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(54) Title: METHOD AND DEVICE FOR ELECTROCHEMICALLY DISINFECTING FLUIDS

(57) **Abrégé/Abstract:**

A method for treating fluids operates on a continuously flowing stream of fluid. The stream is acted upon in a continuous flow process to generate a disinfectant species (e.g., chlorine) in the stream and to simultaneously lower the pH of the stream below approximately 4.0. The stream is passed through an electrochemical cell and an electric potential difference is applied across electrodes of the cell during the passage of the stream through the cell. Relative to its flow through a channel upstream of the cell, the stream is accelerated when flowing through the cell. The stream at an outlet of the electrochemical cell is used to raise the pH of the stream to a neutral range, thus producing a disinfected solution. This step may be implemented by passing the effluent stream between differentially charged electrodes, for example, of the same electrochemical cell. A chemical disinfecting method is also disclosed.



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(54) Title: METHOD AND DEVICE FOR ELECTROCHEMICALLY DISINFECTING FLUIDS

(57) Abstract: A method for treating fluids operates on a continuously flowing stream of fluid. The stream is acted upon in a continuous flow process to generate a disinfectant species (e.g., chlorine) in the stream and to simultaneously lower the pH of the stream below approximately 4.0. The stream is passed through an electrodialytic cell and an electric potential difference is applied across electrodes of the cell during the passage of the stream through the cell. Relative to its flow through a channel upstream of the cell, the stream is accelerated when flowing through the cell. The stream at an outlet of the electrodialytic cell to raise the pH of the stream to a neutral range, thus producing a disinfected solution. This step may be implemented by passing the effluent stream between differentially charged electrodes, for example, of the same electrodialytic cell. A chemical disinfecting method is also disclosed.

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METHOD AND DEVICE FOR ELECTROCHEMICALLY DISINFECTING FLUIDS

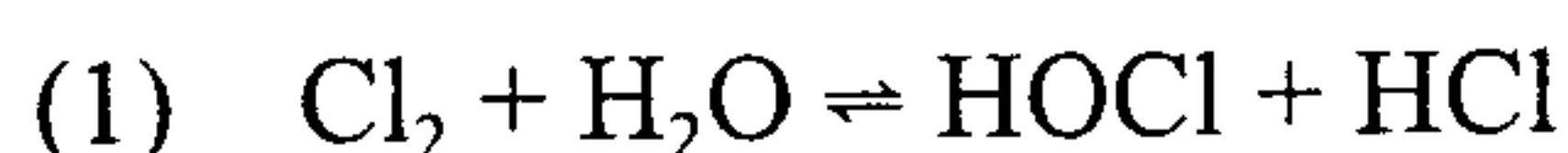
FIELD OF THE INVENTION

This invention relates to the disinfection of water. In particular, this invention relates to the electrochemical disinfection of fluid without the addition of chemicals. In an additional aspect of this invention a chemical method of disinfecting water is also provided.

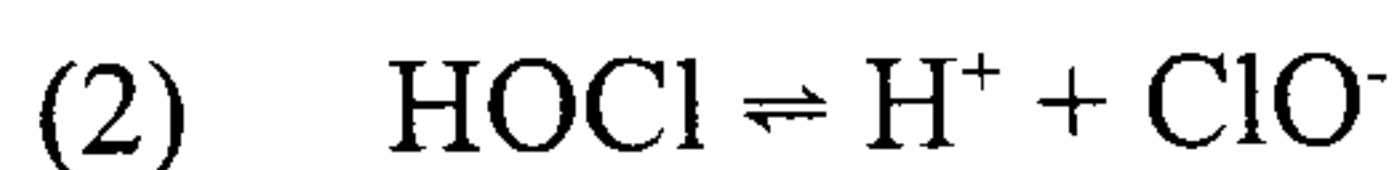
BACKGROUND

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It is well known to disinfect water by the addition of chlorine in an active form. In this context "active" means sufficiently electronegative or electron deficient to react with molecular components of bacteria, fungi, viruses, and algae or other microbes, damaging and ultimately killing these organisms. In practice, despite the claims of some manufacturers for devices producing "monatomic chlorine" and the possible significance of such free-radicals as reaction intermediates, the most biocidally active chlorine containing species likely to be found in significant quantities in aqueous solution is hypochlorous acid, HOCl. The acid forms on dissolution of chlorine gas in water via the reaction:



15 Hypochlorous acid dissociates to form hypochlorite and hydrogen ions via:



Undissociated hypochlorous acid is believed to be approximately 80 - 100 times as biocidally active as the hypochlorite ion, consistent with the observation that less electron saturated chlorine-containing species are more chemically active. Hence solutions of chlorine gas in water are more effective biocides when held at lower pH, as is well known in the art. However, low pH chlorine solutions are so highly unstable and have such a limited shelf life that the storage and use of them as effective bactericides has heretofore been highly impractical. Hence low pH chlorine solutions for use as disinfectants must be produced on demand in situ by chemical addition or by another method. One such method is the chlor-alkali cell -- an electrolytic cell decomposing an alkali salt of chlorine via a redox reaction into an aqueous solution of the corresponding caustic, and chlorine gas (or its aqueous reaction products).

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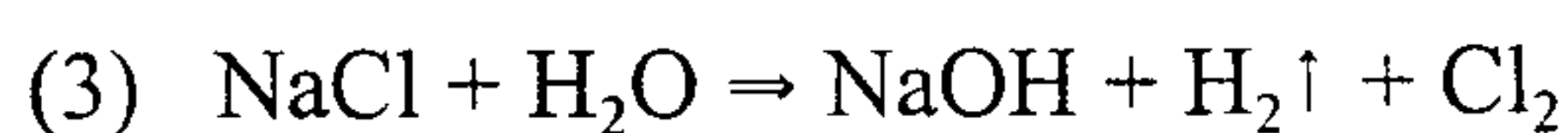
Within the general sector of the application of chlor-alkali cells focussing on the generation of chlorine gas, there exists a division of on-site application which utilize the

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generated chlorine gas as a disinfectant when mixed with water. The active biocide is hypochlorous acid, as discussed above. An optimum pH range for the dominance of hypochlorous acid is 4.5 - 6.0; at lower pH Cl_2 predominates, which dimer may be lost by outgassing because of limited solubility of chlorine in water, and at higher pH ranges hypochlorite ion (OCl^-) is the dominant species. Lower pH in addition to decreasing solution stability increases the caustic effect of active chlorine to mucous membranes, and renders such solutions less suitable than a pH neutral or mildly acidic form for bathing, washing, or drinking. For the aforementioned reasons, a chlorine solution acidified for enhancement of biocidal properties must be adjusted to near neutrality prior to use as potable water. In addition, residual chlorine levels must be held to a level generally no higher than 1 ppm NaOCl weight equivalent, or 1 milligram/liter, to avoid unacceptable chlorine odors. A residual of this order of concentration is however desirable to provide a persistent resistance to reinfection in the effluent.

To produce an acidified aqueous solution of chlorine either electrolysis or chemical addition may be utilized. While direct dissolution of chlorine gas in water is naturally acidifying via a concomitant production of hydrogen chloride as shown in equation (1) above, use of the gas may not be practical for many applications, and more stable and transportable species such as calcium or sodium hypochlorite will frequently be applied in the solid form. A weakly basic solution naturally forming upon aqueous dissolution of sodium hypochlorite may be acidified by addition of a mineral acid, and if necessary subsequently neutralized. However, each subsequent chemical addition step naturally raises the net cost, and moreover, solid hypochlorite salts are more expensive sources than the gas per unit weight of element to begin with.

