

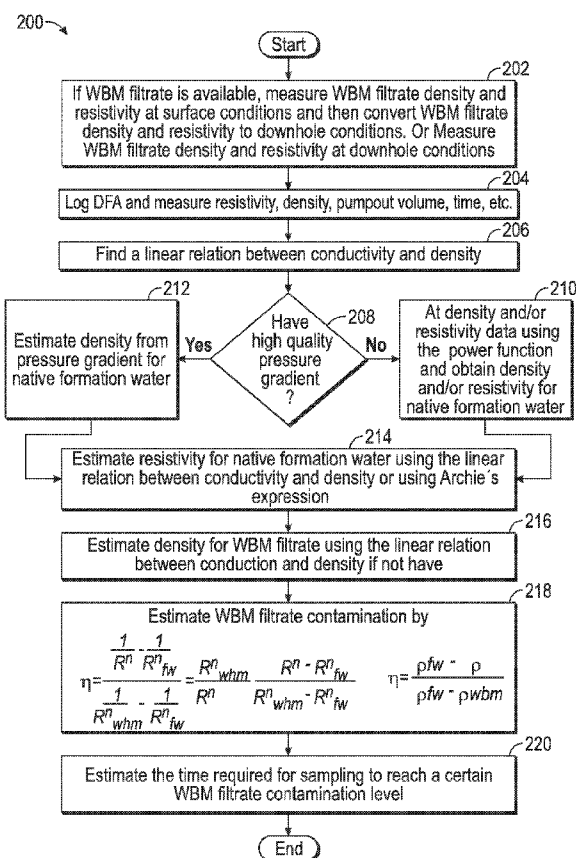


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[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR WATER-BASED MUD FILTRATE CONTAMINATION MONITORING IN REAL TIME DOWNHOLE WATER SAMPLING

(57) Abstract: A method and apparatus for performing water based mud-filtrate contamination monitoring in real time through evaluation of downhole water sampling.





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METHOD AND APPARATUS FOR WATER-BASED MUD FILTRATE CONTAMINATION MONITORING IN REAL TIME DOWNHOLE WATER SAMPLING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from US Non-Provisional Application 14/085550, filed November 20, 2013, which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] Aspects of the disclosure relate to contamination monitoring. More specifically, aspects of the disclosure relate to method and apparatus for water-based mud filtrate contamination monitoring in real time downhole water sampling.

BACKGROUND INFORMATION

[0003] Water based drilling mud filtrate contamination monitoring is a large challenge in downhole formation water sampling. Currently, there are no conventional downhole real time methods available for quantitative water based drilling mud filtrate contamination monitoring during water sampling with the lone exception of using special dyes mixed with the water based drilling mud.

[0004] Use of special dyes adds complexity to drilling operations. Dyes added should be compatible with the drilling mud and the formation and fluids for the formation that are expected to be extracted. Some dyes can be expensive and additional work is required for injection of the dye into the fluid stream.

[0005] Special dyes are expensive for operators in other ways as operators need time to add the dye to wellbore mud systems as rig time can be very constrained. These special dyes, because of the complexities described above, are carefully crafted such that they provide minimal harm from a technological and cost perspective.

SUMMARY

[0006] The following summary is but an example description of one embodiment described. The disclosure in the summary should not be considered limiting. A method for contamination monitoring is described entailing measuring a water based mud filtrate density and a water based mud filtrate resistivity at surface conditions, converting the measured water based mud filtrate density and resistivity to downhole conditions, logging properties of a downhole fluid to find at least a resistivity and a density of a fluid sample at the downhole conditions, establishing a linear relationship between a water based mud filtrate conductivity at downhole conditions and the water based mud density at the downhole conditions, determining an existence of a high quality pressure gradient at the downhole conditions, fitting at least one of a density and a resistivity data using a power function and obtaining at least one of a density and a resistivity for native formation water when no high quality pressure gradient exists, estimating a density from the pressure from the high quality gradient when the high quality pressure gradient exists; estimating a resistivity for native formation water, using the linear relationship between the conductivity and the density, estimating a density for water based mud filtrate using the linear relationship between conductivity and density and estimating a water based mud filtrate contamination.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a graph of density versus conductivity for water sampling with water based mud in real time.

[0008] FIG. 2 is a flowchart for a method of water based mud filtrate contamination modeling.

[0009] FIG. 3 is graph of resistivity variation measurement over pumpout volume obtained.

[0010] FIG. 4 is a graph of water based filtrate contamination monitoring versus pumpout volume obtained.

[0011] FIG. 5 is a graph of density in the sample line versus pumpout volume obtained.

[0012] FIG. 6 is a graph of contamination percentage water based contamination versus pumpout volume obtained.

[0013] FIG. 7 is a graph of conductivity versus pumped volume.

[0014] FIG. 8 is a graph of contamination percentage versus pumped volume.

DETAILED DESCRIPTION

[0015] Aspects described relate to a method and apparatus for water-based mud filtrate contamination monitoring in real time downhole water sampling. The method and system provided are used in downhole apparatus in the exploration of oil and gas in geological formations. Such techniques greatly enhance the capability of engineers and operators to economically find hydrocarbons beneath the ground surface.

[0016] For the purposes of this detailed description, it is assumed that the fluid in the downhole flowline consist of two components: water based mud filtrate and native formation water. The following mixing rule can be used for resistivity:

$$\frac{1}{R^n} = \frac{\eta}{R_{whm}^n} + \frac{1-\eta}{R_{fw}^n} \quad \text{Equation 1}$$

where R , η , R_{whm} and R_{fw} are the resistivity of the mixture (water based mud filtrate and formation water – formation water contaminated by water based mud filtrate), water based mud filtrate contamination fraction, resistivity of the pure water based mud filtrate and resistivity of the native formation water. The value n is an exponent (default $n = 1$), which may be used as an adjustable parameter.

[0017] Rearranging Equation 1 above, the result obtained is the water based mud filtrate contamination based on resistivity measured by downhole fluid analysis:

$$\eta = \frac{\frac{1}{R^n} - \frac{1}{R_{fw}^n}}{\frac{1}{R_{whm}^n} - \frac{1}{R_{fw}^n}} = \frac{R_{whm}^n}{R^n} \frac{R^n - R_{fw}^n}{R_{whm}^n - R_{fw}^n} \quad \text{Equation 2}$$

where R is measured by downhole fluid analysis during water sampling, which is a function of time (or pumpout volume). In Equation 2, two endpoints – resistivity of pure water based mud filtrate (R_{whm}) and native formation water (R_{fw}) should be known to obtain η . It should be noted that resistivity contrast between the pure water based mud filtrate and native formation water should be sufficient in order to use Equation 2.

