

(51) International Patent Classification:
G01F 23/26 (2006.01)(21) International Application Number:
PCT/FI2014/050705(22) International Filing Date:
16 September 2014 (16.09.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
20135940 19 September 2013 (19.09.2013) FI(71) Applicant: **OUTOTEC (FINLAND) OY** [FI/FI];
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Box 148, FI-00121 Helsinki (FI).(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG,
MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM,
PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,
SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG).**Declarations under Rule 4.17:**

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- of inventorship (Rule 4.17(iv))

Published:

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

[Continued on next page]

(54) Title: METHOD AND DEVICE FOR MEASURING A SETTLED BED OF SOLIDS IN A MULTIPHASE SYSTEM

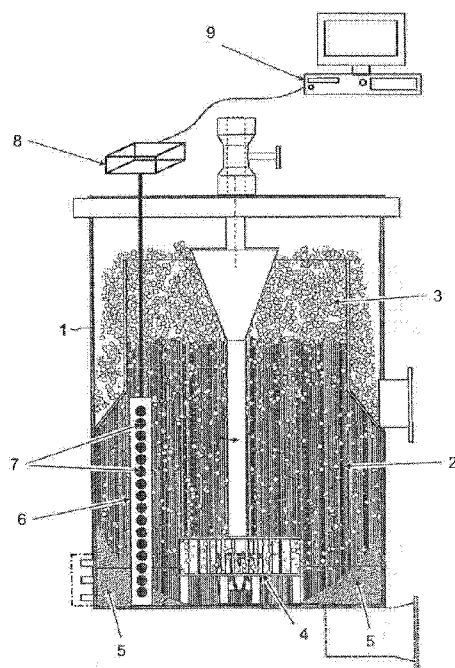


Fig. 1

(57) **Abstract:** In minerals processing and hydrometallurgical industries, settled solids tend to form a solid layer at the bottom of mechanically stirred process vessels, which can lead to severe malfunction or even total shutdown of the process unit. The present invention introduces a method and a system for the real-time measuring of a settled bed of solids (5) in a container (1) comprising a multiphase system (2, 3) using at least one probe (6) comprising together a plurality of electrodes (7).



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- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

METHOD AND DEVICE FOR MEASURING A SETTLED BED OF SOLIDS IN A MULTIPHASE SYSTEM

5 FIELD OF THE INVENTION

The present invention is applied in minerals processing and hydrometallurgical industries. The invention relates to the monitoring of the height of a settled bed of solids in e.g. mechanically stirred
10 process vessels, such as flotation cells and storage tanks.

BACKGROUND OF THE INVENTION

In minerals processing and hydrometallurgical
15 industries, settled solids tend to form a solid layer at the bottom of mechanically stirred process vessels, such as flotation cells, stirred tank reactors and storage tanks. This accumulation can lead to severe malfunction or even total shutdown of the process
20 unit. Therefore, real-time measurement or monitoring of the height of the settled bed of solids gives an opportunity to follow the situation in real time and make corrective action like increasing agitation or decreasing pulp density in time. Thus, said measure-
25 ment is of a crucial importance.

There are some level measurement equipment that can measure the interface between a liquid and a settled bed of solids. One method is to use a vibrating probe extending through the wall of the tank to
30 detect the desired interface. Another type of interface level measurement equipment uses the reflection of sonar pulses to detect the level of solids on the bottom of the vessel.

An apparatus arranged to determine an inter-
35 face between two components, such as water-oil or water-sediment, is disclosed in WO2010001089. Said appa-

ratus comprises a plurality of electrodes configured to measure a potential difference between the measurement electrode and the reference electrode, which measured potential difference is indicative of the interface between the components.

All the above techniques suffer from limitations and they are not reliable in a multiphase environment, such as three phase system (gas-liquid-solid), where multiple interfaces are also present (gas-liquid, liquid-slurry, slurry-settled solids). Contamination of the measurement equipment is often a problem in the existing techniques. In addition, with methods that utilize the reflection of sonar pulses, calibration in the multiphase environment is an issue due to fluctuation in the amounts of liquid, solid particles and gas bubbles.