It is known that active chlorine species may be produced as described above by the electrolysis of brines or saline solutions in an electrolytic cell containing an anode -- or positively charged electrode, and a cathode -- or negatively charged electrode. The total reaction is:



Dissolved chlorine gas possibly further reacts with water according to (1) above, to yield an overall reaction:

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The net product is a weakly basic solution of sodium hypochlorite. However, chlorine and its aqueous reaction products according to (1) are produced at the anode, whilst hydrogen and sodium hydroxide are produced at the cathode, so that reaction (4) will not be complete until physical mixing has occurred between anolyte -- or electrolyte in physical proximity to the anode, and catholyte -- or electrolyte in physical proximity to the cathode. Mixing of the anolyte and catholyte however may be delayed by introduction of a semi-permeable membrane or other barrier to bulk flow between the anode and cathode, thereby isolating an anolyte compartment and a catholyte compartment. Under these circumstances the anolyte will tend towards acidity, while the catholyte will tend towards basicity, considering reactions occurring at the electrodes and neglecting possible ancillary reactions at the barrier or semi-permeable membrane.

On the other end of the biocidal activity scale from chlorine dimer and hypochlorous acid is the ubiquitous and essentially inert chloride ion, Cl^- . Far from being biocidal, chloride plays a necessary role in cell metabolism. Chloride is traditionally excluded from measures of active chlorine content such as "total residual chlorine" (TRC), which measure includes some substantially inactivated or reduced forms of the element, such as the chloramines, but not the fully reduced or anionic form. Chloramines and other chlorine nitrogen compounds are sometimes referred to as a "combined chlorine" component of TRC, while the sum of HOCl and ClO^- concentrations are sometimes known as a "free chlorine" or "free available chlorine" (FAC) component of TRC. Another term of art is "nascent" chlorine. "Nascent" chlorine is most logically identified with "nascent" or newly born free radicals or monatomic gas formed on electrolysis, but also refers in the art to any chemically active or highly oxidized form of the element. The general sense seems to be that in oxidizing chlorine from salt the element will temporally progress from the initially most active forms, such as the free chlorine radical, through forms of intermediate activity, such as the dimer or hypochlorous acid, to forms of low reactivity, such as the chloramines, a progression in accordance with the ordinary laws of thermodynamics. Those forms temporally closer to inception or birth of the "nascent" chlorine monomer are more chemically active, and hence more active disinfectants.

When it is desirable to monitor pH level and FAC these quantities may be measured

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by means of probes functioning as electrodes of standard electrochemical cells, measuring induced voltage against a reference voltage. In the case of measurement of chlorine level, this measurement may with equal justice be referred to as a "redox potential", and is often so referred to in the art. To gauge the biocidal effectiveness of a chlorine containing solution, it is necessary to both know the pH, and some measure of the concentration of active chlorine containing species, such as FAC or a redox potential.

PRIOR ART

It is known that one can produce a combination of chlorine gas and caustic, according to reaction (3), via an electrolytic cell. On-site chlorine generating units incorporating design modifications facilitating operation and convenience in relation to one or more features of the above described chemistry, and in particular relating to the application of electrolytically generated chlorine to swimming pool disinfection, are known in the art.

U. S. Patents Nos. 2,887,444 and 3,378,479 teach direct addition of salt to the pool water and the passing of the resulting saline pool water over an anode and cathode within a non-partitioned electrolytic unit. U. S. Patent 3,351,542 teaches generation of chlorine by means of a non-partitioned cell using a hydrochloric acid electrolyte, and the subsequent addition of electrolyte directly to the swimming pool for chlorination and pH control. The generation of a chlorine gas and hypochlorous acid anolyte solution from a sodium chloride electrolyte using a membrane cell with the application of the anolyte to the pool for disinfection purposes and the alternate addition of caustic catholyte to either the pool or to drain for pH control is taught by U. S. Patent 3,669,857. U. S. Patent 4,097,356 indicates a method of generating chlorine gas using a membrane cell with the chlorine mixed with pool water via an aspirator, surplus caustic being continually withdrawn from the unit.

Other methods and devices utilizing aspects of the above outlined aqueous chlorine chemistry and electro-chemistry are known.

U. S. Patent 3,819,329 to Kaestner et al. discloses a spray sanitizing system for creating a continuous supply of sanitizing liquid. The unit includes an electrolytic cell for

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instantaneously generating a relatively low pH bactericidal solution containing nascent chlorine (in this context, chlorine in an active or highly oxidized form), substantially entirely in the form of hypochlorous acid.

U. S. Patent 4,176,031 to Rosenblum discloses a digital hypochlorous acid analyzer
5 which functions by measuring, with three probes, free available chlorine concentration $[\text{HOCl} + \text{OCl}^-]$, pH, and temperature T. An electronic lookup table listing the value of acid equilibrium constant $K_a = ([\text{H}][\text{OCl}^-])/[\text{HOCl}]$ as a function of T for hypochlorous acid is then consulted and the pH or (log) hydrogen ion concentration $[\text{H}]$ used to evaluate the corresponding concentration ratio $[\text{OCl}^-]/[\text{HOCl}]$.

10 U. S. Patent 4,465,573 to O'Hare teaches a method and apparatus for the purification of water including filtering and passage through an electrodialytic cell. Production of chlorine in an anolyte is identified as a biocidal mechanism.

U. S. Patent 4,710,233 to Hohmann et al. teaches a method and apparatus for cleaning, disinfecting and sterilizing medical instruments, employing a first bath subjected to ultrasonic
15 energy, and a second saline bath passed through an electrolytic cell, followed by a rinse bath.

U. S. Patent 4,769,154 to Saylor et al discloses a method of treating waste water comprising flowing a batch of waste water adjusted to close to acid/base neutrality (pH 7) through a reactor along with chlorine gas. The chlorine gas is said to produce hypochlorous acid, in turn is said to produce "nascent oxygen and hypochlorite ions".

20 U. S. Patent 5,720,438 to Devine et al. teaches a method for treating infectious waste utilizing a sodium hypochlorite (NaOCl) solution adjusted to a pH of from about 4.0 to 6.0 to increase the hypochlorous acid (HOCl) component. This is said to enhance the microbiocidal properties of the solution more than 100 times.

U. S. Patent 5,902,619 to Rubow and Carnfeldt discloses a method and apparatus for

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disinfecting or sterilizing foodstuffs, providing a mist with an oxidizing or reducing potential, the mist being charged with a substance drawn from a list including hydrogen peroxide, ozone, chlorine gas or hypochlorite, which substances may optionally be generated in an electrolytic generator.

5 Also germane is U. S. Patent 5,462,644 to Woodson, which teaches that a broad spectrum of antibiotics is enhanced in effectiveness against pathogens residing in a self-generated semi-permeable membrane or film ("biofilm") following application of an electric field across the membrane or film, by an undisclosed mechanism.

U.S. Patent No. 4,240,489 to Adams et al. is directed to a wastewater treatment process
10 with pH adjustment to less than approximately 4.0 and with the addition of SO₂.

OBJECTS OF THE INVENTION

An object of the present invention is to provide a method for disinfecting fluids, particularly including water.

A more specific object of the present invention is provide a method for disinfecting
15 fluids without the admixture of additional chemicals.