[0018] Below is a description of using density for water based mud filtrate contamination monitoring. The contaminated fluid is divided into two components, the pure water based mud filtrate and the native formation water. It is assumed that the mixing of the water based mud filtrate and native formation water is ideal, i.e. producing no excess volume during mixing:

$$V^{mol} = x_{wbm} V_{wbm}^{mol} + (1 - x_{wbm}) V_{fw}^{mol} \quad \text{Equation 3}$$

where V^{mol} and x are the molar volume and mole fraction. Subscripts wbm and fw represent the pure water based mud filtrate and native formation water. The molar volume and mole fraction can be changed into density (ρ) and water based mud filtrate contamination volume fraction (η) at downhole conditions by:

$$\rho = \eta \rho_{wbm} + (1 - \eta) \rho_{fw} \quad \text{Equation 4}$$

[0019] Rearranging Equation 4, the water based mud filtrate contamination volume fraction is expressed as:

$$\eta = \frac{\rho_{fw} - \rho}{\rho_{fw} - \rho_{wbm}} \quad \text{Equation 5}$$

The value η can be related to the weight fraction of water based mud filtrate contamination at downhole conditions by:

$$w_{wbm} = \frac{\eta \rho_{wbm}}{\rho} = \frac{\rho_{wbm}(\rho_{fw} - \rho)}{\rho(\rho_{fw} - \rho_{wbm})} \quad \text{Equation 6}$$

[0020] In Equations 5 and 6, two endpoints- densities of pure water based mud filtrate (ρ_{wbm}) and native formation water (ρ_{fw}) should be known to obtain η . Density contrast between the pure water based mud filtrate and native formation water are sufficient in order to use Equations 5 and 6 for water based mud filtrate contamination monitoring.

Equalizing Equations 2 and 5:

$$\eta = \frac{\frac{1}{R_{wbm}^n} - \frac{1}{R_{fw}^n}}{\frac{1}{R_{wbm}^n} - \frac{1}{R_{fw}^n}} = \frac{\rho_{fw} - \rho}{\rho_{fw} - \rho_{wbm}} \quad \text{Equation 7}$$

[0021] For specified water based mud filtrate and formation water, the resistivity (R_{wbm} and R_{fw}) and density (ρ_{wbm} and ρ_{fw}) of the pure water based mud filtrate and native formation water are fixed. Therefore, density (ρ) and reciprocal of resistivity (conductivity, $1/R$) is linear (assuming $n=1$). FIG. 1 shows the real time results of density versus conductivity. It should be noted that this linear relation is very useful for determining endpoints for native formation water and/or pure water based mud filtrate. This also constrains exponent in the power function fitting model as provided below.

[0022] The two endpoints for pure water based mud filtrate and native formation water are determined. A determination of resistivity and density of pure water based mud filtrate (R_{wbm} and ρ_{wbm}) occurs. To obtain the endpoints for pure water based mud filtrate entails measuring the resistivity and density of the pure water based mud filtrate

on the surface if pure water based mud filtrate is available before logging at different temperatures and pressure covering the entire set of reservoir conditions. Next, the measured resistivity and density of the pure water based mud filtrate are correlated with the following functions of temperature and pressure:

$$R_{wbm} = \sum_{i=0}^2 \sum_{j=0}^1 a_{ij} P^i T^j \quad \text{Equation 8}$$

$$\rho_{wbm} = \sum_{i=0}^2 \sum_{j=0}^1 b_{ij} P^i T^j \quad \text{Equation 9}$$

where a_{ij} 's and b_{ij} 's are coefficients of the polynomial functions, which are regressed by matching the measured resistivity and density data on the surface for different types of water based mud filtrates.

[0023] In another embodiment, the resistivity of pure water based mud filtrate is measured at surface conditions and converted to flowline conditions. The density of pure water based mud filtrates is measured at surface conditions and converted to flowline conditions.

[0024] Next, the linear relationship between reciprocal of resistivity (conductivity) and density can be used to estimate either density or resistivity of the pure water based mud filtrate if resistivity or density of the pure water based mud filtrate is known. Downhole cleanup data may be used.

[0025] At the beginning of cleanup, 100% water based mud filtrate may be pumped in a flowline. The downhole fluid analysis measured resistivity and density at the beginning of cleanup may be considered as the resistivity and density of the pure water based mud filtrate. In particular, when multiple downhole fluid analysis stations are available or when the filtrate invasion is very deep, a reasonable value may be measured or estimated.

[0026] Resistivity and density of native formation water (R_{fw} and ρ_{wf}) may be determined. The density of native formation water can be determined as follows:

- a) Pretest pressure (pressure gradient) data can be used to determine density of the native formation water-density endpoint for the native formation water, or
- b) During cleanup, live formation water density can also be fitted by the following power function:

$$\rho = \rho_{wf} - \beta V^{-\gamma} \quad \text{Equation}$$

10

where ρ and V are the density and pumpout volume (can be replaced by time t) measured by downhole fluid analysis; ρ_{wf} , β and γ are three adjustable parameters. Once good density data regression is obtained, density (ρ_{wf}) for the native formation water can be extrapolated when the pumpout volume (time) approaches infinity. For focus sampling, V can be replaced by the volume in the sample line (and/or guard line) or by the total volume (summation of sample and guard line volumes). In this case, ρ is replaced by (subscripts s and g stand for sample and guard, Q is the flowrate):

$$\rho = \frac{\rho_s Q_s + \rho_g Q_g}{Q_s + Q_g} \quad \text{Equation}$$

11

[0027] The resistivity of native formation water can be determined as follows:

- a) The resistivity of native formation water can be determined by the linear relationship between reciprocal of resistivity (conductivity) and density once density is determined by the method mentioned previously.
- b) The resistivity of native formation water may be estimated from Archies expression by assuming a clean sandstone formation for which m and n have the value of 2 and $S_w=1$.

$$R_{wf} = \frac{1}{a} \varphi^m S_w^n R_t \approx \frac{1}{.81} \varphi^2 R_t \quad \text{Equation 12}$$

where φ is the formation porosity and R_t is the formation resistivity, which can be measured by conventional wireline logs.

c) The resistivity of native formation water can be determined by the fitting model as done for density:

$$\frac{1}{R} = \frac{1}{R_{wf}} - \beta V^{-\gamma} \quad \text{Equation 13}$$

where R and V are the resistivity and pumpout volume (can be replaced by time t) measured by downhole fluid analysis; R_{wf} , β and γ are three adjustable parameters. Once resistivity data regression is obtained, resistivity (R_{wf}) for the native formation water can be extrapolated when the pumpout volume (time) approaches infinity. For the focus sampling, V can be replaced by the volume in the sample line (and/or guard line) besides total volume (summation of sample and guard line volumes). In this case R is replaced by (subscripts s and g stand for sample and guard, Q is the flow rate):

$$\frac{1}{R} = \frac{\frac{1}{R_s} Q_s + \frac{1}{R_g} Q_g}{Q_s + Q_g} \quad \text{Equation 14}$$

[0028] It should be noted that the linear relationship between reciprocal of resistivity (conductivity) and density constrains the exponent (γ) in the equations above. This means that γ is the same value.

