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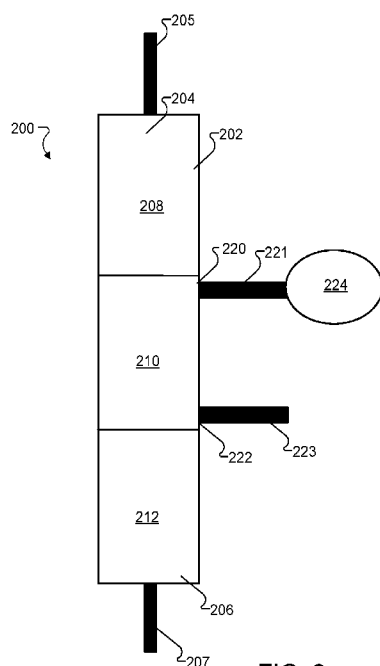


FIG. 2

(57) Abstract: An apparatus for measuring the cation conductivity of a fluid sample includes a housing having an inlet disposed at a first end of the housing and an outlet disposed at a second end of the housing, the second end opposite the first end, wherein the inlet of the housing is configured to receive the fluid sample. The apparatus includes a first cellulose filter disposed in the housing adjacent to the inlet; a second cellulose filter disposed in the housing adjacent to the outlet; and a cation exchange resin filter disposed in the housing between the first cellulose filter and the second cellulose filter. The outlet of the housing is configured to be fluidically connected to a cation conductivity sensor configured to measure a cation conductivity of an effluent output from the outlet of the housing.



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ION CONDUCTIVITY FILTER AND MEASUREMENT SYSTEM

Claim of Priority

[001] This application claims priority to U.S. Patent Application No. 16/942,589
5 filed on July 29, 2020, the entire contents of which are hereby incorporated by
reference.

Background

[002] Cation conductivity is a test that can be used to monitor water purity. For
instance, cation conductivity is used for monitoring of the presence of contaminants in
10 steam generation systems, such as in a heat recovery steam generator (HRSG). HRSG
systems are treated with chemicals such as ammonia or hydrazine. Cation conductivity
can be used to detect contamination of an HRSG system by cooling water, such as sea
water or well water as cooling water, by monitoring for the presence of salts, such as
sodium chloride.

Summary

15 [003] In an aspect, an apparatus for measuring the cation conductivity of a fluid
sample includes a housing having an inlet disposed at a first end of the housing and an
outlet disposed at a second end of the housing, the second end opposite the first end,
wherein the inlet of the housing is configured to receive the fluid sample. The
20 apparatus includes a first cellulose filter disposed in the housing adjacent to the inlet; a
second cellulose filter disposed in the housing adjacent to the outlet; and a cation
exchange resin filter disposed in the housing between the first cellulose filter and the
second cellulose filter. The outlet of the housing is configured to be fluidically
connected to a cation conductivity sensor configured to measure a cation conductivity
25 of an effluent output from the outlet of the housing.

[004] Embodiments may include one or any combination of two or more of the
following features.

[005] The first cellulose filter includes a 0.45 μm cellulose filter.

[006] The second cellulose filter includes a 0.45 μm cellulose filter.

30 [007] The cation exchange resin filter is formed of a material including acidic
functional groups.

[008] The apparatus includes a side inlet disposed along a length of the housing; and a side outlet disposed along the length of the housing. The side inlet and side outlet are aligned with the cation exchange resin filter. The side inlet is configured to be fluidically connected to a fluid source. The apparatus includes a source of
5 regeneration fluid fluidically connected to the side inlet. The source of regeneration fluid includes a source of hydrochloric acid or sulfuric acid. A distance between the side inlet and the inlet of the housing is less than a distance between the side outlet and the inlet of the housing.

[009] The apparatus includes the cation conductivity sensor.

10 [010] In an aspect, a method of measuring the cation conductivity of a fluid sample includes flowing the fluid sample through an ion conductivity filter, including flowing the fluid sample across a first cellulose filter disposed in a housing, wherein the first cellulose filter is disposed adjacent to an inlet to the ion conductivity filter, the inlet disposed at a first end of the housing; flowing the fluid sample from the first cellulose
15 filter across a cation exchange resin filter disposed in the housing; and flowing the fluid sample from the cation exchange resin filter across a second cellulose filter disposed in the housing. The second cellulose filter is disposed adjacent to an outlet from the ion conductivity filter, the outlet disposed at a second end of the housing, the second end opposite the first end. The method includes providing an effluent from the
20 outlet of the ion conductivity filter to a cation conductivity sensor configured to measure a cation conductivity of the effluent.

[011] Embodiments can include one or any combination of two or more of the following features.

25 [012] The method includes by the cation conductivity sensor, measuring the cation conductivity of the effluent. The method includes comparing the measured cation conductivity of the effluent to a baseline cation conductivity. The method includes determining a contamination of the fluid sample based on the measured cation conductivity of the effluent. The method includes determining that the fluid sample is contaminated when the measured cation conductivity of the effluent exceeds a baseline
30 cation conductivity by at least a threshold amount.

[013] Flowing the fluid sample across the cation exchange resin filter includes binding contaminant cations from the fluid sample to the cation exchange resin filter.

The cation exchange resin filter releases hydrogen ions responsive to the binding of contaminant cations.

[014] Flowing the fluid sample across the first cellulose filter includes removing suspended solids from the fluid sample.

5 [015] Flowing the fluid sample across the second cellulose filter includes removing particulate matter from the cation exchange resin filter from the fluid sample.

[016] The method includes flowing a regeneration fluid across the cation exchange resin filter. The method includes flowing the regeneration fluid into a side inlet disposed along a length of the housing and aligned with the cation exchange resin filter, across the cation exchange resin filter, and out a side outlet disposed along the length of the housing and aligned with the cation exchange resin filter.