SUMMARY

The present invention introduces a method for the real-time measuring of a settled bed of solids in a container comprising a multiphase system using at least one probe comprising together a plurality of electrodes capable of being in contact with the medium, and the method comprises the steps of injecting currents or voltages through at least two electrodes; measuring voltages or currents, respectively, through the at least two electrodes; calculating the electrical conductivity distribution in the multiphase system the basis of the measurement results and the known injected currents, which calculation comprises reconstruction of a vertical conductivity profile as a function of location in the multiphase system; and concluding the height of the settled bed of solids on the basis of the electrical conductivity distribution and electrode location information.

In an embodiment of the invention, the geometry of the used at least one probe is linear and the

plurality of electrodes are assembled in the same vertical plane at a predetermined distance from each other.

In an embodiment of the invention, the method
5 further comprises the step of monitoring contamination of the electrodes by measuring contact impedances between each electrode and the multiphase system.

In an embodiment of the invention, the method
10 further comprises the step of estimating voltage losses due to contamination on electrode surfaces during calculation of the electrical conductivity distribution.

In an embodiment of the invention, at least one probe is submerged to the bottom of the container.

15 In an embodiment of the invention, at least one probe is in contact with the solid settled on the bottom of the container.

In an embodiment of the invention, the container comprises at least one of the following: a flotation cell, a stirred tank reactor, a storage tank, a
20 filter feed tank, a conditioning tank, a thickener.

In an embodiment of the invention, the multiphase system comprises a three phase system of a gas, a liquid and a solid.

25 In an embodiment of the invention, the method further comprises mixing the multiphase system in the container; submerging the at least one probe to the bottom of the container to be in contact with the solid settled on the bottom of the container; monitoring
30 contamination of the electrodes by measuring contact impedances between each electrode and the multiphase system; calculating the electrical conductivity distribution in the multiphase system on the basis of the measurement results, the contact impedances and the
35 known injected currents.

In an embodiment of the invention, at least one probe is submerged so that it is in contact with

both the solid settled on the bottom of the container and with the slurry phase above the solid.

In an embodiment of the invention, compensating, during calculation of the electrical conductivity distribution, inaccuracy of the measurements due to contamination of the electrodes that are in contact with the solid by estimating voltage losses over the measured contact impedances.

Another aspect of the invention comprises a system for the real-time measuring of a settled bed of solids in a container comprising a multiphase system. The system comprises a probe arrangement of at least one probe comprising together a plurality of electrodes capable of being in contact with the multiphase system; a current source configured to inject currents or voltages through at least two electrodes; measuring means configured to measure voltages or currents, respectively, through the at least two electrodes; a processor configured to control the measurements; the processor being further configured to calculate the electrical conductivity distribution in the multiphase system on the basis of the measurement results and the known injected currents, which calculation comprises reconstruction of a vertical conductivity profile as a function of location in the multiphase system, conclude, on the basis of the electrical conductivity distribution and electrode location information, the height of the settled bed of solids.

In an embodiment of the invention, the geometry of the at least one probe is linear and the plurality of electrodes are assembled in the same vertical plane at a predetermined distance from each other.

In an embodiment of the invention, the measuring means are configured to monitor contamination of the electrodes by measuring contact impedances between each electrode and the medium to be analyzed.

In an embodiment of the invention, the measuring means are configured to estimate voltage losses due to contamination on electrode surfaces during calculation of the electrical conductivity distribution.

5 In an embodiment of the invention, at least one probe is submerged to the bottom of the container.

In an embodiment of the invention, at least one probe is in contact with the solid settled on the bottom of the container.

10 In an embodiment of the invention, a mixing mechanism is arranged to mix the multiphase system in the container; at least one probe of the probe arrangement is submerged to the bottom of the container to be in contact with the solid settled on the bottom
15 of the container; the measuring means are further configured to monitor contamination of the electrodes by measuring contact impedances between each electrode and the medium to be analyzed; the processor is further configured to calculate the electrical conductivity distribution in the multiphase system on the basis
20 of the measurement results, the measured contact impedances and the known injected currents.