Additionally, the resistivity of native formation water may be directly fitted by:

$$R = R_{wf} - \beta V^{-\gamma'} \quad \text{Equation 13}$$

[0029] Once the two endpoints of resistivity and/or density are obtained, Equations 2 and 5 can be used to estimate water based mud filtrate contamination in water samples. The time required for sampling to reach a certain water based mud filtrate contamination level can be calculated by:

$$\Delta t = \frac{\Delta V}{Q_{\text{pump}}} \quad \text{Equation 14}$$

where Δt , ΔV and Q_{pump} are the time required to reach a specified water based mud filtrate contamination level, the pumpout volume required to reach the specified water based mud filtrate contamination level, and the pumpout volume flowrate (assuming to be constant).

[0030] Referring to FIG. 2, an example method **200** of performing the analysis presented above is provided. In **202**, if water based mud filtrate is available, the water based mud filtrate density and resistivity are measured as surface conditions and then converted to downhole conditions. In another embodiment, the water based mud filtrate density and resistivity conditions are measured downhole. In **204**, downhole fluid analysis is logged and resistivity, density, pumpout volume and time are logged. In **206**, a linear relationship is found between conductivity and density. In **208**, a decision is made whether there is a high quality pressure gradient. If there is no high pressure gradient, the method moves to **210** where the density is fit and/or resistivity data using the power function and the density is obtained and/or resistivity for native formation water. The method then progresses to **214**. If the high pressure quality pressure gradient is available in **208**, then in **212** density is estimated from the pressure gradient for native formation water. The method then progresses to **214**. In **214**, resistivity is estimated for native formation water using the linear relation between conductivity and density or using Archie's expression. In **216**, density is estimated for water based mud filtrate using the linear relation between conduction and density. In **218**, water based mud filtrate contamination is estimated. In **220**, the time required for sampling to reach a certain water based mud filtrate contamination level is estimated.

[0031] Referring to FIG. 3, the density and resistivity of the pure mud filtrate are obtained from downhole measurements at the beginning of clean up due to deep invasion. The endpoints of the native formation water are determined as follows. Resistivity variation with pumpout volume is shown in FIG. 3. The power function fitting curves are illustrated in FIG. 3. The fitting is done for the sample and guard lines respectively. Therefore, the resistivity of the native formation water is obtained from the fitting curves.

[0032] Referring to FIG. 4, water based mud filtrate contamination is estimated where contamination percentage is on the Y axis and volume is provided on the X axis.

[0033] Referring to FIG. 5, density fitting in the sample line is shown. Density in the guard line is not measured. The density of the native formation water is obtained from the fitting curve. Density is provided on the Y axis and volume is described in the X axis.

[0034] The estimated water based mud filtrate contamination in the sample line based on the density mixing rule is provided in FIG. 6. The contamination percentage in the Y axis is compared to the volume in the X axis.

[0035] The resistivity of the native formation water can be determined from total conductivity fitting. Referring to FIG. 7, the power function fitting for the total conductivity of the combined sample and guard lines is shown. The density and conductivity cross plot is given in FIG. 1. Once either the density or conductivity of the native formation water, the cross plot can be used to obtain either conductivity or density of the native formation water. The Y axis of the plot provides conductivity and the X axis of the plot refers to pumped volume.

[0036] Referring to FIG. 8, a comparison of the water based mud filtrate contamination estimated by the above described method is performed in the sample and guard lines. The curves stand for the water based mud filtrate contamination estimated by the

resistivity and density mixing rules provided above. As can be seen, the sample line cleans up faster than the guard line.

[0037] In one example embodiment, a method for contamination monitoring is provided comprising measuring a water based mud filtrate density and a water based mud filtrate resistivity at surface conditions, converting the measured water based mud filtrate density and resistivity to downhole conditions; logging properties of a downhole fluid to find at least a resistivity and a density of a fluid sample at the downhole conditions, establishing a linear relationship between a water based mud filtrate conductivity at downhole conditions and the water based mud density at the downhole conditions, determining an existence of a high quality pressure gradient at the downhole conditions, fitting at least one of a density and a resistivity data using a power function and obtaining at least one of a density and a resistivity for native formation water when no high quality pressure gradient exists, estimating a density from the pressure from the high quality gradient when the high quality pressure gradient exists, estimating a resistivity for native formation water, using the linear relationship between the conductivity and the density, estimating a density for water based mud filtrate using the linear relationship between conductivity and density and estimating a water based mud filtrate contamination.

[0038] The method may also be accomplished wherein the estimating the resistivity for native formation water is performed using the linear relationship between the conductivity and the density.

[0039] The method may also be accomplished wherein the estimating the resistivity for native formation water is performed using Archie's expression.

[0040] The method may also be accomplished wherein the method further comprises estimating a time required for sampling to reach a water based mud filtrate contamination level.

[0041] The method may also be accomplished wherein the estimating the water based mud filtrate contamination is performed through an equation:

$$\eta = \frac{\frac{1}{R^n} - \frac{1}{R_{fw}^n}}{\frac{1}{R_{wbm}^n} - \frac{1}{R_{fw}^n}} = \frac{\rho_{fw} - \rho}{\rho_{fw} - \rho_{wbm}} .$$

[0042] The method may also be accomplished, wherein the determining the existence of the high quality pressure gradient at the downhole conditions is performed through downhole pretests.

[0043] In another example embodiment, a method for contamination monitoring is provided, comprising measuring water based mud filtrate density and resistivity at downhole conditions; logging properties of a downhole fluid to find at least a resistivity and a density of a fluid sample at the downhole conditions, establishing a linear relationship between a water based mud filtrate conductivity at downhole conditions and the water based mud density at the downhole conditions, determining an existence of a high quality pressure gradient at the downhole conditions, fitting at least one of a density and a resistivity data using a power function and obtaining at least one of a density and a resistivity for native formation water when no high quality pressure gradient exists, estimating a density from the pressure from the high quality gradient when the high quality pressure gradient exists, estimating a resistivity for native formation water, using the linear relationship between the conductivity and the density, estimating a density for water based mud filtrate using the linear relationship between conductivity and density, and estimating a water based mud filtrate contamination.

[0044] In another example embodiment, the method is accomplished wherein the estimating the resistivity for native formation water is performed using the linear relationship between the conductivity and the density.