[017] The method includes rinsing the cation exchange resin filter with a cleaning fluid. The method includes flowing the cleaning fluid into a side inlet disposed along a length of the housing and aligned with the cation exchange resin filter, across the cation exchange resin filter, and out a side outlet disposed along the length of the housing and aligned with the cation exchange resin filter.

[018] The method includes detaching the ion conductivity filter from the cation conductivity sensor. The method includes filling the housing with a fluid and capping the inlet and outlet of the ion conductivity filter. The method includes storing the capped, detached ion conductivity filter.

[019] In an aspect, a method of making an apparatus for measuring the cation conductivity of a fluid sample includes disposing a first cellulose filter in the interior of a housing adjacent to an inlet disposed at a first end of the housing; disposing a cation exchange resin filter in the interior of the housing adjacent to the first cellulose filter; and disposing a second cellulose filter in the interior of the housing adjacent to the cation exchange resin filter and adjacent to an outlet disposed at a second end of the housing, the second end opposite the first end. The outlet is configured to be fluidically connected to a cation conductivity sensor configured to measure a cation conductivity of an effluent output from the outlet.

30 [020] The approaches described here can have one or more of the following advantages. The laboratory-scale ion conductivity measurement system described here are small, portable, and inexpensive to install and maintain. These systems provide a

low-cost approach to determining contamination of fluid samples in a laboratory setting.

[021] The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features and advantages will be apparent from the description and drawings, and from the claims.

Brief Description of Drawings

[022] Fig. 1 is a diagram of an electrical conductivity measurement system.

[023] Fig. 2 is a diagram of an electrical conductivity filter.

[024] Figs. 3 and 4 are flow charts.

Detailed Description

[025] We describe here a laboratory-scale ion conductivity measurement system, such as a cation conductivity measurement system. The ion conductivity measurement system includes an ion conductivity filter that includes three filters disposed in a housing: a first cellulose filter for removal of solids suspended in a fluid sample, an ion exchange resin filter for ion exchange with contaminant ions in the fluid sample, and a second cellulose filter for removal of particulate matter from the ion exchange resin filter. The ion conductivity (for instance, the cation conductivity) of the effluent exiting the ion conductivity filter is measured to characterize the purity of the fluid sample.

[026] Referring to Fig. 1, a laboratory-scale ion conductivity measurement system 100 is configured for measurement of the ion conductivity (for instance, the cation conductivity) of a fluid sample 102. The fluid sample can be, for instance, a fluid sample from a steam generation facility, such as a power plant. For instance, the fluid sample can be steam, condensate, feed water, boiler water, evaporator water, or other fluid sample from a power plant. In an example, the fluid sample can be fluid obtained from a steam generation system, such as a heat recovery steam generator (HRSG). Measurement of the ion conductivity of the fluid sample can provide an indication of the purity of the fluid sample and hence the purity of the steam or water. Fluid purity in a power plant is important, for instance, to avoid the danger of corrosion of power plant elements or deposition of contaminants from the fluid onto power plant elements.

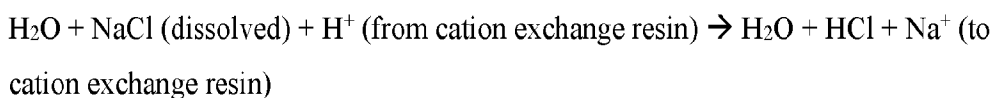
[027] Fluid in a power plant is sometimes treated with treatment chemicals such as ammonia or hydrazine, for instance, to reduce the potential for corrosion. In addition, power plants are sometimes cooled with cooling fluid such as sea water or well water, which include salts such as sodium chloride. Contamination of the power plant fluid by cooling water will result in an increase in the salt concentration in the power plant fluid, which can be detected by ion conductivity measurements. With the laboratory-scale ion conductivity measurement system 100, salt contamination can be detected in small samples of fluid. By detecting salt contamination on a small scale, the need for an online ion conductivity analyzer integrated into the power plant can be reduced, reducing the capital and maintenance costs and space requirements associated such online analyzers.

[028] The fluid sample 102 is provided to an ion conductivity filter 104 in the ion conductivity measurement system 100. The ion conductivity filter 104 includes multiple filter components disposed in a housing 106, such as three layers of filters. The filter components include a first cellulose filter 108 that is configured to filter solids suspended in the fluid sample 102. The filter components include an ion exchange resin filter 110 that acts as a medium for ion exchange, such as cation or anion exchange. The filter components also include a second cellulose filter 112 that is configured to filter particulate matter from the cation exchange resin filter 110. Filtered effluent 114 exiting the ion conductivity filter 104 flows to an ion conductivity sensor 116 that measures the ion conductivity (such as the cation or anion conductivity) of the effluent 114. The ion conductivity of the effluent is an indication of the level of contamination of the fluid sample, as discussed *infra*.

[029] The ion exchange resin filter 110 is formed of a material that is capable of binding to dissolved ions in the fluid sample 102. For instance, to facilitate detection of contaminant salts in the fluid sample, the ion exchange resin filter 110 can be a cation exchange filter that is formed of a material that is capable of binding to cations in the fluid sample 102. As the fluid sample 102 flows across the cation exchange resin filter, dissolved cations from the contaminant salt bind to the cation exchange resin filter, which releases a hydrogen ion (H^+) in exchange. The released hydrogen ions react with the dissolved anions from the contaminant salt to form an acid.