A further object of the present invention is to provide a method of disinfecting fluids which is rapid.

An additional object of the present invention is to provide a method of disinfecting fluids which is efficient.

20 It is another object of the present invention to provide a method for introducing disinfecting quantities of chlorine into an aqueous solution without requiring storage of chlorine.

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It is also an object of the present invention to provide a disinfectant solution.

These and other objects of the present invention will be apparent from the drawings and descriptions herein.

SUMMARY OF THE INVENTION

5 A method for treating water, in accordance with a generalized embodiment of the present invention, operates on a continuously flowing stream. The stream of water is acted upon in a continuous flow process to generate a disinfectant species in the stream and to simultaneously lower the pH of the stream below approximately 4.0. The disinfectant species is preferably of chlorine. The solution produced by this process may be used as a disinfectant,
10 for example, in the cleansing of livestock and food products. An advantage of this method is that the method may use tap water or other generally available water. The aqueous disinfectant is produced on site without the necessity of transporting chlorine gas or adding salt.

 In accordance with another feature of the present invention, the stream is operated on
15 by passing the stream through an electrodialytic cell and applying an electric potential difference across electrodes of the cell during passing of the stream through the cell. Where the stream is guided initially through a channel upstream of the cell, the passing of the stream through the cell preferably includes accelerating the stream so that the stream when flowing through the cell has a velocity substantially greater than the stream when flowing through the
20 channel.

 In accordance with another feature of the present invention, the water treatment method further comprises operating on the stream at an outlet of the electrodialytic cell to raise the pH of the stream to a neutral range, thus producing a disinfected solution. This step may be implemented by passing the effluent stream between differentially charged electrodes,
25 for example, of the same electrodialytic cell. Where the cell has vertically oriented electrodes,

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the accelerating of the original stream and the effluent stream including directing the respective stream in a vertically upward direction.

A method for disinfecting water in accordance with the present invention includes feeding an influent stream of water of approximately neutral pH to an electrolytic cell in a continuous flow operation to produce a first effluent stream at an outlet of the cell, the first effluent stream having a pH below about 4.0, guiding the first effluent stream back to an inlet of the cell, and passing the first effluent stream through the cell to produce a second effluent stream having an approximately neutral pH. The resulting water is a disinfected solution.

Where the influent stream is guided through a channel upstream of the electrolytic cell, the feeding of the influent stream through the cell includes accelerating the influent stream so that the influent stream when flowing through the cell has a velocity substantially greater than the velocity of the influent stream flowing through the channel. Where the guiding of the first effluent stream preferably includes directing the first effluent stream through a feedback channel, the passing of the first effluent stream through the cell includes accelerating the first effluent stream so that the first effluent stream when flowing through the cell has a velocity substantially greater than the velocity of the first effluent stream flowing through the feedback channel.

The present invention identifies an efficient method of producing a disinfected solution. Moreover, the present invention identifies an efficient method of utilizing aqueous chlorine compounds generated *in situ* for the disinfection of flowing water. In particular, the present invention utilizes a device disclosed in United States Patent Application No. 08/982,700, which application is hereby incorporated by reference in its entirety. The device disclosed in United States Patent Application No. 08/982,700 may be referred to generically as an electrolytic pH adjuster. The electrolytic pH adjuster described in U.S. Patent Application No. 08/982,700 has been discovered to have an unexpected utility in the disinfection or sterilization of water. The electrolytic pH adjuster of U.S. Patent Application No. 08/982,700 is further described in International Application

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PCT/US98/25114, also incorporated herein by reference in its entirety.

A disinfected solution produced in accordance with the present invention may be useful in its own right as, for example, potable water, or it may have further utility as a means of disinfection of materials and surfaces. Water having a free residual chlorine content of approximately 1 ppm NaOCl weight equivalent is suitable for human consumption, whereas
5 water having a free residual chlorine content typically of from 50 to 200 ppm is suitable for use to disinfect other materials and surfaces. Free residual chlorine content in an effluent stream produced by the present invention will depend on a number of conditions, including influent quality, in particular chlorine demand or burden of chlorine-getting compounds, and
10 salinity or concentration of chloride ion. It is found by experience that substantially clean fresh water will have a low chlorine demand and typically sufficient chlorine as chloride to produce a pH-neutralized effluent containing from 5 - 6 ppm free residual or available chlorine, which can be controlled to a target value of 1 ppm. More concentrated saline solutions can however be used as feedstock in order to achieve more concentrated effluent.
15 Potential hydrogen (pH) and concentration of active chlorine containing species at the effluent can be measured by probes comprising specialized electrochemical cells. In this case the measurement providing imputed concentration of active chlorine containing species is sometimes referred to as an oxidation-reduction or redox potential.

The electrodialytic pH adjuster or water treatment device preferably comprises a space
20 or action zone between two electrodes, more specifically between a cathode and an anode, the device being operated with direct current. Where a diaphragm or membrane is disposed between the electrodes for establishing a low-pH anolyte passageway and a high-pH catholyte passageway, the low-pH anolyte passageway is the action zone i.e., that space or region where an aqueous solution is subjected to an electric field and to associated electrochemical activity
25 to lower the pH of the solution and to generate a disinfecting oxidant species into the solution. The fluid to be sterilized thus flows past electrode and membrane surfaces in the low-pH passageway. In the preferred embodiment of the electrodialytic pH adjuster or water treatment device in accordance with the present invention, an aqueous solution to be disinfected is fed through the low-pH passageway and the high-pH passageway *in seriatim*.

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The water treatment device includes an inlet and a channel in fluid communication with the inlet. The channel or inlet plenum forms one leg of an overall U-shaped vessel. A second leg of the U-shaped vessel, in communication with the inlet plenum through a bottom member or horizontal run of the U-shaped vessel, contains a zone or passage between two spaced electrodes and more specifically between an anode and a membrane, the zone or passage being configured to have a major or longitudinal dimension parallel to a major or longitudinal axis of the second leg of the U-shaped vessel. This zone or passage between the electrodes is known as the *action zone*. The action zone has a small cross section relative to the cross section of the inlet plenum, the cross sections being taken essentially perpendicular to a direction of fluid flow. This ratio of cross-sections serves to accelerate fluid flow through the action zone relative to the inlet plenum, in compliance with the physics of fluid flow through connected systems.

Accordingly, a liquid sterilizing method in accordance with the present invention utilizes an electrochemical or electrodialytic cell assembly having a pair of electrodes disposed adjacent to one another and additionally having an ion-permeable but hydraulically impermeable membrane, or else a substantially hydraulically impermeable diaphragm, disposed between the electrodes for dividing the space between the electrodes into a first passageway or chamber and a second passageway or chamber. The first passageway or chamber constitutes an action zone wherein a rapidly flowing aqueous stream is subjected to an electric field and to associated electrochemical activity to lower the pH of the stream and to generate a disinfecting oxidant species into the stream. Pursuant to the sterilization method, a first liquid stream is guided through the first passageway, the first liquid stream having an initial pH value typically near neutrality, an active chlorine content typically essentially zero, and an inactive chlorine content in the form of chloride, and a second liquid stream having an initially low pH and active and inactive chlorine content is directed through the second passageway. During this guiding and directing of first and second liquid streams, a potential difference is generated across the electrodes. The guiding of the first liquid stream, the directing of the second liquid stream, and the generating of the potential difference across the electrodes are coordinated or controlled so that an effluent liquid stream at an outlet of the

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electrochemical or electrodialytic cell has a desired pH value, and a redox potential corresponding to a certain concentration of active chlorine species.