In an embodiment of the invention, the at least one submerged probe is arranged to be in contact
25 with both the solid settled on the bottom of the container and with the slurry phase above the solid.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are included
30 to provide a further understanding of the invention and constitute a part of this specification, illustrate embodiments of the invention and together with the description help to explain the principles of the invention. In the drawings:

35 **Figure 1** illustrates a flotation cell comprising a probe arrangement according to an example of the invention.

Figures 2a and 2b illustrate curves depicting measured conductivity height profiles at different rotation speeds of the tank, where the distance d (in cm) from the bottom of the tank is shown as a function of conductivity σ (in mS/cm).

DETAILED DESCRIPTION

Reference will now be made in detail to the embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

The present invention introduces techniques based on a computational electrical resistance tomography approach which is applied to be used with a probe arrangement for measuring a settled bed of solids in real time in a container comprising a multiphase system.

In this approach, metal electrodes can be attached on a surface of a probe, through which sinusoidal currents are injected to the target substance and resulting voltages are measured through at least two electrodes. Alternatively, voltages can be supplied between any two of the electrodes, and the resulting currents may be measured through the electrodes. The electronics in the system hardware handles the injection, the measurements and the analysis performed based on the measurement results.

The probe arrangement may comprise one or more separate probes. The probe(s) is submerged to the bottom of a container comprising a multiphase system, such as a flotation cell, a stirred tank reactor, or a storage tank, for measuring a settled bed of solids in a continuous real time measurement that updates the desired value (height of the settled solids bed) with at least a few seconds' interval. The probe arrangement according to the invention is capable of detecting the interface between e.g. a settled bed of solids

and mixed slurry that contains fluctuating amounts of liquid, solid particles and gas bubbles.

A model based computational approach is utilized to analyze the measured data. This means that
5 such an approach takes into account for instance the geometry of the probe, the geometry of the container, as well as possible contamination of the electrodes. Through mathematical analysis of the model, the location of the different interfaces such as the slurry-
10 settled solid interface can be detected, based on which the height of the settled bed of the solid on the bottom of the container can be determined.

In the method according to the present invention an injection signal, which can be either injected
15 voltage or current, is applied to the electrodes. An estimate of the electrical conductivity of the target substance as a function of location is calculated based on the measured voltages and the known injected currents. Measured data is used to determine the actual
20 situation, i.e. the conductivity distribution which caused the observations - this approach is known as an inverse problem. The calculation is based on a mathematical model determining the relation between the injected currents, the electrical conductivity distribution of the target substance and the voltages of the
25 electrodes. Said technique is called electrical impedance tomography (EIT), and is applied in e.g. medical imaging or soil characterization. One advantage of EIT is that it is based on a mathematical model which also
30 takes into account the electrode impedances; the model can be also modified to take into account the voltage losses due to contamination on electrode surfaces.

In an exemplary arrangement of the invention, the probe comprises 16 electrodes in operation. Said
35 probe was submerged to the bottom of the container, which was a flotation cell with a fluid volume of 50l. Said flotation cell was filled with an authentic slur-

ry sample that contained 33w% of solids. The probe was submerged so that the lowest electrode was at a 7cm distance from the bottom of the container. The rotation speed of the mixing mechanism was alternated and height of the settled solids bed was measured with and without air feed.

It shall be noted, however, that another number of electrodes is also applicable, but at least two electrodes are always needed for supplying and measuring voltages or currents between the electrodes. As already mentioned, the probe arrangement may comprise one or more separate probes. The geometry of a probe can be linear, i.e. said probe can be formulated as a straight piece of probe. The electrodes can be placed or arranged in the same vertical plane at a predetermined distance from each other. However, in every arrangement each electrode shall be insulated from the remainder of the electrodes in order for the current or voltage measurement to be possible.

More precisely, the electrodes can also be connected to the surface of a straight piece of body in such a way that electrodes remain electrically insulated from each other. The probe itself can be connected or fixed to any material, e.g. the walls of the container or flotation cell, in a way that the electrode's contact with the surrounding medium or substance can easily be achieved. Also the alignment or angle, in which the straight probe is submerged in the container, can be selected. However, in order to reconstruct a vertical conductivity profile as a function of location in the multiphase system, electrodes shall not be located on the same horizontal plane. Therefore, the probe shall not be submerged in the container in such a way that all the electrodes are in the same horizontal plane.