[030] In a specific example, the fluid sample 102 may be water, such as sea water or well water, that is contaminated with sodium chloride (NaCl). The ion exchange resin

filter 110 is a cation exchange filter that includes hydrogen ions (H^+). The hydrogen ions from the ion exchange resin filter 110 exchange with the dissolved sodium ions (Na^+) in the fluid sample. The sodium ions bind to the cation exchange resin filter, and the hydrogen ions from the cation exchange filter react with the dissolved chlorine ions (Cl^-) in the fluid sample to form hydrochloric acid (HCl). This example reaction is given as follows:



[031] The presence of acid (for instance, hydrochloric acid) in the effluent 114 that exits the ion conductivity filter 104 increases the cation conductivity of the effluent 114 as compared to an effluent without acid. As the amount of contaminant in the fluid sample 102 increases, the amount of acid in the effluent 114 also increases, causing a corresponding increase in the cation conductivity of the effluent 114. Thus, measuring the cation conductivity of the effluent 114 provides an indication of whether the fluid sample is contaminated with salt. A high cation conductivity value indicates that the fluid sample is contaminated. Conversely, if the fluid sample 102 has little to no salt contamination, the cation conductivity of the effluent 114 will be substantially the same as the cation conductivity of a baseline, uncontaminated sample, such as a sample of pure water.

[032] Referring to Fig. 2, an example laboratory-scale cation conductivity filter 200 includes a filter housing 202 with an inlet 204 at one end of the filter housing 202 and an outlet 206 at the opposite end of the filter housing 202. The inlet 204 and outlet 206 can be connected to tubing 205, 207, respectively, via a screw connection, press fit connection, or other suitable fluid tight connection. The inlet 204 and outlet 206 are fluidically connected to an interior of the filter housing 202 such that fluid entering the filter housing 202 via the inlet 204 can flow through the filter housing 202 and exit the filter housing 202 via the outlet 206. The filter housing 202 can be, for instance, a cylindrical housing. The filter housing 202 is formed of material that is non-reactive to the filters housed in the filter housing and to the fluid samples to be filtered through the cation filter 200. The filter housing has a length of up to about 12 cm, for instance, 10-12 cm. The width of the housing is up to about 2 cm, for instance, 1-2 cm. The thickness of the walls of the housing is up to about 0.4 cm, for instance, 0.2-0.4 cm.

[033] A first cellulose filter 208 is disposed in the interior of the filter housing 202, adjacent to the inlet 204. A second cellulose filter 210 is disposed in the interior of the filter housing 202, adjacent to the outlet 206. A cation exchange resin filter 212 is disposed in the interior of the filter housing 202, between the first and second cellulose filters 208, 210. The filters 208-212 are arranged in the interior of the filter housing 202 such that fluid entering the filter housing 202 via the inlet 204 flows first through the first cellulose filter 208, then through the cation exchange resin filter 212, then through the second cellulose filter 210, before exiting from the filter housing 202 via the outlet 206.

[034] The first cellulose filter 208 is designed to capture solids suspended in the fluid that flows into the electrical conductivity filter 200, and can be sized based on the expected size of such solids. For instance, the first cellulose filter 208 can be a 0.45 μm filter. The first cellulose filter has a length of up to about 0.4 cm, for instance, 0.2-0.4 cm, and is dimensioned to fill the width of the interior space of the housing. In some examples, the cellulose filter is made from high-quality cotton linters, such as cotton linters that have been treated to achieve a minimum alpha cellulose content of 98% and certified not to leach ions raising the electrical conductivity to less than about 0.1-0.2 $\mu\text{S}/\text{cm}$ (micro Siemens per centimeter). In some examples, a glass microfiber or quartz filter is used instead of a cellulose filter.

[035] The cation exchange resin filter 212 acts as a medium for cation exchange with the fluid flowing through the cation conductivity filter 200. The cation exchange resin filter 212 has a high surface area-to-volume ratio to facilitate efficient cation exchange. In an example, the cation resin filter is a macro porous polystyrene cross linked with divinylbenzene with spherical beads and having the following technical properties:

Functional Group	Sulfonic Acid
Ionic Form	Na^+ form or H^+
Total Capacity	1.8 eq/L (equivalent per liter) (39.3 kg/ft^3) (Na^+ form)
Moisture Retention	48 - 53 % (Na^+ form)
Particle Size Range	300 - 1200 μm
Uniformity Coefficient	1.7 (maximum)
Reversible Swelling, $\text{Na}^+ \rightarrow \text{H}^+$	4% (maximum)

Specific Gravity	1.25
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[036] The material for the cation exchange resin filter 212 is capable of binding to negatively charged ions in the fluid sample, such as contaminant cations in the fluid sample, such as calcium ions, magnesium ions, sodium ions, ammonium ions, or other cations. In exchange, the cation exchange resin filter 212 releases hydrogen ions into the fluid sample. The cation exchange resin filter 212 can be formed of a material with acidic functional groups, such as carboxylic acid groups, sulfonic acid groups, or other appropriate acidic functional groups, that can supply hydrogen ions to the fluid sample. For instance, the sulfonic acid group is the source of the H^+ , which gives this chemical structure the ability to behave as a reactive acid.

[037] The second cellulose filter 210 is designed to capture particulate matter from the cation exchange resin filter 212, to prevent particulate matter from leaching into the fluid sample that is output from the cation conductivity filter 200. The second cellulose filter 210 can be sized based on the expected size of such solids. For instance, the second cellulose filter 210 can be a 0.45 μm filter. The materials and design characteristics of the second cellulose filter are similar to those discussed *supra* for the first cellulose filter.

[038] The dimensions and design characteristics of the cellulose filters and cation exchange filter are selected to allow the exchange to occur with a reasonable time rate that enables a measurable amount of a sample at the outlet.

[039] A side inlet 220 and a side outlet 222 are disposed along the length of the filter housing 202. The side inlet 220 and side outlet 222 are aligned with the cation exchange resin filter 212, with the distance between the side inlet 220 and the inlet 204 of the filter housing 202 being less than the distance between the side outlet 222 and the inlet 204 of the filter housing 202.