The effluent stream of the desired sterile and biocidal properties may be the first liquid stream (an acidic stream), or a combination of the first and second liquid streams, or the first
5 liquid stream after it has subsequently transversed the second passageway (pH neutral), the first and second liquid streams in the latter instance being temporally displaced manifestations of but a single liquid stream.

In accordance with another feature of the present invention, the coordinating or controlling step includes varying the flow rate of at least one of the first liquid stream and the
10 second liquid stream. The varying of the flow rate may include diverting at least a portion of one of the first liquid stream and the second liquid stream from a downstream end of the electrodes to an inlet end of the first passageway or the second passageway. In that case, the varying of the flow rate may further include operating a pump to move the portion from the downstream end of the electrodes to the inlet end thereof. The variation in flow rate may be
15 implemented by operating a pump and/or by actuating a valve.

Pursuant to another feature of the present invention, the method further comprises automatically measuring a pH and a redox potential of a liquid stream at an outlet end of the electrochemical cell assembly and automatically comparing the measured pH and redox potential to a preselected reference pH value and redox potential value.

20 Where the first liquid stream and the second liquid stream are both derived at least in part from a third liquid stream at an inlet of the electrochemical cell assembly, the method further comprises dividing the third liquid stream to form at least portions of the first liquid stream and the second liquid stream. Where the first stream and the second stream are both entirely derived from the third liquid stream, the first stream and the second stream of course
25 have the same initial pH value and redox potential.

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In a particular embodiment of the present invention, the first liquid stream and the second liquid stream are along the same flow path through the electrochemical cell assembly, the second liquid stream being downstream of the first liquid stream. Thus, the first liquid stream and the second liquid stream are the same stream, viewed at different points along a flow path. The liquid flows through one passageway of the electrochemical or electrodialytic cell and subsequently flows through the other passageway thereof. In this embodiment, utilization of all of the liquid is assured, there being no diversion of a waste stream.

In accordance with another feature of the present invention, the method further comprises stabilizing a pH level and a redox potential of at least one of the first liquid stream and the second liquid stream at a fluid outlet end of the electrodes. The stabilizing is effected by guiding the one stream so that a substantial amount of the one stream flows over an electrode edge after adjustment of the one stream in the respective first passageway or second passageway. This edge is maintained at a common electrical potential with one of the electrodes.

As used herein, the term "adjust" or "adjusting" or "adjusted" when applied to the pH or redox potential of a fluid refers to a change or alteration in the pH and free chlorine content, of the fluid. As used herein, the term "stabilize" or "stabilizing" or "stabilized" means that a fluid of adjusted pH or redox potential corresponding to a particular concentration profile of active chlorine containing species is treated or acted upon to impart an enhanced degree of permanence to the adjusted pH level or concentrations of active chlorine containing species. This stabilizing effect is believed to result from contact with an electrode edge as described above. A similar effect is hypothesized for the redox potential. The mechanism of this stabilization is believed to be either a catalytic or rate enhancing effect of intense electric fields at the edge in driving aqueous ionic reactions to completion or equilibrium, or a turbulent or mixing effect eliminating stratification and driving a possibly inhomogeneous solution to overall equilibrium, or both. The correctness of any proposed mechanism, however, is neither essential to the description of nor limiting to the scope of the instant invention.

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In accordance with an additional feature of the present invention, the method further comprises feeding an incoming stream of liquid to an accumulating chamber upstream of the action zone, the accumulating chamber having a substantially greater cross-sectional area than the two passageways together or separately. In this way, liquid passing to the action zone is automatically accelerated pursuant to the principles of hydraulic flow.

The coordinating or controlling step may include varying a characteristic of electrical power applied to the electrodes. The current or the voltage may be varied. More particularly, the amplitude or intensity of the voltage or current may be varied. Where the voltage or current includes an a-c component, the variable characteristic or characteristics may include the period or frequency, the pulse shape, the interval between pulses, etc.

A liquid processing apparatus in accordance with the present invention comprises an electrochemical cell assembly having a pair of electrodes disposed adjacent to one another and additionally optionally having an ion-permeable membrane or diaphragm disposed between the electrodes for dividing an interelectrode space into a first passageway or sub-chamber and a second passageway or sub-chamber. The passageway or sub-chamber between the anode and the membrane constitutes an action zone wherein electrochemical disinfecting processes operate. A first flow guide extends to an inlet end of the first passageway for delivering to the first passageway a first liquid stream having an initial pH value and redox potential or concentration of active or free available chlorine (FAC). A second flow guide extends to an inlet end of the second passageway for delivering to the second passageway a second liquid stream. A voltage source is operatively connected to the electrodes to apply a potential difference across the electrodes. A flow control component is operatively connected to a least one of the electrochemical cell assemblies, the first flow guide and the second flow guide for coordinating the first liquid stream, the second liquid stream, and the potential difference so that an effluent liquid stream at an outlet of the electrochemical or electrodialytic cell assembly has a desired pH value and redox potential or FAC different from the initial pH value and FAC content.

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The flow control component may include a flow rate control element for varying a flow rate of at least one of the first liquid stream and the second liquid stream. The flow rate control element may be a valve and/or a pump which is operative to selectably divert at least a portion of one of the first liquid stream and the second liquid stream from a downstream end
5 of the action zone to an inlet end of one of the first passageway and the second passageway.

The apparatus may further comprise a pH detector and a redox potential probe disposed at an outlet end of the electrochemical cell assembly for automatically measuring a pH of a liquid stream at the outlet end. The flow rate control element is operatively connected to the pH detector and redox potential detector for varying the flow rate in response to a pH
10 value measured by the pH detector and redox or oxidation potential measured by the redox potential detector.

In a chemical method for producing a disinfectant solution, the present invention also relates to a batch or continuous process for disinfecting an aqueous solution comprising the steps of providing an aqueous solution at a pH of about 4.0 or less, preferably by adding to a
15 solution having a pH of greater than about 4.0 an effective concentration of a protic acid to lower the pH of said solution to about 4.0 or less to produce a low pH solution; adding to said low pH solution an effective amount of least one oxidizing disinfectant compound, preferably in solution at a pH of about 4.0 or less; exposing the low pH solution to the oxidizing disinfectant compound at a pH of less than about 4.0 and for a period of time sufficient to
20 allow the oxidizing disinfectant compound to disinfect the low pH solution and after the disinfection step, raising the pH of the resulting disinfected solution to a pH of at least about 5.5, preferably, at least about 6.0.

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BRIEF DESCRIPTION OF THE DRAWINGS

Unique advantages of the present invention as a method of electrolytically disinfecting or sterilizing aqueous solutions will be readily appreciated as the invention becomes understood by reference to the following detailed description when considered in connection
5 with the accompanying drawings wherein:

Fig. 1 is a flow diagram of an electrolytic disinfection system in accordance with the present invention.

Fig. 2 is a flow diagram of an alternative embodiment of an electrolytic disinfection system, in accordance with the present invention, cross-connecting anolyte and catholyte
10 chambers in a single continuous pass through.

Fig. 3 is a front elevational view, partly broken away, of another device which may be used to produce an electrochemically disinfected liquid stream, in accordance with the present invention.

Fig. 4 is a rear elevational view of the device of Fig. 3.