In one embodiment of the invention, the effect of contamination or dirtying of at least one

electrode in the probe arrangement is taken into account. As widely known, the contamination around the electrode(s) leads into a non-ideal connection between the metallic electrode and target substance, which
5 further causes additional electric resistance. The non-ideal connection can be seen as an additional voltage drop and it can be expressed by a quantity called contact impedance. The voltage (or current) measured through a pair of electrodes is generally a
10 function of the injected current (or voltage), the conductivity distribution in the path of the electrical current and the contact impedances between the electrodes and the surrounding medium to be measured. The contact impedances may be used to compensate for
15 the dirtying of the electrodes by inserting them to the calculation model as additional voltage loss parameters.

The obtained height of the settled bed of a solid in the container can be used when determining if
20 said accumulation of a solid is significant enough and can lead to malfunction of the container. If the height of the solid layer formed at bottom of a container reaches predetermined high levels, it will be possible to make corrective action like increasing agitation or decreasing pulp density in time.
25

Figure 1 illustrates a measurement arrangement in a container 1, such as a flotation tank or cell, a stirred tank reactor, a storage tank, a filter feed tank, a conditioning tank, a thickener, etc. Material can be fed into and away from the container and
30 it comprises solid particles suspended in a liquid phase 2 with or without gas 3 (slurry or gassed slurry). The container comprises a mixing mechanism 4 necessary e.g. for the flotation process. A separate volume(s) of solid 5 is settled on the bottom of the container. There can also be a transitional layer between
35

the slurry phase and liquid phase or the liquid phase and gas phase (not shown).

A probe arrangement comprising in this case a single probe 6 is submerged or lowered into the container 1 and fixed in its measurement position, preferably in such a manner that the lower end of the probe 6 is in contact with the bottom of the container 1. In practice the probe is submerged so that it is in contact with both the settled solid 5 at the bottom of the container and with the slurry phase that may contain also gas bubbles.

The probe arrangement comprises a set of electrodes 7. Here, 16 electrodes are used. The two lowest electrodes on the probe are in contact with the settled solid 5 and the rest of the electrodes are in contact with the slurry phase 2. Naturally, also another configuration is possible depending on the size of the probe, the number of the electrodes and the height of the settled solid. In the illustrated arrangement the probe is aligned in a vertical plane, i.e. it is submerged perpendicularly to the bottom of the container. However, the alignment or angle of the probe in relation to the bottom of the container may vary according to the desired measurement, as long as not all the electrodes are in the same horizontal plane.

The controller 8 determines the vertical coordinates of the probe and its electrodes in relation to the container geometry. Said controller also takes care of the current or voltage supply and all the voltage or current measurements between different pairs of electrodes 7. A computer (i.e. a processor) 9 or a similar device performs all the required calculations and data storing. All the measurement, analysis and calculation steps may be executed through a computer program implemented in the controller 8, computer 9 or through an external server (not shown) located

remotely in the network. The process control means, such as providing a signal to change a parameter value, e.g. an input rate of the medium to be fed into the process, increasing agitation or decreasing pulp density in time, can also be implemented through the controller 8 or computer 9. It can be noted that the controller 8 may comprise a motor directing the probe arrangement and being aware of the orientation and location of the probe(s) all the time, while the computer 9 controls the motor and the overall process, e.g. flotation process.

Figures 2a and 2b illustrate curves depicting measured conductivity height profiles at different rotation speeds of the tank, where the distance d (in cm) from the bottom of the tank is shown as a function of conductivity σ (in mS/cm). In all the measurements the probe was submerged to the bottom of the container so that the lower end of the probe was in contact with the bottom of the container and the lowest electrode was at a 7cm distance from the bottom. In Figure 2a the rotation speed of the mixing mechanism (i.e. rotor) was 192rpm, in Figure 2b it was 230rpm. The measurements were performed implementing the method according to the present invention, and on the basis of the measurement results the electrical conductivity distribution was determined in this multiphase system. Measurement results were obtained with and without air feed to the container.