[040] The side inlet 220 can be fluidically connected to a fluid reservoir 224 via inlet tubing 221. Fluid from the fluid reservoir 224 can enter the cation conductivity filter 200 via the side inlet 220, flow along at least a portion of the length of the cation exchange resin filter 212, and exit the cation conductivity filter 200 via the side outlet 222. In some examples, the fluid from the side outlet 222 returns to the fluid reservoir 224 via outlet tubing 223. In some examples, the fluid from the side outlet 222 is discarded. The fluid reservoir 224 can be a reservoir of a cleaning fluid, such as water,

that can be flowed along the cation exchange resin filter 212 to rinse the cation exchange resin filter 212 prior to use. The fluid reservoir 224 can be a reservoir of a regeneration fluid, such as an acid (for instance, 5% hydrochloric acid or 5% sulfuric acid), that can be flowed along the cation exchange resin filter 212 for cation
5 regeneration. In some examples, the side inlet 220 is configured to be connected to multiple reservoirs, such as to both a cleaning fluid reservoir and a regeneration fluid reservoir.

[041] Effluent exiting the cation conductivity filter 200 via the outlet 206 flows to a cation conductivity sensor (not shown), where the cation conductivity of the effluent is
10 measured.

[042] Referring to Fig. 3, in an example process for making a laboratory-scale ion conductivity measurement system, a first cellulose filter is placed into the interior of a filter housing adjacent to an inlet of the ion conductivity filter (300). An ion exchange resin filter (for instance, a cation exchange resin filter) is placed into the interior of the
15 filter housing adjacent to the first cellulose filter (302). A second cellulose filter is placed into the interior of the filter housing adjacent to the first cellulose filter and to an outlet of the ion conductivity filter (304). In some examples, the first cellulose filter can be placed adjacent to the outlet of the filter housing and the second cellulose filter can be placed adjacent to the inlet of the filter housing.

[043] The inlet of the ion conductivity filter is connected to tubing, for instance, by a
20 screw connection, press fit connection, or other suitable fluid tight connection (306). The tubing is fluidically connected to a fluid source such that a fluid sample can be provided to the inlet of the electrical conductivity filter via the tubing (308). In some examples, rather than connecting the tubing to a fluid source, a fluid sample is
25 provided directly to the tubing, for instance, by a laboratory technician.

[044] The outlet of the ion conductivity filter is connected to tubing, for instance, by a screw connection, press fit connection, or other suitable fluid tight connection (310). The tubing is fluidically connected to an ion conductivity sensor that can measure the ion conductivity of the effluent leaving the ion conductivity filter (312). In some
30 examples, the ion conductivity sensor can be connected close to the outlet of the filter housing to reduce the likelihood of gas bubbles being present in the ion conductivity sensor.

[045] Referring to Fig. 4, in an example process for operating a laboratory-scale cation conductivity measurement system, a cation exchange resin filter disposed in a filter housing of a cation conductivity filter is cleaned with a regeneration fluid to regenerate the resin (400). For instance, the resin is regenerated by flowing an acidic regeneration fluid, such as a solution of 5% hydrochloric acid or 5% sulfuric acid in water, is flowed across the cation exchange resin filter. The regeneration solution is input into a side inlet of the cation conductivity filter, flows along the length of the cation exchange resin filter, and exits from the electrical conductivity filter via a side outlet. The cation exchange resin filter is rinsed with a cleaning fluid, such as water, that is input into the side inlet of the cation conductivity filter and exits from the cation conductivity filter via the side outlet (402).

[046] A fluid sample is provided to the inlet of the cation conductivity filter (404). The fluid sample first flows across a first cellulose filter disposed in a housing of the cation conductivity filter (406). The first cellulose filter captures solids that are suspended in the fluid sample. The fluid sample then flows across a cation exchange resin filter disposed in the housing of the cation conductivity filter (408). Cation exchange occurs between the cation exchange resin filter and cations of any salt contaminant that may be in the fluid sample, with cations from the salt contaminant (such as sodium ions) binding to the cation exchange resin filter and hydrogen ions from the cation exchange resin filter entering into solution in the fluid sample (410). The hydrogen ions from the cation exchange resin filter react with anions from the salt contaminant (such as chlorine ions) to produce an acid (such as hydrochloric acid) (412).

[047] The fluid sample, having undergone cation exchange, then flows across a second cellulose filter disposed in the housing of the cation conductivity filter (414). The second cellulose filter captures particulate matter from the cation exchange resin filter. The fluid sample exits the cation conductivity filter as an effluent (416) and the cation conductivity of the effluent is measured by the cation conductivity sensor (418). The measured cation conductivity is compared to a baseline electrical cation conductivity, such as the electrical cation conductivity of pure water (420). If the measured cation conductivity is greater than the baseline cation conductivity by at least a threshold amount, the fluid sample can be considered to be contaminated with a salt. If the measured cation conductivity is within the threshold amount of the baseline

cation conductivity, the fluid sample can be considered to be substantially uncontaminated.

[048] After use, the cation conductivity filter can be rinsed, detached from the various tubings, filled with a fluid, such as demineralized water, and capped at the inlet and outlet, for instance, for storage or transport (422).

[049] In some examples, the contamination of the fluid sample can be evaluated based on a threshold difference between the cation conductivity of the effluent and a baseline cation conductivity, such as the cation conductivity of pure water. If the measured cation conductivity of the effluent is greater than the baseline cation conductivity by at least a threshold amount, the fluid sample can be considered as contaminated with salt. If the measured cation conductivity of the effluent is within the threshold amount of the baseline cation conductivity, the fluid sample can be considered to be substantially uncontaminated. The threshold can be, for instance, 0.5 μmho per centimeter, with higher measured cation conductivity values indicating greater contamination of the tested sample]

Example

[050] A laboratory scale cation conductivity measurement system including a cation conductivity filter such as that shown in Fig. 2 was tested to measure the cation conductivity of two different fluid samples with compositions as shown in the following Table. As indicated in the Table, the conductivity of the two samples was different, indicating a different level of contamination in each sample.