15 Fig. 5 is a block functional diagram of a power supply for use with the device of Fig. 3.

Fig. 6 is a longitudinal cross-sectional view, on a slightly larger scale, taken along line VI-VI in Fig. 3.

Fig. 7 is a longitudinal cross-sectional view, on yet a larger scale, taken along line VII-VII in Fig. 6.
20

Fig. 8 is a partial cross-sectional view, on still a larger scale, also taken along line VII-

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VII in Fig. 6.

Fig. 9A is a side elevational view of the device of Figs. 3 and 4, additionally showing a component for extracting gases.

Fig. 9B is a cross-sectional view of the gas extraction component of Fig. 9A.

5 Fig. 10 is an elevational view of a system for collecting treated fluids at an outlet end of the interconnected U-shaped channels of Figs. 6 and 7, also comprising a further view of the aerosol and gas collection system of Figs. 9A and 9B.

DETAILED DESCRIPTION OF THE INVENTION

10 An electrodialytic pH adjuster, as the term is used herein, is an assembly for adjusting the pH and redox potential of an aqueous fluid and, more particularly, the free available chlorine (FAC) content of an aqueous fluid to a desirable level. These changes are accomplished by an electrochemical or electrodialytical method. Most generally, the present invention provides a device including an electrochemical adjusting mechanism for adjusting the pH and FAC of an aqueous fluid in combination with a mechanism for stabilizing the
15 adjusted pH and FAC, or corresponding redox potential, of the aqueous fluid.

The terms "disinfectant" and "biocide" are used herein to refer to a chemical species such as a molecule or ion which reacts with molecular or cellular components of microorganisms to incapacitate those microorganisms and to effectively impair the ability of those microorganisms to infect a human host. The term "disinfectant" is also used herein to
20 refer to a fluid or solution which contains such a chemical species in a concentration sufficient to reduce the active population of microorganisms on surfaces with which the fluid comes into contact, so that any remaining microorganisms are ineffective to infect a human being coming into contact with the surface so treated. A chemical species serving as a disinfectant or biocide is preferably an oxidant.

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The word "disinfect" and variations thereof accordingly refer to the effective impairment or destruction of microorganisms in a sample of fluid to a point where contact of the fluid with a human being, whether by drinking or bathing, etc., will not result in any infection or other adverse effect on the human being.

5 The term "rinse" is used throughout the specification and claims to describe a method of treating a surface (whether a biological or non-biological surface) to render it substantially free of microbes. The disinfectant compositions according to the present invention may be used to treat virtually any surface to render it substantially free of microbes. In preferred aspects of the present invention, the disinfectant solutions according to the present invention
10 render surfaces sterile, i.e. essentially free from microbes (greater than about a 99% kill, more preferably greater than about a 99.5% kill, even more preferably greater than about a 99.99% kill). In certain aspects, the present invention may provide a complete kill (defined as at least a 5 log kill or 99.999% kill). Rinse applications according to the present invention may be used, for example, to treat kitchen surfaces such as cutting boards and counter tops, rinsing
15 of poultry and meats, as hand-cleansers, as sanitary rinses of contaminated vegetables or fruits, for sanitation in bathrooms, intestinal or stomach lavage, disinfection (washing and rinsing) of clothes, to disinfect wounds and cuts, to disinfectant surfaces after surgery, to disinfect medical instruments, to produce sterile water, to disinfect swimming pool water, to disinfect waste water or to sanitize waste water in a waste treatment facility, or water in a cooling
20 tower, or well water or room air, among numerous others.

Disinfectant solutions according to the present invention may also be used to substantially eliminate one or more of the following microbes from treated surfaces: virtually all protozoa, bacteria (gram negative or gram positive), fungi and viruses. The present invention is particularly useful for sterilizing surfaces which have been contaminated with
25 fecal coliform (*E. Coli*), *Staphylococcus sp.*, *Streptomyces sp.*, *Klebsiella sp.*, *Enterobacter sp.*, *Chlamydia sp.*, Herpes viruses, Influenza viruses, HIV, Hepatitis viruses and Flaviviruses, among numerous others. The disinfectant activity of the present invention includes the active as well as the dormant (in many instances the spore) forms of the organism. In particularly

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preferred aspects of the present invention, the present invention has exhibited exceptional activity against *Cryptosporidium* sp., protozoa and fecal coliform bacteria.

The term “disinfected solution” refers to a fluid mixture or composition wherein
5 microbial populations have been decimated or reduced to such an extent that contact of the fluid mixture or composition with a human being, whether by drinking or bathing, etc., will not result in any infection or other adverse effect on the human being.

The term “total residual chlorine content” is intended to denote biochemically active chlorine remaining in solution regardless of the form of the chlorine. Thus, this content
10 includes dissolved molecular chlorine, hypochlorite, hypochlorous acid and chlorine dioxide.

The term “action zone” as used herein refers to that space or region between two electrodes where a moving aqueous solution is subjected to an electric field and to associated electrochemical activity to lower the pH of the solution and to generate a disinfecting oxidant species into the solution.

15 The term “disinfecting oxidizing agent” refers to molecular species having a pronounced oxidizing tendency, particularly including molecular chlorine, hypochlorous acid, hypochlorite, chlorine dioxide, ozone, and peroxide.

The term “acid” or “protic acid” refers to a chemical species which can lower the pH of a solution to within an acidic range. The term acid preferably is used throughout the
20 specification to describe a chemical species which releases hydrogen ions in solution. Acids for use in the present invention include strong inorganic acids such as hydrochloric, sulfuric, sulfamic and nitric acid, organic acids such as citric, fumaric, glycolic, lactic, malic, propionic, acetic, mandelic, tartaric acid as well as other acids such as sodium and potassium bisulfate (NaHSO₄ and KHSO₄), benzenesulfonic acid as well as other sulfonic acids,
25 phosphoric acid (or its monosodium salt form), ethylenediamine tetracetic acid and maleic acid, among numerous other acids.

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As illustrated in Fig. 1, a continuous-type electrochemical water treatment system comprises an electrochemical or electrochemical cell 230 having an I-shaped configuration with a pair of inlet ports 232, 234 and a pair of outlet ports 236, 238. Cell 230 contains a pair of electrodes 240, 242 each having a vertically oriented main portion 244, 246 and a horizontal extension 248, 250 at an upper end. Each horizontal extension 248, 250 is provided with a respective stabilizing edge 252, 254, disposed at a trailing end of the extension. A vertically oriented membrane 256 is disposed between the main electrode portions 244, 246 for defining a pair of flow path segments or subchambers 258, 260 between the electrode portions 244, 246.

A pair of conduits 262, 264 extend to the inlet ports 232, 234 of the electrochemical or electrochemical cell 230 from a fluid reservoir 266 which is provided with a mixer 268. Fluid is delivered from the reservoir 266 to inlet ports 232, 234 under the action of a pair of pumps 270, 272. The volume flow rates of the fluid through the conduits 262, 264 are monitored by two flow meters or rotameters 274, 276.

The outlet ports 236, 238 of the electrochemical or electrochemical cell 230 are connected to a pair of conduits 278, 280 which extend to a receiving tank 279 provided with a stirrer 281. A pH sensor or detector 286 and a redox potential sensor or detector 287 inserted into ancillary chamber 282 are operatively connected to a controller 288 such as a microprocessor.