[0045] In another example embodiment, the method is accomplished wherein the estimating the resistivity for native formation water is performed using Archie's expression.

[0046] In another example embodiment, the method described above may further comprise estimating a time required for sampling to reach a water based mud filtrate contamination level.

[0047] In another example embodiment, the method described above may be accomplished wherein the estimating the water based mud filtrate contamination is performed through an equation:

$$\eta = \frac{\frac{1}{R^n} - \frac{1}{R_{fw}^n}}{\frac{1}{R_{wbm}^n} - \frac{1}{R_{fw}^n}} = \frac{\rho_{fw} - \rho}{\rho_{fw} - \rho_{wbm}} .$$

[0048] In another example embodiment, the method described above may be accomplished wherein the determining the existence of the high quality pressure gradient at the downhole conditions is performed through downhole pretests.

[0049] While the aspects have been described with respect to a limited number of embodiments, those skilled in the art, having benefit of the disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the disclosure herein.

What is claimed is:

1. A method for contamination monitoring, comprising:
 - measuring a water based mud filtrate density and a water based mud filtrate resistivity at surface conditions;
 - converting the measured water based mud filtrate density and resistivity to downhole conditions;
 - logging properties of a downhole fluid to find at least a resistivity and a density of a fluid sample at the downhole conditions;
 - establishing a linear relationship between a water based mud filtrate conductivity at downhole conditions and the water based mud density at the downhole conditions;
 - determining an existence of a high quality pressure gradient at the downhole conditions;
 - fitting at least one of a density and a resistivity data using a power function and obtaining at least one of a density and a resistivity for native formation water when no high quality pressure gradient exists;
 - estimating a density from the pressure from the high quality gradient when the high quality pressure gradient exists;
 - estimating a resistivity for native formation water, using the linear relationship between the conductivity and the density;
 - estimating a density for water based mud filtrate using the linear relationship between conductivity and density; and
 - estimating a water based mud filtrate contamination.
2. The method according to claim 1, wherein the estimating the resistivity for native formation water is performed using the linear relationship between the conductivity and the density.
3. The method according to claim 1, wherein the estimating the resistivity for native formation water is performed using Archie's expression.

4. The method according to claim 1, further comprising:
 estimating a time required for sampling to reach a water based mud filtrate contamination level.

5. The method according to claim 1, wherein the estimating the water based mud filtrate contamination is performed through an equation:

$$\eta = \frac{\frac{1}{R^n} - \frac{1}{R_{fw}^n}}{\frac{1}{R_{wbm}^n} - \frac{1}{R_{fw}^n}} = \frac{\rho_{fw} - \rho}{\rho_{fw} - \rho_{wbm}} .$$

6. The method according to claim 1, wherein the determining the existence of the high quality pressure gradient at the downhole conditions is performed through a downhole pretest.

7. A method for contamination monitoring, comprising:

measuring water based mud filtrate density and resistivity at downhole conditions;

logging properties of a downhole fluid to find at least a resistivity and a density of a fluid sample at the downhole conditions;

establishing a linear relationship between a water based mud filtrate conductivity at downhole conditions and the water based mud density at the downhole conditions;

determining an existence of a high quality pressure gradient at the downhole conditions;

fitting at least one of a density and a resistivity data using a power function and obtaining at least one of a density and a resistivity for native formation water when no high quality pressure gradient exists;

estimating a density from the pressure from the high quality gradient when the high quality pressure gradient exists;

estimating a resistivity for native formation water, using the linear relationship between the conductivity and the density;

estimating a density for water based mud filtrate using the linear relationship between conductivity and density; and
estimating a water based mud filtrate contamination.

8. The method according to claim 7, wherein the estimating the resistivity for native formation water is performed using the linear relationship between the conductivity and the density.
9. The method according to claim 7, wherein the estimating the resistivity for native formation water is performed using Archie's expression.
10. The method according to claim 7, further comprising:
estimating a time required for sampling to reach a water based mud filtrate contamination level.
11. The method according to claim 7, wherein the estimating the water based mud filtrate contamination is performed through an equation:

$$\eta = \frac{\frac{1}{R^n} - \frac{1}{R_{fw}^n}}{\frac{1}{R_{wbm}^n} - \frac{1}{R_{fw}^n}} = \frac{\rho_{fw} - \rho}{\rho_{fw} - \rho_{wbm}} .$$

12. The method according to claim 7, wherein the determining the existence of the high quality pressure gradient at the downhole conditions is performed through a downhole pretest.