	Cation column Inlet Sample Analysis	Cation column Outlet Sample Analysis
Sample	Electrical Conductivity at 25°C	Electrical Cation Conductivity at 25°C
	$\mu\text{mhos/cm}$	$\mu\text{mhos/cm}$
1	6.0	1.2*
2	6.0	0.4

*The conductivity result shows a higher electrical cation conductivity for sample 1 indicating a possible contamination.

[051] Particular embodiments of the subject matter have been described. Other embodiments are within the scope of the following claims. For example, the actions recited in the claims can be performed in a different order and still achieve desirable results. As one example, the processes depicted in the accompanying figures do not
5 necessarily require the particular order shown, or sequential order, to achieve desirable results.

What is claimed is:

1. An apparatus for measuring the cation conductivity of a fluid sample, the apparatus comprising:

a housing having an inlet disposed at a first end of the housing and an outlet
5 disposed at a second end of the housing, the second end opposite the first end, wherein the inlet of the housing is configured to receive the fluid sample;

a first cellulose filter disposed in the housing adjacent to the inlet;

a second cellulose filter disposed in the housing adjacent to the outlet; and

10 a cation exchange resin filter disposed in the housing between the first cellulose filter and the second cellulose filter,

wherein the outlet of the housing is configured to be fluidically connected to a cation conductivity sensor configured to measure a cation conductivity of an effluent output from the outlet of the housing.

15

2. The apparatus of claim 1, wherein the first cellulose filter comprises a 0.45 μm cellulose filter.

3. The apparatus of claim 1, wherein the second cellulose filter comprises a 0.45 μm
20 cellulose filter.

4. The apparatus of claim 1, wherein the cation exchange resin filter is formed of a material comprising acidic functional groups.

25 5. The apparatus of claim 1, comprising:

a side inlet disposed along a length of the housing; and

a side outlet disposed along the length of the housing,

wherein the side inlet and side outlet are aligned with the cation exchange resin
filter.

30

6. The apparatus of claim 5, wherein the side inlet is configured to be fluidically connected to a fluid source.

7. The apparatus of claim 6, comprising a source of regeneration fluid fluidically connected to the side inlet.
8. The apparatus of claim 7, wherein the source of regeneration fluid comprises a source of hydrochloric acid or sulfuric acid.
9. The apparatus of claim 5, wherein a distance between the side inlet and the inlet of the housing is less than a distance between the side outlet and the inlet of the housing.
10. The apparatus of claim 1, comprising the cation conductivity sensor.
11. A method of measuring the cation conductivity of a fluid sample, the method comprising:
- flowing the fluid sample through an ion conductivity filter, comprising:
 - flowing the fluid sample across a first cellulose filter disposed in a housing, wherein the first cellulose filter is disposed adjacent to an inlet to the ion conductivity filter, the inlet disposed at a first end of the housing;
 - flowing the fluid sample from the first cellulose filter across a cation exchange resin filter disposed in the housing; and
 - flowing the fluid sample from the cation exchange resin filter across a second cellulose filter disposed in the housing, wherein the second cellulose filter is disposed adjacent to an outlet from the ion conductivity filter, the outlet disposed at a second end of the housing, the second end opposite the first end; and
 - providing an effluent from the outlet of the ion conductivity filter to a cation conductivity sensor configured to measure a cation conductivity of the effluent.
12. The method of claim 11, comprising by the cation conductivity sensor, measuring the cation conductivity of the effluent.

13. The method of claim 12, comprising comparing the measured cation conductivity of the effluent to a baseline cation conductivity.
14. The method of claim 12, comprising determining a contamination of the fluid sample based on the measured cation conductivity of the effluent.
15. The method of claim 14, comprising determining that the fluid sample is contaminated when the measured cation conductivity of the effluent exceeds a baseline cation conductivity by at least a threshold amount.
16. The method of claim 11, wherein flowing the fluid sample across the cation exchange resin filter comprises binding contaminant cations from the fluid sample to the cation exchange resin filter.
17. The method of claim 16, wherein the cation exchange resin filter releases hydrogen ions responsive to the binding of contaminant cations.
18. The method of claim 11, wherein flowing the fluid sample across the first cellulose filter comprises removing suspended solids from the fluid sample.
19. The method of claim 11, wherein flowing the fluid sample across the second cellulose filter comprises removing particulate matter from the cation exchange resin filter from the fluid sample.
20. The method of claim 11, comprising flowing a regeneration fluid across the cation exchange resin filter.
21. The method of claim 20, comprising flowing the regeneration fluid into a side inlet disposed along a length of the housing and aligned with the cation exchange resin filter, across the cation exchange resin filter, and out a side outlet disposed along the length of the housing and aligned with the cation exchange resin filter.

22. The method of claim 11, comprising rinsing the cation exchange resin filter with a cleaning fluid.
23. The method of claim 22, comprising flowing the cleaning fluid into a side inlet
5 disposed along a length of the housing and aligned with the cation exchange resin filter, across the cation exchange resin filter, and out a side outlet disposed along the length of the housing and aligned with the cation exchange resin filter.
24. The method of claim 11, comprising detaching the ion conductivity filter from the
10 cation conductivity sensor.
25. The method of claim 24, comprising filling the housing with a fluid and capping the inlet and outlet of the ion conductivity filter.
- 15 26. The method of claim 25, comprising storing the capped, detached ion conductivity filter.
27. A method of making an apparatus for measuring the cation conductivity of a fluid sample, the method comprising:
- 20 disposing a first cellulose filter in the interior of a housing adjacent to an inlet disposed at a first end of the housing;
- disposing a cation exchange resin filter in the interior of the housing adjacent to the first cellulose filter; and
- 25 disposing a second cellulose filter in the interior of the housing adjacent to the cation exchange resin filter and adjacent to an outlet disposed at a second end of the housing, the second end opposite the first end,
- wherein the outlet is configured to be fluidically connected to a cation conductivity sensor configured to measure a cation conductivity of an effluent output from the outlet.