Sensors or detectors 286 and 287 automatically measure a pH and a redox potential, hence an imputed free available chlorine content, of a liquid stream emptying into receiving tank 279 of the electrochemical cell assembly. Controller or microprocessor 288 automatically compares the measured pH and redox potential with preselected reference pH and redox potential values. These reference pH and redox potential values may be input into the controller by a human operation. As discussed hereinafter, one or more flow rate through the device are adjusted in response to the results of the comparison of the measured pH and redox potential with the preselected referenced pH and redox potential level.

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The outlet ports 236, 238 of the electrochemical or electrodialytic cell 230 are connected to the respective inlet ports 232, 234 via feedback loops 290, 292, each incorporating a flow meter or rotameter 294, 296 and a valve 298, 300. The valves 298, 300 are operated by the controller 288, as are the pumps 270, 272. The controller 288 energizes the pumps 270, 272 and determines the state of the valves 298, 300 in response to the pH and redox potential values of the output fluid in the tank 278 and in accordance with desired pH and redox potential levels programmed by an operator. The rotameters 274, 276, 294, 296 are operatively connected to controller 288 for informing the controller of instantaneous volume flow rates. The controller 288 is optionally connected at an output to a DC power supply 302 for modifying a voltage applied to the electrodes 240, 242. Power supply 302 may advantageously comprise isolated and regulated power supply 48 (Fig. 3). As discussed above, the amplitudes, frequencies or periodicities, polarizations, waveforms; in general, the characteristics of the voltage signal applied to cell 230 may be varied by controller 288.

In the pH and redox potential adjustment system of Fig. 1, a desired pH or redox potential may be produced in the receiving tank 279 by the microprocessor's operating of the valves 298, 300 to determine the proportional amounts of anolyte and catholyte fluids which are recycled or returned to the inlet ports 232, 234. The microprocessor 288 may also vary the pumping speeds of the pumps 270, 272 to compensate for the return of fluid to the inlet ports 232, 234 via feedback loops 290, 292. The pH or redox potential adjustment system of Fig. 1 allows lower or higher pH values to be reached, depending on which side is recycled to its respective inlet port 232, 234. Generally, to achieve a redox potential corresponding to a free available chlorine concentration beyond that attained on a first pass, looping or returning the flow to the head end of the reactor cell can be implemented.

As depicted in Fig. 2, another system for altering the pH of a liquid includes a reservoir or source 304 connected to a pump 306 via a conduit 308. The pump 306 moves liquid from the reservoir 304 through the conduit 308 and a pipe 310 to an inlet port 312 of an electrochemical or electrodialytic cell 314. The inlet port 312 communicates with an accumulating passageway or channel 316 of the electrochemical or electrodialytic cell 314

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which in turn communicates with an accelerating passageway or channel 318 via an aperture 320. Fluid introduced into the electrochemical or electrodialytic cell 314 through the inlet port 312 flows downwardly along the accumulating passageway 316, through the aperture 320 and upwardly along the accelerating passageway 318 between panels or partitions 322 and 324.

5 At an upper end of the accelerating passageway 318, on opposite sides thereof, are disposed an electrode 326 and a membrane 328 defining an action zone 330 as a sub-chamber of an interelectrode zone 332.

After passing through the subchamber or action zone 330, fluid flows over a horizontal extension 334 of the electrode 326 and past a pH-stabilizing edge 336 at the trailing or

10 downstream end of the horizontal electrode extension 334. The fluid exits the electrochemical or electrodialytic cell 314 and is guided through a pipe or conduit 338 to a pump 340 which moves the fluid through a conduit 342 into a second accumulating passageway 344 of the electrochemical or electrodialytic cell 314. At a lower end, the second accumulating passageway 344 communicates with a lower end of a second accelerating passageway 346 via

15 an aperture 348. The second accelerating passageway 346 is defined by the partition 324 and another partition 350. At an upper end, the second accelerating passageway 346 is flanked by the membrane 328 and another electrode 352 which define another sub-chamber 354 of the interelectrode zone 332. Fluid moving upwardly through the accelerating 346 passageway passes through the sub-chamber 354 and then laterally over a horizontal extension 356 of the

20 electrode 352 and past a pH-stabilizing edge 358 at the downstream end of the horizontal extension 356. Effluent exits the system via a pipe 360.

Optionally, the fluid moving through pipe or conduit 338 is subjected to ultraviolet (UV) radiation from an ultraviolet disinfection system 341 disposed adjacent to or within the pipe or conduit. Although the use of ultraviolet radiation to disinfect water is well known, the

25 UV process normally has some operating disadvantages such as precipitation of hardness, biogrowth and iron precipitation on the quartz sheath surrounding the UV source. The use of an electrodialytic adjustment apparatus as shown in Fig. 2 creates conditions favorable and supplemental to the application of UV radiation. These favorable conditions include the

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creation of low-pH water that will not precipitate hardness, hinder or stop biogrowth and will not precipitate the iron to avoid any precipitation on the UV lamp sheath. This insures that the UV disinfection system will have minimum reduced maintenance.

5 The passing of water through the action zone 330 reduces the pH of the water to below approximately 3.0 where calcium and iron are solubilized. In addition, the low pH prevents biogrowth and provides initial disinfection together with the chlorine generated which will also oxidize the ferrous iron. A short-retention-time chamber (not shown) for the anodic liquid may be provided along pipe or conduit 338 upstream of UV disinfection system 341 to enhance disinfection.

10 It is to be noted that the directions of fluid flow can be reversed. Thus, the system can be reconfigured so that the pump 306 conveys fluid from the reservoir 304 to the conduit 342 and thus to the upper end of the accumulating passageway 344, while the pump 340 moves fluid from the pipe 360 downstream of the electrode 352 to the upper end of the accumulating passageway 316. The effect of this system reconfiguration can be alternatively achieved by
15 reversing the polarity of the electrodes 326, 352. Those electrodes are supplied with DC or AC power from a source 362 which is connected to the horizontal extensions 334, 356 of the electrodes 326, 352 via current lead connector rods 364, 366.

It is to be noted that the system of Fig. 2 incorporates two U-shaped connected vessels. The first vessel includes accumulating passageway 316 as one leg and accelerating
20 passageway 318 as the other leg. The second vessel includes accumulating passageway 344 and accelerating passageway 346 as the two legs. Also, pump 340 may be omitted so that the fluid is pressure fed.

An example of reversing the flow is indicated in Tables I and II. The first flow direction was through the acid side and the second flow direction was through the base side.
25 Reversing the flow pattern to the base side followed by the acid side shows a pH range of 6.55 to 7.29 and the highest pH was at the higher flow rate. It is well understood that the changing of variables could change the results. These could include variables such as electrode spacing,

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membrane material, electrode material, electrode length, power input, and flow rate.