By observing the conductivity σ behavior one can clearly see that there are three different phases in the container, each phase having a different conductivity. The height of the solid settled on the bottom of the container can be estimated from the distance d value on the y-axis that correspond to the first rapid change of conductivity σ on the x-axis. From the curves one can determine that the height of the solid, settled on the bottom of the tank at the

point where the probe was located, was approximately between 7 and 8 cm in Fig. 2a and between 6 and 7 cm in Fig. 2b. Visual inspections confirmed that in these cases the height of the settled bed of solids was 8.0cm and 7.0cm, respectively.

There are numerous advantages of the present invention compared to the prior art measurement methods and arrangements. It shall be emphasized that the measurement arrangement according to the present invention, where at least one probe is submerged to the bottom of the container and is in contact (i.e. at least one of the electrodes is in contact) with the solid that is settled on the bottom of the container, enables a faster and more reliable calculation, because the currents can be injected directly to the settled solid. Studies performed by the applicant showed that arrangements where probes comprising electrodes are located in the container above the settled solid, so that none of the electrodes is in contact with the solid, do not provide accurate results. In the method according to the present invention, the inaccuracy of the measurements caused by fouling or contamination of the electrodes that are in contact with the solid is solved by measuring contact impedances between each electrode and the multiphase system and estimating voltage losses due to contamination on electrode surfaces during calculation of the electrical conductivity distribution.

The method according to the present invention is particularly suitable for calculating the electrical conductivity distribution in a multiphase system and concluding the height of the settled bed of solids, because settled solids do not contain a notable amount of gas - the electrical conductivity of the solid is significantly lower than that of a slurry or gas-containing slurry phase. Due to the large contrast (i.e. difference) in conductivity between settled sol-

ids and other phases, the mathematical models provide reliable results when calculating the electrical conductivity distribution. In addition, the modeling and calculation is fast compared to e.g. the determining
5 of the electrical conductivity distribution of a two-phase system comprising gas and liquid phases or froth and slurry.

The known methods that are based on a potential difference measurement between the measurement
10 electrode and the reference electrode are not directly applicable to flotation cells or stirred tank reactors, because in said cells and reactors the bottom part of the tank contains a multitude of solid phase particles. These particles act as insulators and may
15 contaminate the electrodes in a short period of time.

The other known solutions for determining a conductivity profile of a target are not directly applicable to flotation cells or stirred tank reactors, because in said cells and reactors the solid phase
20 particles, which act as insulators, are mixed in the whole volume of the cell or reactor. Therefore, in flotation cells or stirred tank reactors, it is in practice very hard to find a pure liquid phase without any impurities. Further, gas bubbles that are mixed in
25 the whole volume of the cell or reactor also act as an insulator and thus make it very difficult to detect an interphase between e.g. solid and liquid phases.

The requirements for successful determination of the height of a settled bed of solids are: the liquid phase (if any) present in the container shall be
30 electrically conductive and the electrical conductivity of said liquid phase and settled solid(s) shall not be the same.

It is obvious to a person skilled in the art
35 that with the advancement of technology, the basic idea of the invention may be implemented in various ways. The invention and its embodiments are thus not

limited to the examples described above; instead, they may vary within the scope of the claims.

CLAIMS

1. A method for the real-time measuring of a settled bed of solids in a container comprising a multiphase system using at least one probe comprising together a plurality of electrodes capable of being in contact with the medium, the method comprising:
- injecting currents or voltages through at least two electrodes;
 - measuring voltages or currents, respectively, through the at least two electrodes;
 - calculating the electrical conductivity distribution in the multiphase system on the basis of the measurement results and the known injected currents, which calculation comprises reconstruction of a vertical conductivity profile as a function of location in the multiphase system;
 - concluding, on the basis of the electrical conductivity distribution and electrode location information, the height of the settled bed of solids.
2. The method according to claim 1, wherein the geometry of the used at least one probe is linear and the plurality of electrodes are assembled in the same vertical plane at a predetermined distance from each other.
3. The method according to any of the claims 1-2, further comprising:
- monitoring contamination of the electrodes by measuring contact impedances between each electrode and the multiphase system.
4. The method according to any of the claims 1-3, further comprising:
- estimating voltage losses due to contamination on electrode surfaces during calculation of the electrical conductivity distribution.