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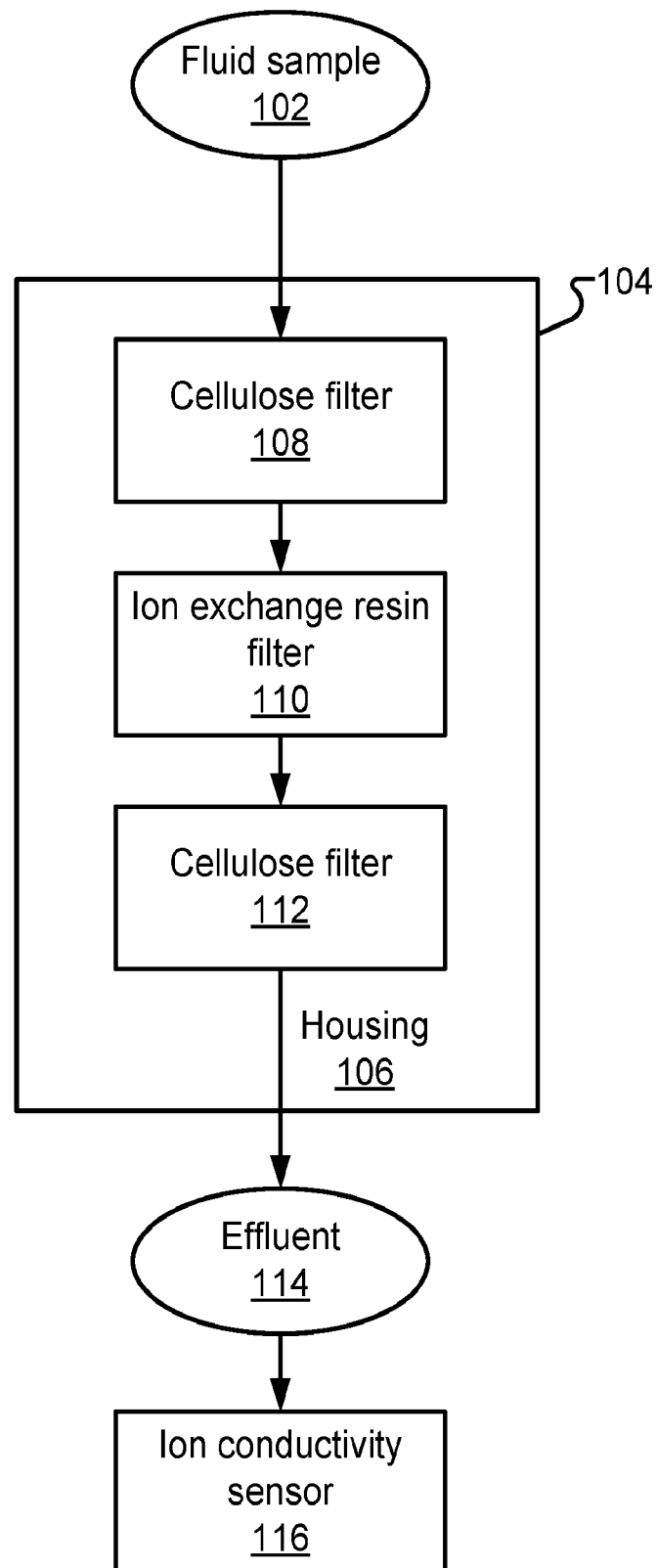