Table I

Influent (ml/min)	pH	Conductivity (μ S)	Temp. (°C)	Total Chlorine (mg/L)	Current (amps)	Voltage (volts)	Power (Watts)
400	9.11	443	34.7	9.98	5.73	102.2	585.61
800	8.98	387	24.5	3.03	3.46	106.8	369.53
1200	8.88	364	21.5	0.7	2.96	108.1	319.98

Table II

Influent (ml/min)	pH	Conductivity (μ S)	Temperature (°C)	Total Chlorine (mg/L)	Current (amps)	Voltage (volts)	Power (Watts)
400	6.55	420	31.7	7.76	4.28	104.7	448.12
800	7.17	376	23.5	2.37	3.12	107.3	334.78
1200	7.29	367	21.6	1.35	2.89	107.6	310.96

In the particular electrochemical cell 314 used to generate the results of Tables I and II, the electrodes 326, 352 (not including the horizontal extensions 336, 356) were approximately 10 and 11/16 inches long and 1/16 inch thick. The distance between the electrodes 326, 352 was approximately 1/4 inch, while the distance between each electrode 326, 352 and the membrane 328 was approximately 3/32 inch. The membrane 328 and a holder or frame (not separately illustrated) therefor had a length or height of approximately 12 1/2 inches. The distance between each partition 322, 350 and partition 324, i.e., the width of accelerating passageways 318, 346, was approximately 3/16 inch, whereas the width of each accumulating passageway 316, 344 was approximately 2.75 inches. The reduction in cross-sectional area (assuming the same breadth) from the accumulating passageways 316, 344 to the respective accelerating passageways 318, 346 is representative of other embodiments of a pH adjustment apparatus disclosed herein.

When tap water is first passed through the acid side of the series flow system of Fig.

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2, a sterile water is produced. This has been demonstrated in laboratory tests described below. The passage of water through the acid side would also wash out non-sterile water present in the basic side of the series flow system. This assures the input of low pH, chlorine contacted water with a disinfection capability so that the basic side would be displaced by a sterile water
5 as a final product.

The ability of the electrochemical or electrodialytic pH adjustment assembly of Fig. 2 to produce water on demand with almost instant sterilizing properties makes available to the user a means of providing a safe sterilizing rinse water that possesses topical disinfection qualities capable of killing most pathogenic microorganisms that are a public health concern.
10 Residential or home applications include purification of drinking water, disinfection of hands, sanitation of bathroom surfaces, sanitation of kitchen surfaces such as cutting boards, disinfection of clothing during the washing process, and the rinsing of foodstuffs including meats, fruits and vegetables. Industrial, medical or commercial applications include a wound
rinse, intestinal or stomach lavage, a personal hand sanitizing rinse for surgeons and
15 individuals handling food, a disinfecting rinse for providing a sanitizing rinse for meats, poultry, vegetables or fruit as well as for cooking utensils, medical instruments, or sick room supplies. In such applications, a primary disinfecting rinse for a short period would also be of use in industries where sterile water is required for washing, rinsing or in producing a product. Examples of such applications are in the food and beverage industry and in the
20 cosmetics industry.

Other industrial applications include cooling tower disinfection and the waste water treatment field, for the purification of unprocessed or untreated water, sanitary waste treatment, and purification of contaminated water supplies, for example, in emergencies such as those brought on by storms and earthquakes. In another application, air or any type of
25 vapor is passed through the low-pH passageway or sub-chamber of an electrodialytic pH adjustment apparatus as disclosed herein. The cleaned air is then supplied to a hospital operating room or other space where clean or disinfected air is required. The air may be mixed with an aqueous solution prior to the feeding thereof to the electrodialytic pH

adjustment apparatus. This mixing may be effectuated with a line mixer. Subsequently to the disinfection process, the air-water mixture is fed to a vapor separator which removes the air from the water. The water may then be recycled or discarded as waste.

Liquid is passed only through the basic side or cathodic section of an electro dialytic adjustment apparatus as described herein would not produce sterile water. However, subsequent passage of the base side effluent through the acid side or anodic section will produce chlorine at a pH near or above neutrality. The water would be partially disinfected but would not provide the advantages of the acid-side-first process described above.

Experimental results using the above-described electro dialytic water treatment device are stated below:

EXAMPLE 1

Example 1 was an experiment using dechlorinated tap water from northern New Jersey (Northvale, N.J.,U.S.A.) that was inoculated with fecal coliform (FC) bacteria to a concentration of about 700,000 FC/mL. This suspension was then passed through the electro dialytic pH adjuster at a rate of 50L/hr and catholyte and anolyte sample were collected for analysis. The data summarized as Table III show that the fecal coliforms from the anodic side of the reactor collected immediately and for a time period of up to 30 minutes showed total kill (more than a 6 log reduction). The conditions of kill were found to be a pH of 2.8 and the total residual chlorine (TRC) was found to be 6 mg/L, or 6 ppm, of which 5.5 mg/L consisted of free chlorine ($\text{Cl}_2 + \text{HOCl} + \text{OCl}^-$).

Catholyte fecal coliform levels showed some decrease from the control to 39,000 FC/mL after 30 minutes contact at which time the pH was measured to be 10.4. No chlorine was detected.

Contact Time (min)	Fecal Coliform (PFU/mL)			pH		Residual Chlorine Anolyte (mg/L)		Residual Chlorine Catholyte (mg/L)	
	Control	Anolyte	Catholyte	Anolyte	Catholyte	Total	Free	Total	Free

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0	700,000	0	490,000	2.8	10.4	6	5.5	<DL	<DL
10	-	0	250,000	2.8	10.4	6	5.5	<DL	<DL
20	-	0	160,000	2.8	10.4	6	5.5	<DL	<DL
30	-	0	39,000	2.8	10.4	6	5.5	<DL	<DL

Table III. Northvale Tap Water (Influent pH 7.4) Flow rate = 50 L/hr

In the tables, the entry "<DL" means "less than the detection limit."

EXAMPLE 2

Example 2 is a run similar to example 1, but using New York City tap water, a water of less hardness and conductivity than the Northvale, N.J. tap water in example 1. Similar to Example 1, as shown in Table IV, the water was first dechlorinated and then seeded with fecal coliform bacteria. The water was then mixed and split into four aliquots. Each aliquot was subjected to a different treatment condition:

- (1) Electrodiallytically treated pH adjusted water
- (2) Chlorine and low pH
- (3) No chlorine and low pH
- (4) Chlorine at neutral pH

The results are shown in Table IV. Water treated in the electrodialytic pH adjuster showed 100 percent kill under the conditions achieved (pH 2.7 and a TRC of approximately 1.5 mg/L of which free chlorine constituted approximately 1 mg/L), indicating that a combination of moderately acidic pH and moderate to low residual chlorine resulted in a total reduction of greater than a 6 log reduction in fecal coliform bacteria.

Similarly, using chemical additions to achieve the desired chlorine and pH conditions of the electrodialytic pH adjuster (test aliquot 2) showed similar results except that a few surviving fecal coliforms were detected at time zero.

Test aliquot 3, low pH (2.9) and no active chlorine, did not show complete kill until after 30 minutes contact.

Chlorine at neutral pH (7.2), test aliquot 4, showed progressive fecal coliform kill

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through 20 minutes contact. The TRC in this solution was 1.8 mg/L, of which 1.3 mg/L was free chlorine after twenty minutes.

EXAMPLE 3

An experiment similar to Example 2 was carried out but using Northvale, N.J. tap
5 water. The results are summarized in Table V. The water by an electrolytic pH adjuster showed complete kill at all of the times tested (0-30 minutes; pH = 2.9 and TRC $\approx$ 2 mg/L). Similarly, pH lowered with sulfuric acid and chlorine added as sodium hypochlorite showed complete kill essentially immediately upon chemical addition. Under conditions of low,
acidic, pH a progressive kill was observed as before, in this instance incomplete after 30
10 minutes.