5. The method according to any of the claims 1-4, wherein:

- at least one probe is submerged to the bottom of the container.

6. The method according to any of the claims 1-5, wherein:

- at least one probe is in contact with the solid settled on the bottom of the container.

7. The method according to any of the claims 1-6, wherein the container comprises at least one of the following: a flotation cell, a stirred tank reactor, a storage tank, a filter feed tank, a conditioning tank, a thickener.

8. The method according to any of the claims 1-7, wherein the multiphase system comprises a three phase system of a gas, a liquid and a solid.

9. The method according to claim 1 or 2, comprising:

- mixing the multiphase system in the container;
- submerging the at least one probe to the bottom of the container to be in contact with the solid settled on the bottom of the container;
- monitoring contamination of the electrodes by measuring contact impedances between each electrode and the multiphase system;
- calculating the electrical conductivity distribution in the multiphase system on the basis of the measurement results, the contact impedances and the known injected currents.

10. The method according to claim 9, wherein at least one probe is submerged so that it is in contact with both the solid settled on the bottom of the container and with the slurry phase above the solid.

11. The method according to any of the claims 9-11, further comprising compensating, during calculation of the electrical conductivity distribution, inaccuracy of the measurements due to contamination of the electrodes that are in contact with the solid by estimating voltage losses over the measured contact impedances.

12. A system for the real-time measuring of a settled bed of solids (5) in a container (1) comprising a multiphase system (2, 3), said system comprising

- a probe arrangement of at least one probe (6) comprising together a plurality of electrodes (7) capable of being in contact with the multiphase system;
- a current source (8) configured to inject currents or voltages through at least two electrodes;
- measuring means (8) configured to measure voltages or currents, respectively, through the at least two electrodes;
- a processor (9) configured to control the measurements; the processor (9) being further configured to:
 - calculate the electrical conductivity distribution in the multiphase system on the basis of the measurement results and the known injected currents, which calculation comprises reconstruction of a vertical conductivity profile as a function of location in the multiphase system,
 - conclude, on the basis of the electrical conductivity distribution and electrode location information, the height of the settled bed of solids.

13. The system according to claim 9, wherein the geometry of the at least one probe (6) is linear

and the plurality of electrodes (7) are assembled in the same vertical plane at a predetermined distance from each other.

14. The system according to any of the
5 claims 9-10, wherein the measuring means (8) are further configured to:

- monitor contamination of the electrodes by measuring contact impedances between each electrode and the medium to be analyzed.

10 15. The system according to any of the claims 9-11, wherein the measuring means (8) are further configured to:

- estimate voltage losses due to contamination on electrode surfaces during calculation of the electrical conductivity distribution.

16. The system according to any of the claims 9-12, wherein at least one probe (6) is submerged to the bottom of the container (1).

20 17. The system according to any of the claims 9-13, wherein at least one probe (6) is in contact with the solid (5) settled on the bottom of the container (1).

25 18. The system according to claim 10 or 11, wherein:

- a mixing mechanism (4) is arranged to mix the multiphase system in the container (1);
- at least one probe of the probe arrangement is submerged to the bottom of the container to be in contact with the solid settled on the bottom of the container (1); the measuring means (8) are further configured to monitor contamination of the electrodes by measuring contact impedances between each electrode (7) and the medium to be analyzed;

- the processor (9) is further configured to calculate the electrical conductivity distribution in the multiphase system on the basis of the measurement results, the measured contact impedances and the known injected currents.

19. The system according to claim 10 or 11, wherein the at least one submerged probe is arranged to be in contact with both the solid settled on the bottom of the container and with the slurry phase above the solid.