FIG. 1

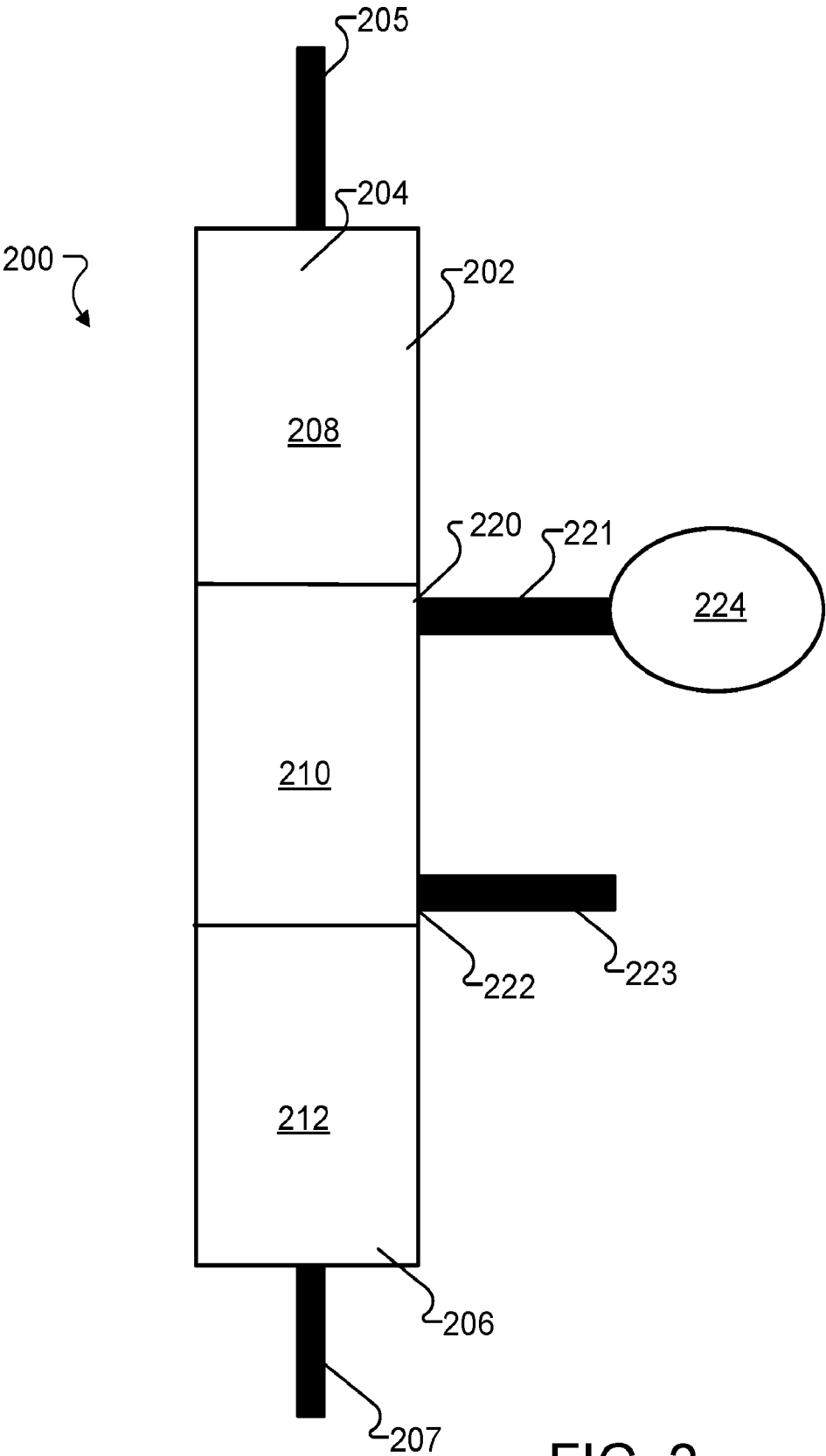


FIG. 2

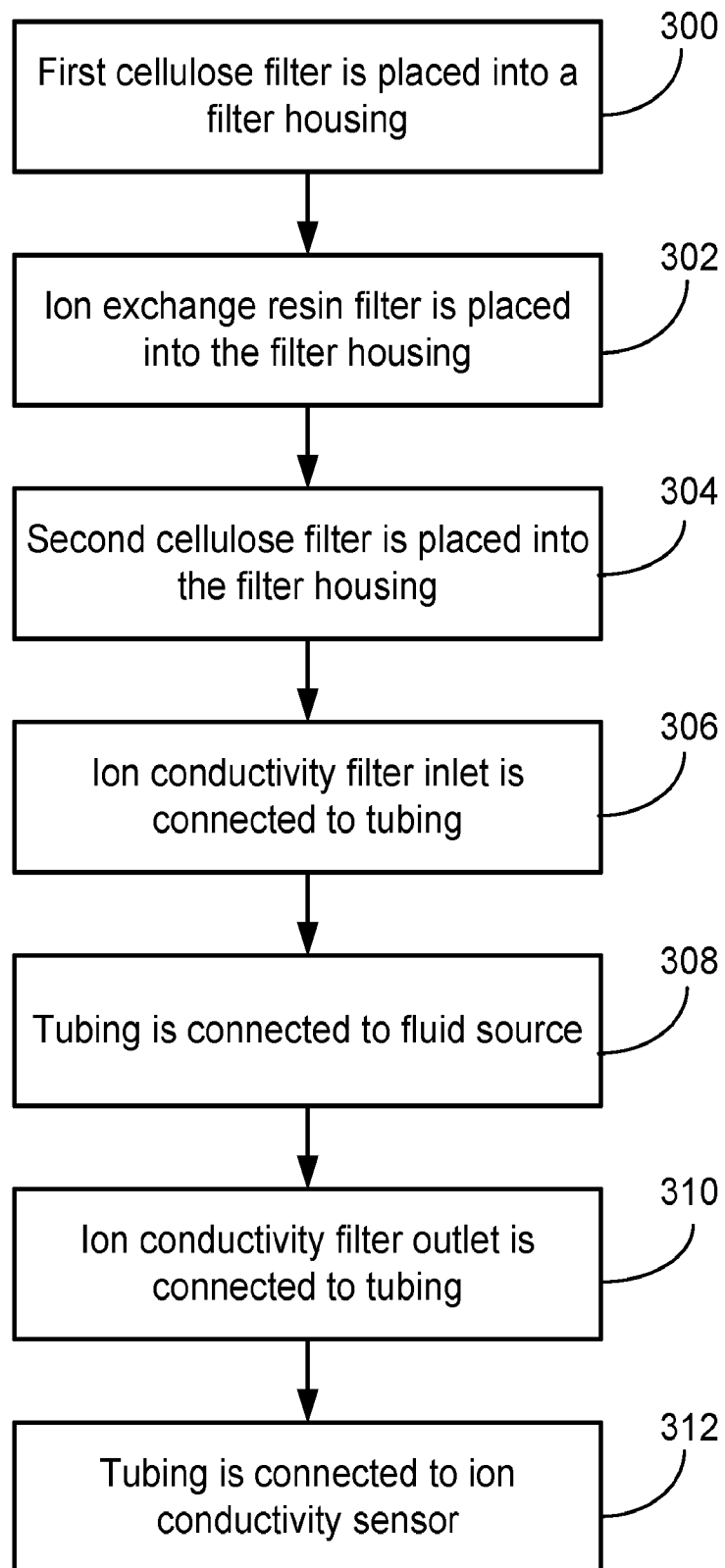


FIG. 3

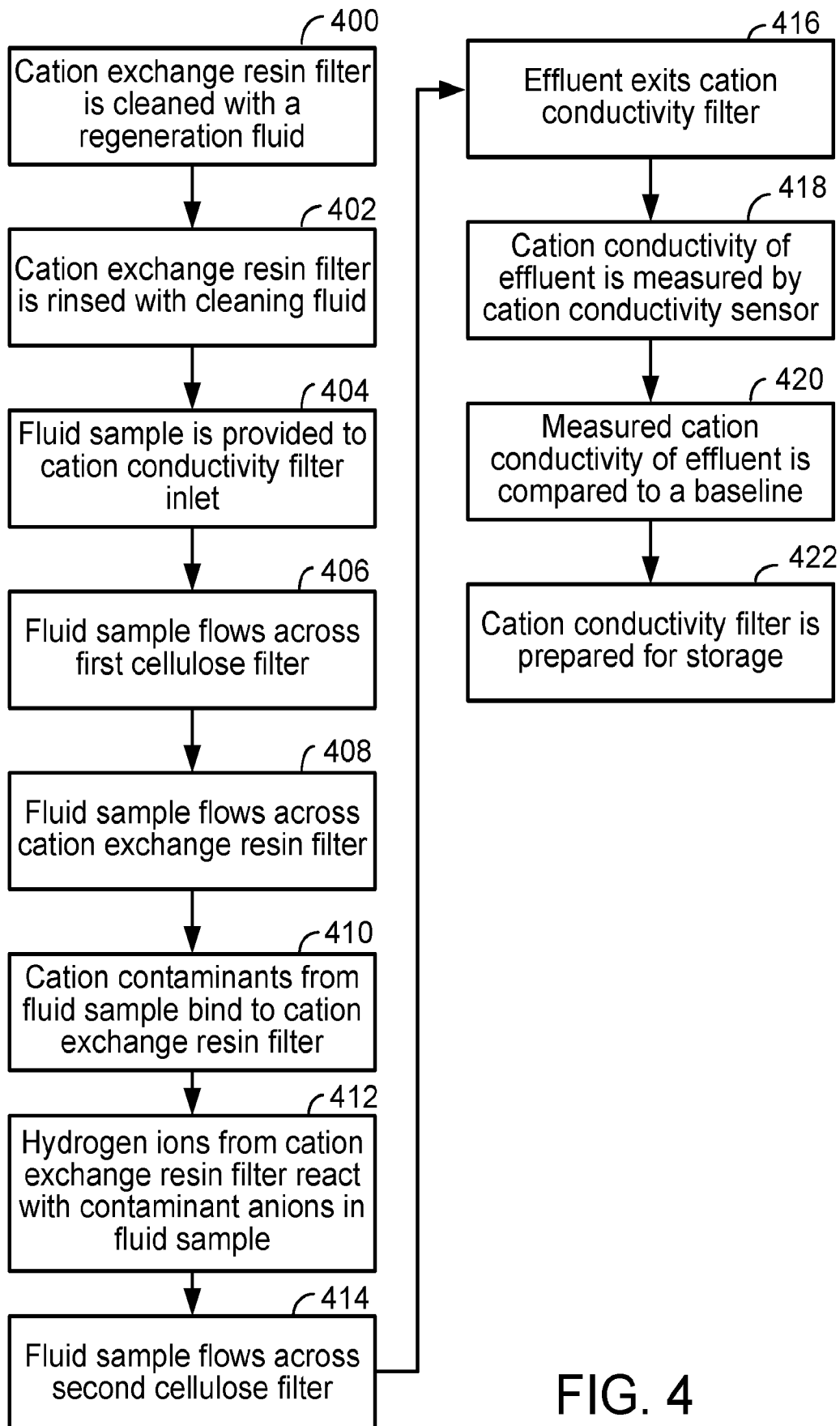


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2021/043652

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01N33/18
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)
G01N

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	US 6 114 176 A (EDGSON RAYMOND [GB] ET AL) 5 September 2000 (2000-09-05) the whole document	1-27
X	EP 2 816 348 A1 (UNIVERSITÄT WIEN [AT]) 24 December 2014 (2014-12-24) the whole document	1-27
X	JP S60 91259 A (DENKI KAGAKU KEIKI KK) 22 May 1985 (1985-05-22) the whole document	1-27
X	JP 2010 029104 A (NITTETSU KANKYO ENGINEERING KK; UNIV KYUSHU) 12 February 2010 (2010-02-12) the whole document	1-27
	----- -/-	

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

26 October 2021

Date of mailing of the international search report

05/11/2021

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Authorized officer

De Masi, Rita

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2021/043652