1/5

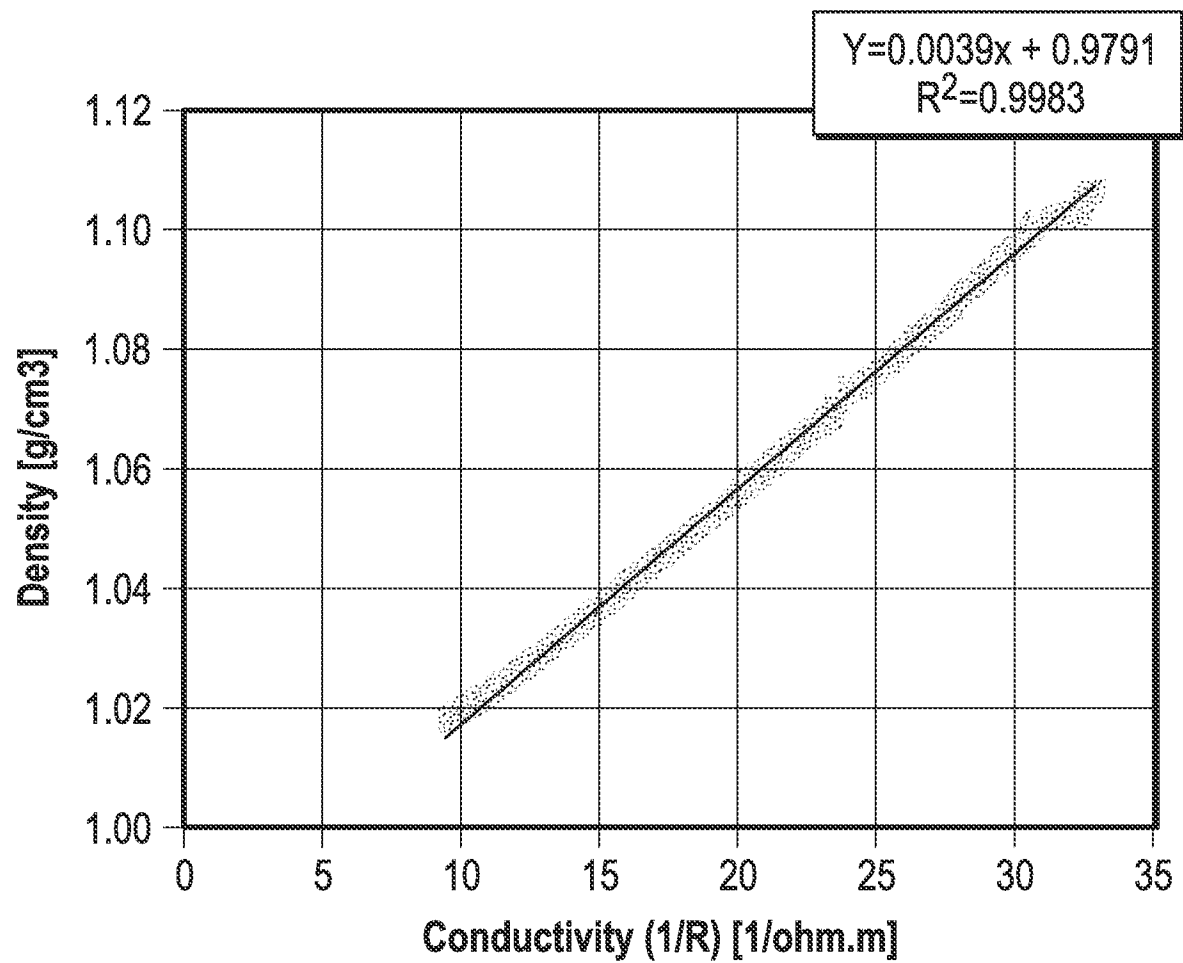


FIG. 1

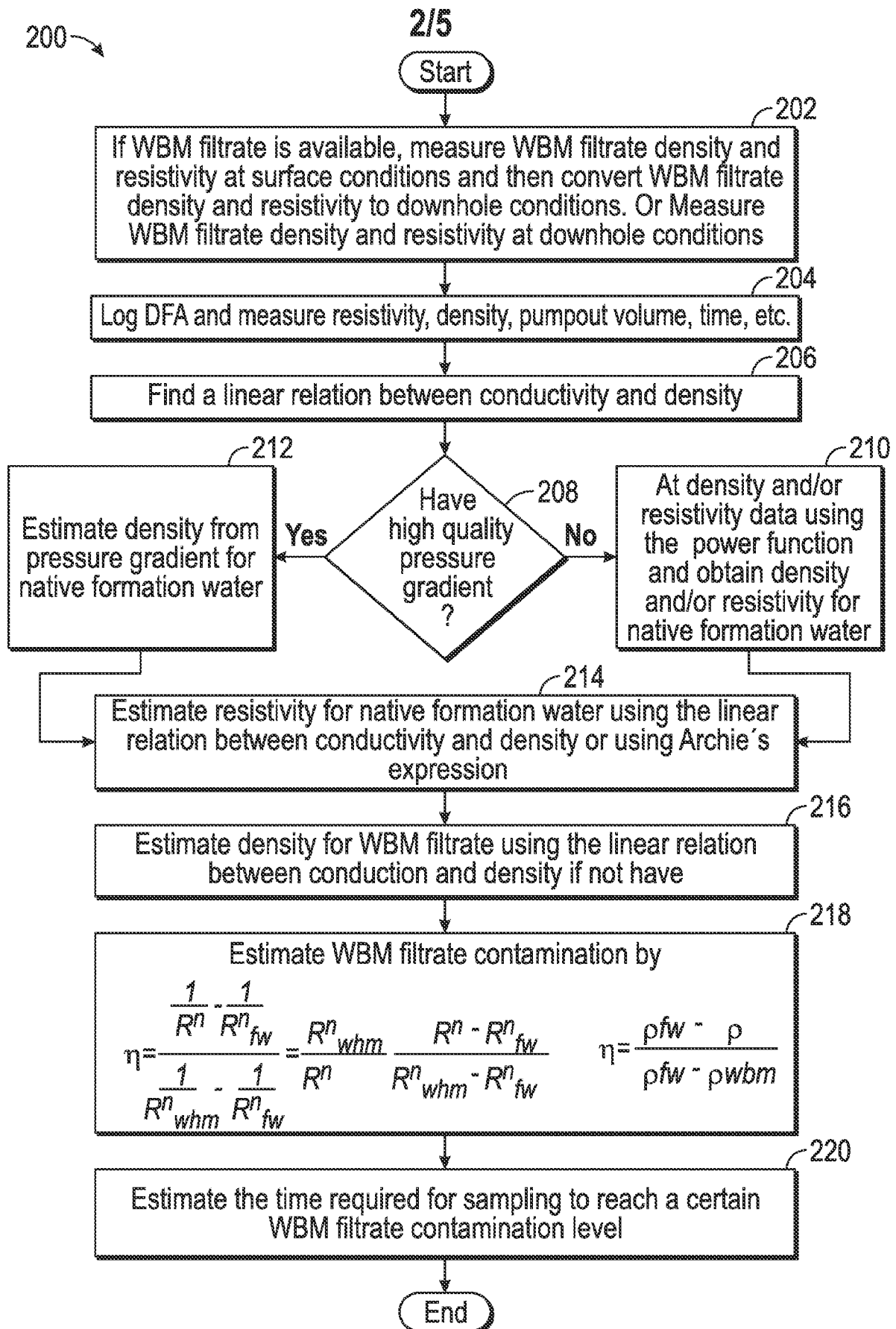


FIG. 2

3/5

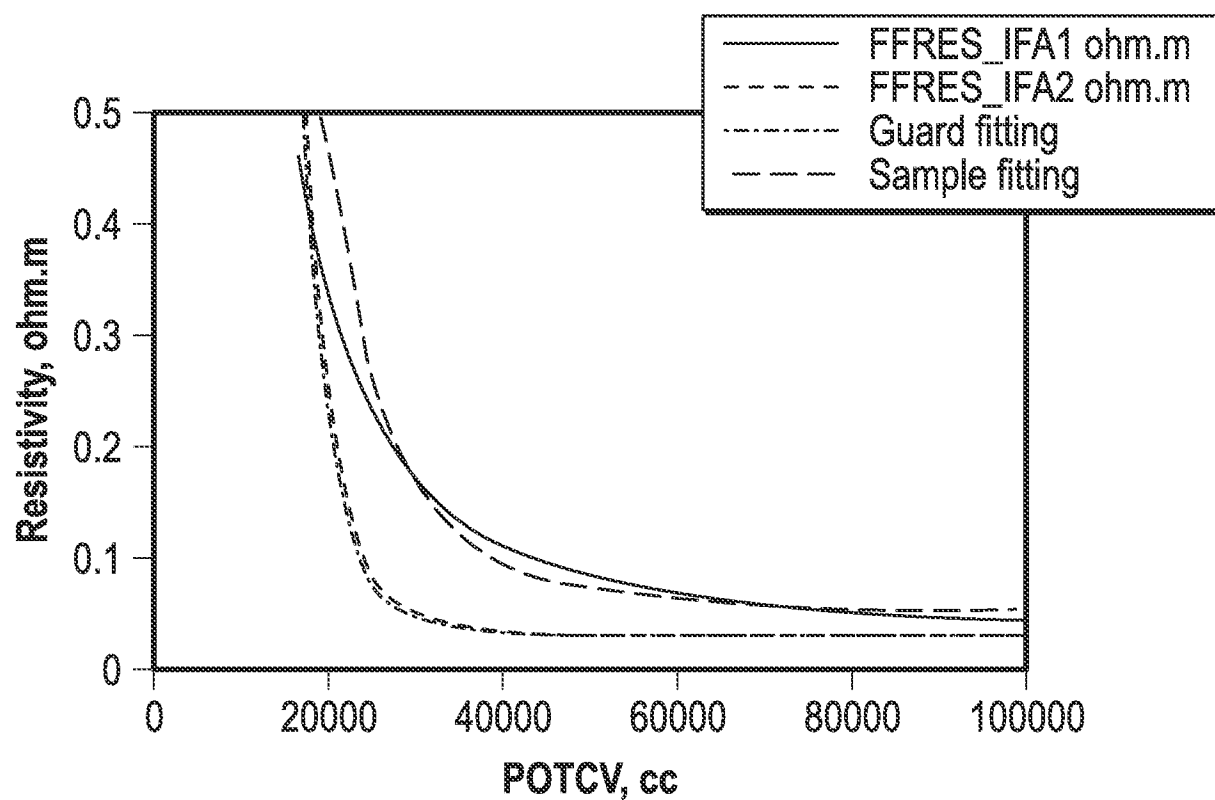


FIG. 3

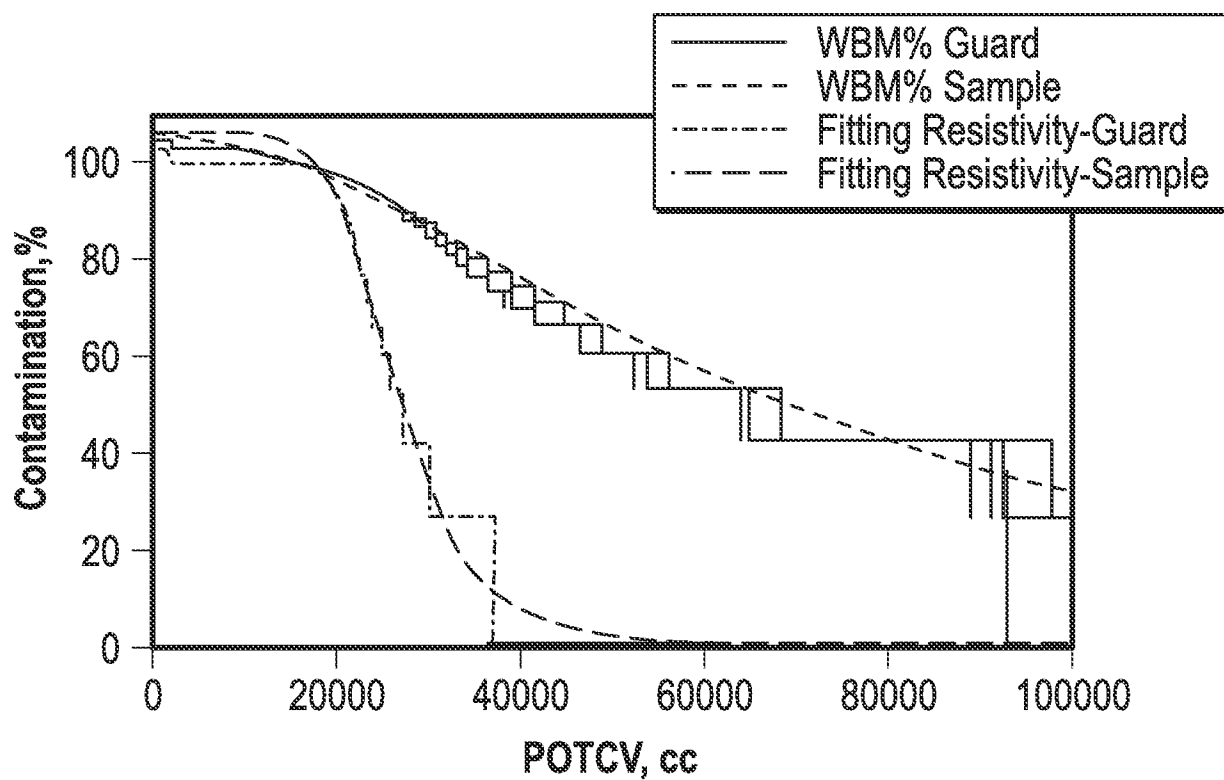


FIG. 4

4/5

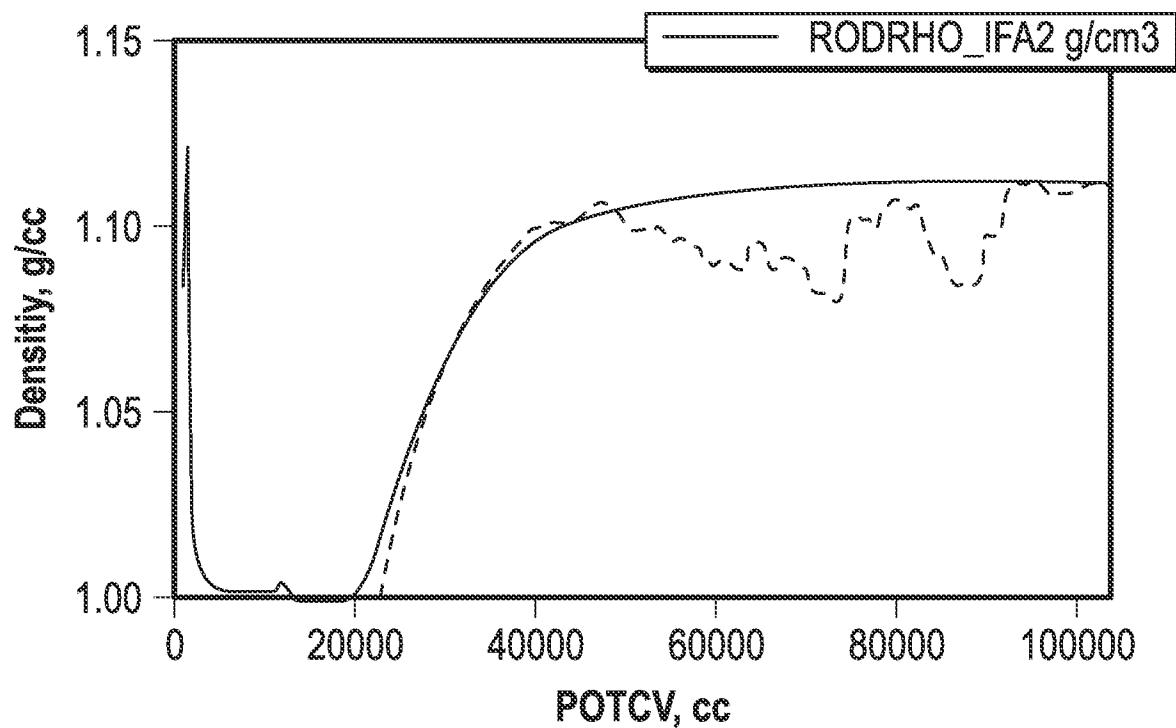


FIG. 5

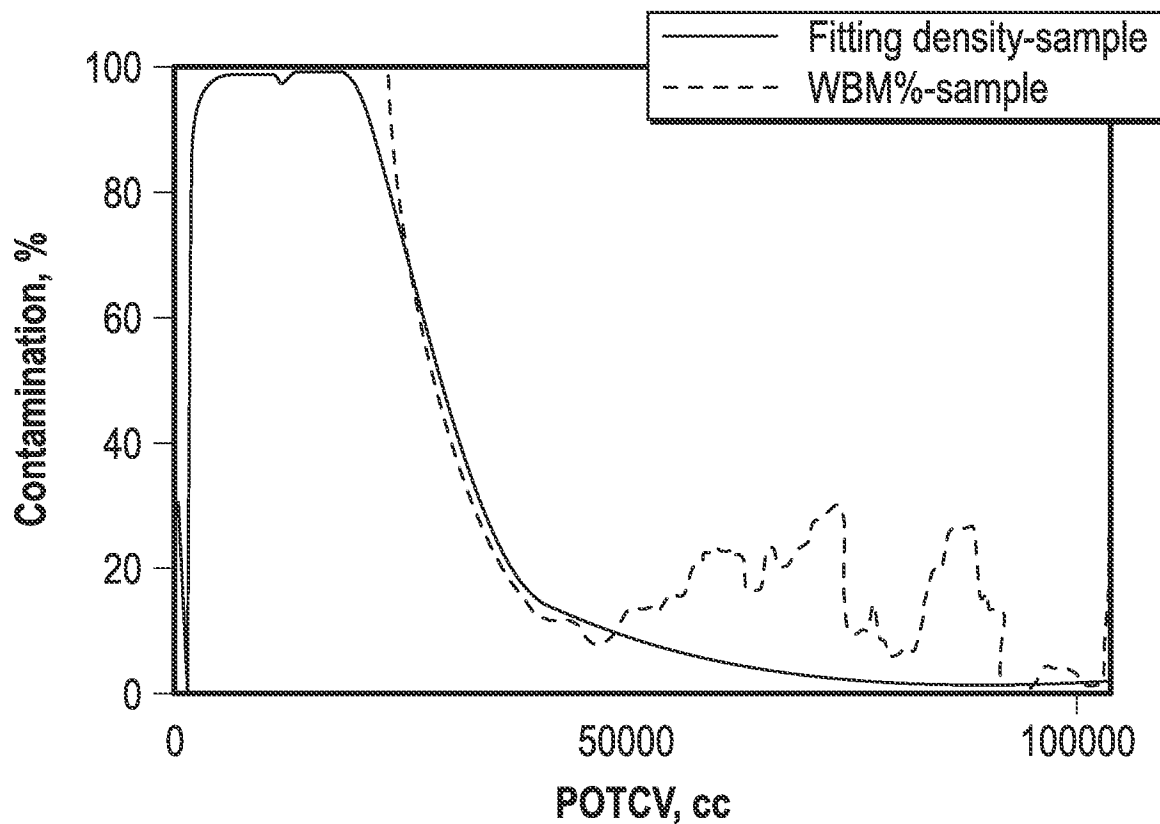


FIG. 6

5/5

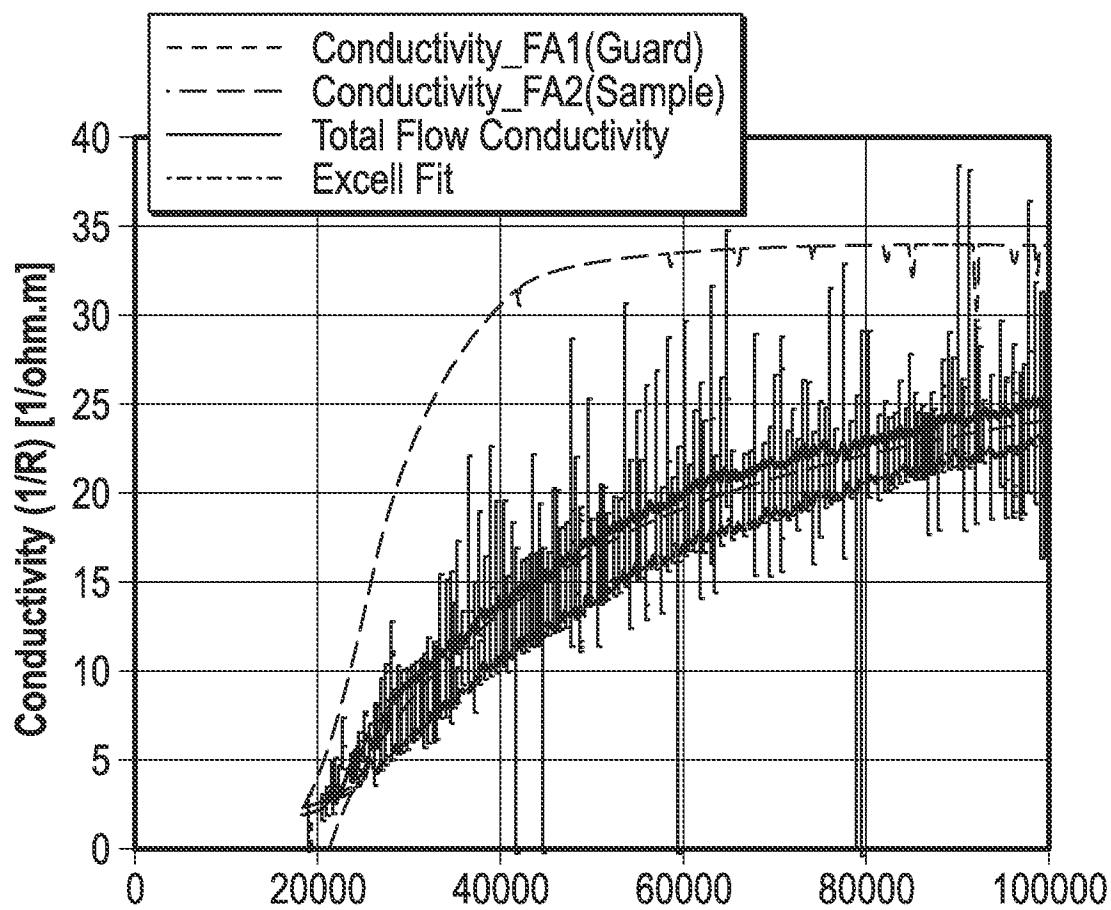


FIG. 7

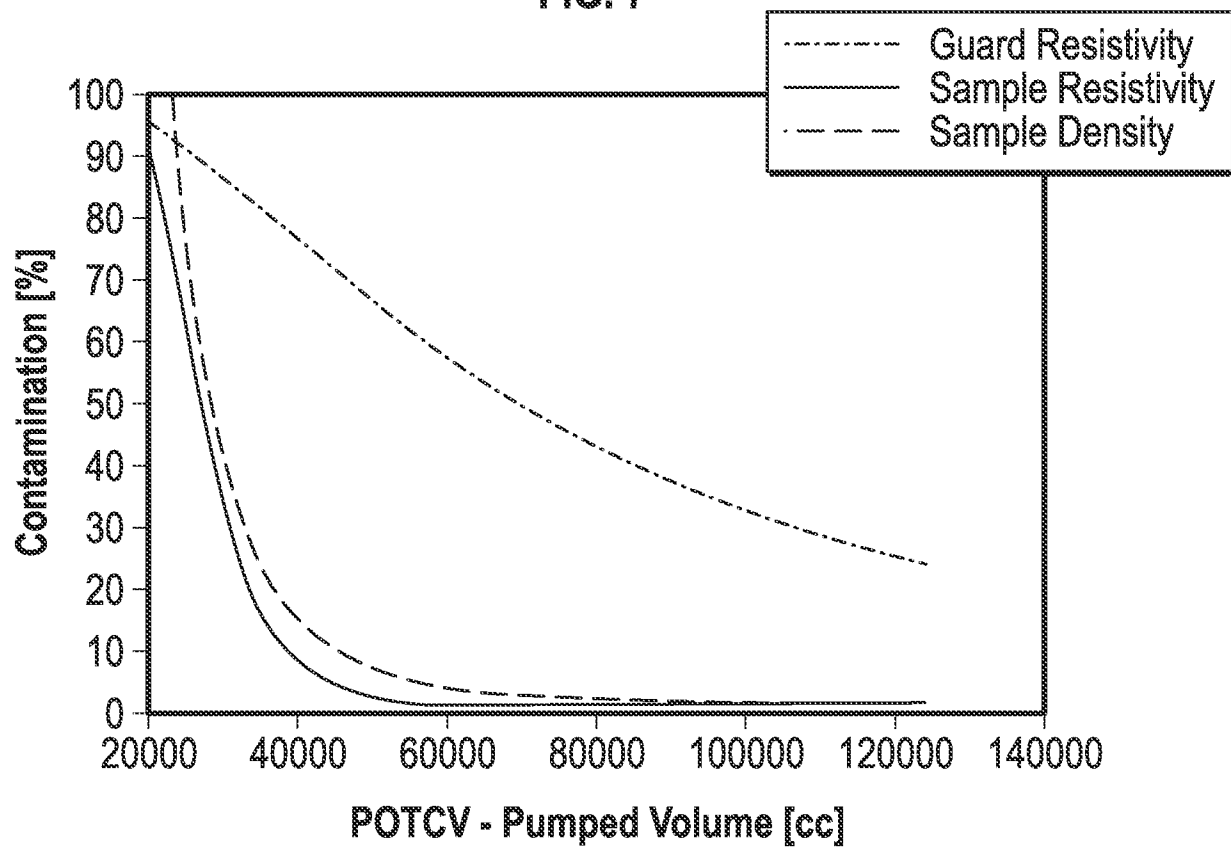


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/066434**A. CLASSIFICATION OF SUBJECT MATTER****E21B 21/01(2006.01)i, E21B 43/02(2006.01)i**