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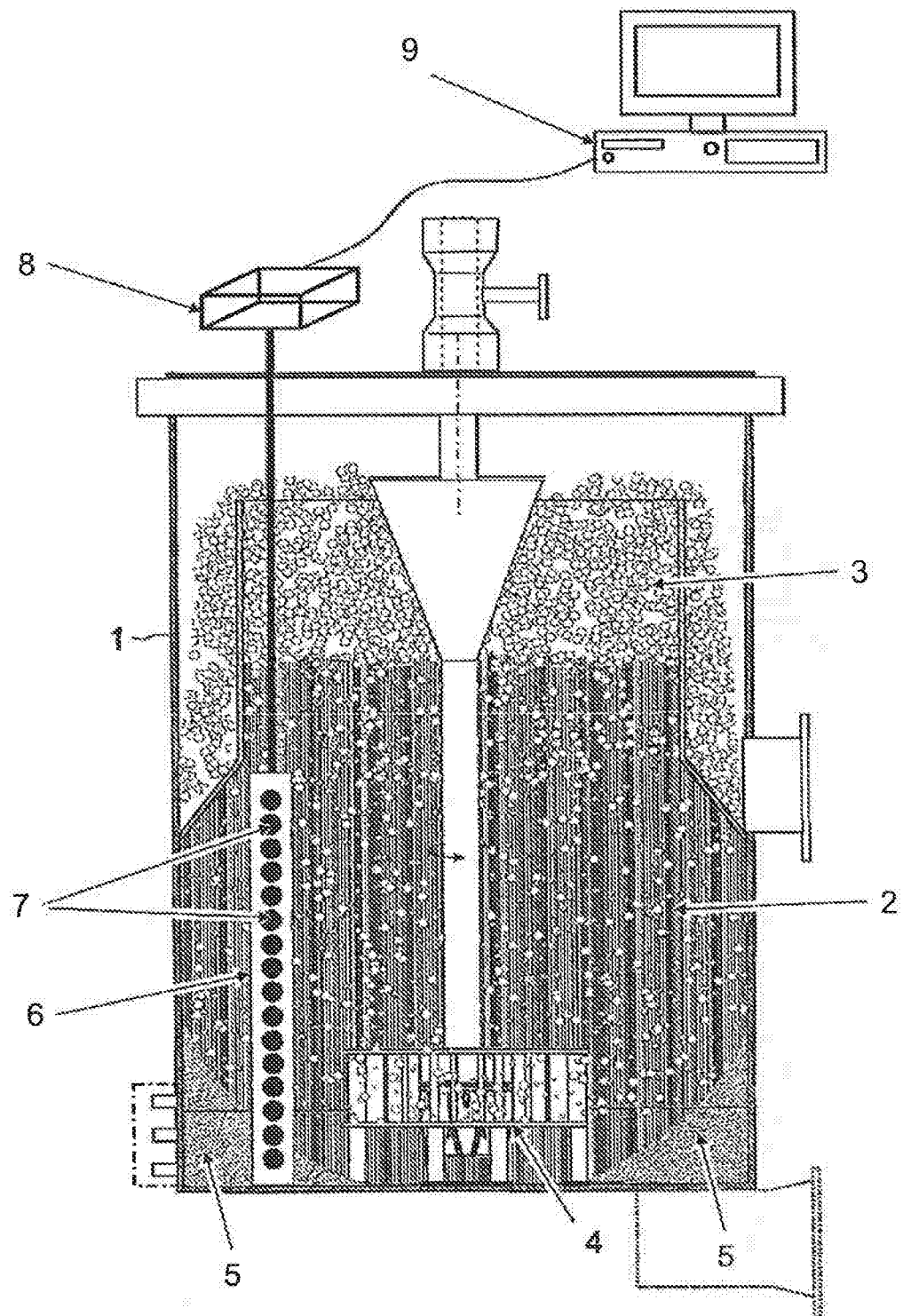