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2007 183133 A (NICHIRI KOGYO KK) 19 July 2007 (2007-07-19) the whole document -----	1-27
X	US 2005/274676 A1 (KUMAR MUKESH [US] ET AL) 15 December 2005 (2005-12-15) the whole document -----	1-27
X	JP S60 152931 A (JGC CORP) 12 August 1985 (1985-08-12) the whole document -----	1-27

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2021/043652

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6114176	A	05-09-2000	AT 242338 T 15-06-2003
			AT 318929 T 15-03-2006
			AU 693233 B2 25-06-1998
			BR 9508456 A 23-12-1997
			CA 2196161 A1 15-02-1996
			DE 69530986 T2 19-05-2004
			DE 69534809 T2 10-08-2006
			EP 0772693 A1 14-05-1997
			EP 1182264 A2 27-02-2002
			ES 2194916 T3 01-12-2003
			JP 3616644 B2 02-02-2005
			JP H10504190 A 28-04-1998
			US 6114176 A 05-09-2000
			US 6521184 B1 18-02-2003
			WO 9604401 A1 15-02-1996
EP 2816348	A1	24-12-2014	NONE
JP S6091259	A	22-05-1985	JP H0442620 B2 14-07-1992
			JP S6091259 A 22-05-1985
JP 2010029104	A	12-02-2010	JP 5504439 B2 28-05-2014
			JP 2010029104 A 12-02-2010
JP 2007183133	A	19-07-2007	NONE
US 2005274676	A1	15-12-2005	DE 102005024991 A1 23-02-2006
			US 2005274676 A1 15-12-2005
JP S60152931	A	12-08-1985	NONE