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 21/01; E21B 43/00; G01N 33/24; G01V 3/18; E21B 49/08; E21B 47/13; E21B 43/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: wellbore, contamination, density, pressure, conductivity, linear, resistivity, property and mud filtrate

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2012-094007 A2 (HALLIBURTON ENERGY SERVICES, INC. et al.) 12 July 2012 See paragraphs [0002], [0042]–[0074] and figure 1.	1–12
A	US 2007-0238180 A1 (DIFOGGIO et al.) 11 October 2007 See paragraphs [0031]–[0047] and figures 4–6.	1–12
A	US 2005-0182566 A1 (DIFOGGIO, ROCCO) 18 August 2005 See paragraphs [0034]–[0066] and figures 3A–4B, 10.	1–12
A	US 2003-0145988 A1 (MULLINS et al.) 07 August 2003 See paragraphs [0019]–[0050] and figures 1–3.	1–12
A	US 2004-0000400 A1 (FUJISAWA et al.) 01 January 2004 See claims 1–7 and figure 1.	1–12



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23 February 2015 (23.02.2015)

Date of mailing of the international search report

24 February 2015 (24.02.2015)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/066434

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012-094007 A2	12/07/2012	AU 2011-353763 A1 CA 2823687 A1 EP 2661540 A2 MX 2013007928 A US 2013-0340518 A1 WO 2012-094007 A3	04/07/2013 12/07/2012 13/11/2013 01/11/2013 26/12/2013 20/03/2014
US 2007-0238180 A1	11/10/2007	CN 101460841 A EP 2005154 A2 MY 143616 A US 7445934 B2 WO 2007-120553 A2 WO 2007-120553 A3	17/06/2009 24/12/2008 15/06/2011 04/11/2008 25/10/2007 18/09/2008
US 2005-0182566 A1	18/08/2005	WO 2005-068994 A1	28/07/2005
US 2003-0145988 A1	07/08/2003	GB 2382604 A GB 2382604 B US 2004-0000400 A1 US 6729400 B2 US 7028773 B2	04/06/2003 17/03/2004 01/01/2004 04/05/2004 18/04/2006
US 2004-0000400 A1	01/01/2004	GB 2396412 A GB 2396412 B NO 20035280 A NO 333596 B1 US 2003-0145988 A1 US 6729400 B2 US 7028773 B2	23/06/2004 14/12/2005 28/05/2004 15/07/2013 07/08/2003 04/05/2004 18/04/2006