Fig. 1

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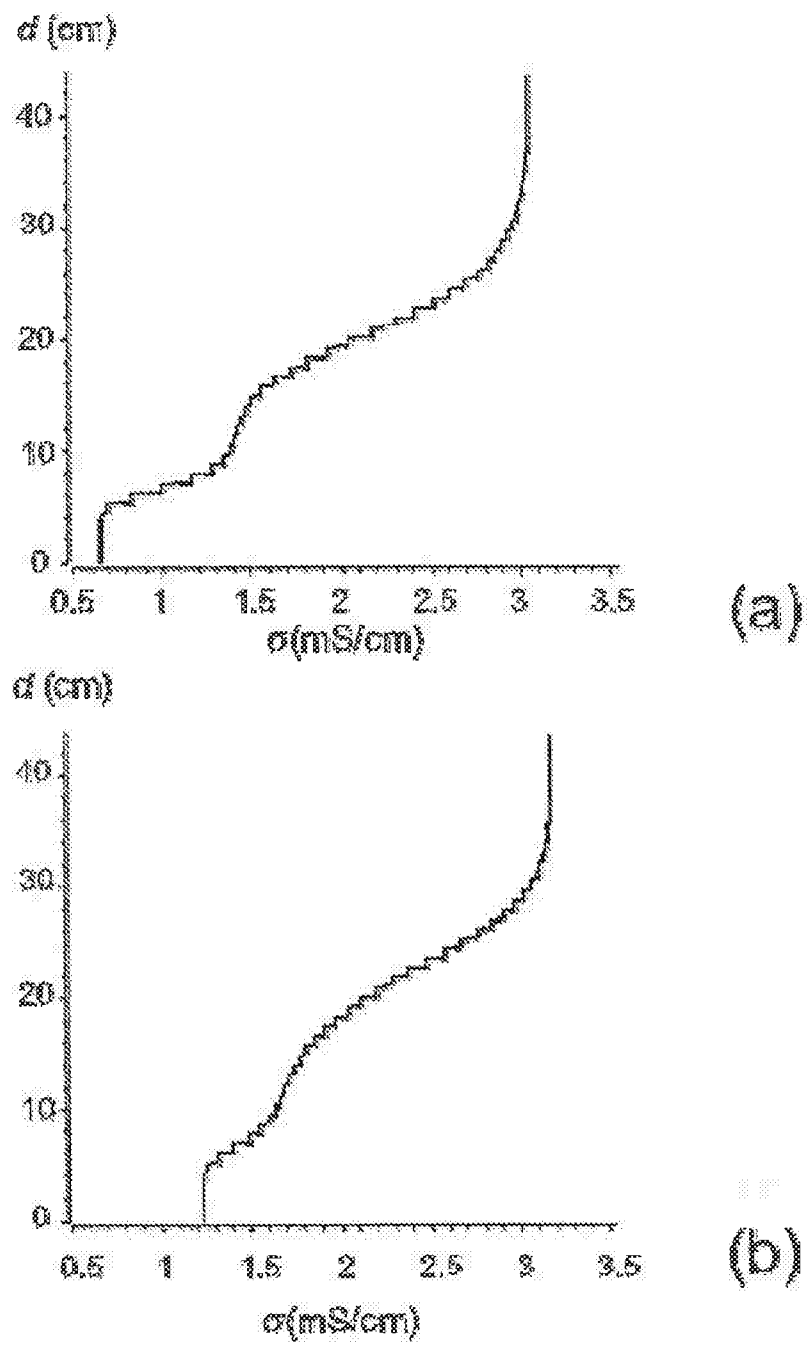


Fig. 2

INTERNATIONAL SEARCH REPORT

International application No

PCT/FI2014/050705

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01F23/26

ADD.

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)

G01F

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013/024198 A1 (OUTOTEC OYJ [FI]; LEHIKONEN ANSSI [FI]; VAUHKONEN MARKO [FI]) 21 February 2013 (2013-02-21) page 10, line 5 - page 12, line 20 page 13, line 27 - page 14, line 9 page 17, line 1 - line 15; claim 1; figures 1,3 -----	1-19
X A	WO 2011/107657 A1 (NUMCORE OY [FI]; KAIPIO JARI [NZ]; VAUHKONEN MARKO [FI]; REUNANEN JUHA) 9 September 2011 (2011-09-09) page 2, line 15 - line 17 page 3, line 35 - page 4, line 8 page 12, line 1 - line 22 page 15, line 15 - page 16, line 19 page 23, line 28 - page 26, line 36; claim 1; figures 2,5a -----	1,3,4,7, 8,11,12, 14,15 2,5,6,9, 10,13, 16-19



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

2 February 2015

Date of mailing of the international search report

27/02/2015

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/FI2014/050705

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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