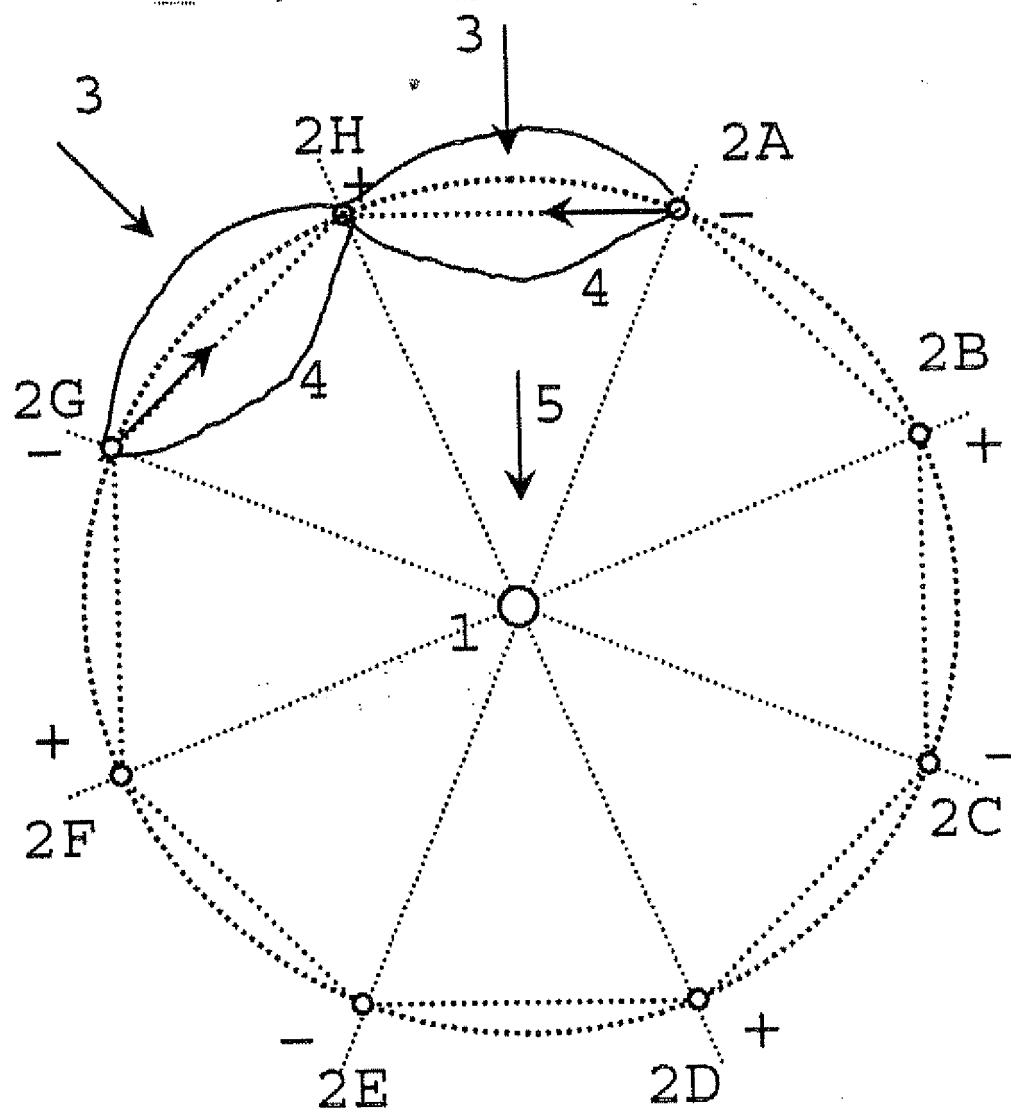


Figure 1



EUROPEAN SEARCH REPORT

Application Number
EP 10 15 7025

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A	EP 0 312 174 A1 (HYDRACONSULT BV [NL]) 19 April 1989 (1989-04-19) * claim 1; figure 3 * -----	1-15	TECHNICAL FIELDS SEARCHED (IPC)
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 2 July 2010	Examiner Strømmen, Henrik
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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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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