EXAMPLE 4

To demonstrate the effectiveness of the instant invention to treat municipal wastewater (e.g., treated secondary RBC effluent), additional fecal coliform bacteria were added to the effluent to raise the concentration to about 300,000/mL. The results are shown in Table VI,
15 below. Immediate fecal coliform reductions and complete fecal coliform kill occurred after five minutes contact. The conditions obtained for this experiment were a pH of 2.6 and a TRC of $\sim$ 11-12 mg/L.

EXAMPLE 5

Using a different microorganism, MS-2 Coliphage was passed through the pH-
20 adjusting electrolytic cell to determine its effectiveness to destroy this virus. The test was conducted at the University of South Florida, Department of Marine Sciences at St. Petersburg, Florida. Protocols for this test were the same as the other experiments previously described. The test virus, Coliphage MS-2 was added at a concentration of 10^7 per mL to a test water consisting of St. Petersburg Municipal water fortified with 50 mg/L sodium
25 chloride.

The results are shown in Table VII, and clearly indicate that viral counts were reduced

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from 10 million viral particles to less than 1 (detectable limit) when tested after both 5 and 20 minute contact times. This is a 7 log unit reduction in the virus concentration.

EXAMPLE 6

Cryptosporidium is a pathogenic protozoan parasite that is presently of public health concern and was the major cause of an intestinal disease outbreak associated with drinking water supplies in Milwaukee, Wisconsin. Example 6, as shown in Table VIII, summarized the results of a test carried out at the University of South Florida, Department of Marine Science, using St. Petersburg, Florida tap water with an additional 50 mg/L of sodium chloride added, into which solution approximately 100,000 cryptosporidium oocysts per milliliter had been added prior to passing the solution through the electrolytic pH adjuster. Passage through the electrolytic pH adjuster gave a complete kill, or a 5 log reduction after 5 minutes. No viable oocysts could be found. The conditions obtained in the electrolytic pH adjuster which resulted in this kill were a pH of 2.25 accompanied by a total residual chlorine of ~ 25 mg/L. Initial conditions: pH=7.41; Total Chlorine = 0 mg/L; Cl⁻ concentration = 92.5 mg/L; Conductivity = 510 μ S. Results: Series flow was from influent to anolyte then catholyte. Flow rate was 300 ml/min, total chlorine was 25.6 mg/L; pH was 2.25 (anolyte) and 9.85 (final effluent); Power was 768 Watts.

Conclusion:

The results summarized above in example six clearly illustrate that the electrolytic pH adjuster is an effective disinfectant or sterilizing unit for virus and protozoa. The principal reason for this highly effective microbial kill, as shown by the data, appears to be a combination of chlorine and low pH. This surmisal was corroborated by reproducing the condition of low pH and moderate TRC through chemical addition. Thus, it is also possible, without passing the solution through the electrolytic pH adjuster ("e-cell"), to attain the previously described conditions of low pH and moderate TRC, and to achieve an effective microbial kill.

Contact Time (min)	Fecal Coliform (PFU/mL)						pH			
	Control	Chlorine Low pH	No chlorine Low pH	e-cell Treated	Chlorine Neut.. pH	Control	Chlorine Low pH	No Chlorine Low pH	e-cell Treated	Chlorine Neut. pH
0	740,000	0	250,000	0	480	7.2	2.9	2.9	2.7	7.2
2	850,000		400	0	14	7.2	2.9	2.9	2.7	7.2
5	860,000		100	0	80	7.2	2.9	2.9	2.7	7.2
10	750,000	0	100	0	11	7.2	2.9	2.9	2.7	7.2
20	810,000	0	100	-	9	7.2	2.9	2.9	-	7.2
30	710,000	0	0	-	-	7.2	2.9	2.9	-	7.2

Contact Time (min)	Total Residual Chlorine (TRC) (mg/L)									
	Control		Chlorine Low pH		No Chlorine Low pH		e-cell Treated		Chlorine Neut. pH	
	Free	Comb.	Free	Comb.	Free	Comb.	Free	Comb.	Free	Comb.
0	<DL	<DL	1.87	0.45	<DL	<DL	0.9	0.4	1.3	480
2	<DL	<DL	1.65	0.46	<DL	<DL	1.0	0.6	1.1	14
5	<DL	<DL	1.49	0.51	<DL	<DL	1.0	0.6	1.1	80
10	<DL	<DL	1.39	0.5	<DL	<DL	1.1	0.5	1.0	11
20	<DL	<DL	1.4	0.47	<DL	<DL	-	-	1.0	9
30	<DL	<DL	0.23	0.1	<DL	<DL	-	-	0.9	-

Table IV. New York City Tap Water Flow rate = 50 L/hr

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Contact Time (min)	Fecal Coliform (PFU/mL)				pH			
	Control	Chlorine Low pH	No chlorine Low pH	e-cell Treated	Control	Chlorine Low pH	No Chlorine Low pH	e-cell Treated
0	740,000	0	520,000	0	7.35	2.9	2.9	2.9
2	620,000	0	450,000	0	7.35	2.9	2.9	2.9
5	650,000	0	-	0	7.35	2.9	2.9	2.9
10	610,000	0	-	0	7.35	2.9	2.9	2.9
20	590,000	0	2800	0	7.35	2.9	2.9	2.9
30	580,000	-	650	-	7.35	2.9	2.9	-

Contact Time (min)	Total Residual Chlorine (TRC) (mg/L)							
	Control		Chlorine Low pH		No Chlorine Low pH		e-cell Treated	
	Free	Comb.	Free	Comb.	Free	Comb.	Free	Comb.
0	<DL	<DL	0.91	2.09	<DL	<DL	1.7	1.92
2	<DL	<DL	1.34	2.37	<DL	<DL	1.74	1.88
5	<DL	<DL	0.83	1.92	<DL	<DL	1.74	1.87
10	<DL	<DL	0.81	1.81	<DL	<DL	1.72	1.86
20	<DL	<DL	0.81.	1.97	<DL	<DL	1.72	1.86
30	<DL	<DL	-	-	<DL	<DL	-	-

Table V. Northvale Tap Water Flow rate = 50 L/hr

Contact Time (min)	Fecal Coliform (PFU/mL)				pH			TRC (mg/L)			Conductivity (µS)			
	Control	e-cell Treated	Chlorine Low pH		Control	e-cell Treated	Chlorine Low pH	Control	e-cell Treated	Chlorine Low pH	Control	e-cell Treated	Chlorine Low pH	
t<0	290,000	290,000	290,000		7.61	7.61	7.61	0	0	0	795	795	795	
0	290,000	10	250		7.61	2.64	2.72	0	16	13.2	795	2370	2020	
2	-	10	58		-	2.64	2.72	-	13.8	12.4	-	2120	2550	
5	-	0	0		-	2.64	2.72	-	12	10.6	-	2180	2560	
10	260,000	0	0		-	2.64	2.72	-	11.6	10.8	-	2140	2580	
20	260,000	0	0		-	2.64	2.72	-	10.8	10.5	-	2220	2610	

Table VI. Final settled RBC effluent used as influent

Contact Time (min)	Virus (PFU/mL)		pH		TRC (mg/L)		Conductivity (µS)		Chloride (mg/L)*	Flow (mL/min)	Power (Watts)
	Control	Anolyte	Control	Anolyte	Control	Anolyte	Control	Anolyte			
5	1.5 x 10 ⁷	< 1	7.4	2.2	< DL	18.8	510	-	92.5	400	376
20	1.5 x 10 ⁷	< 1	7.4	2.2	< DL	18.8	510	-	92.5	400	376

Table VII-A. Split flow - Anolyte

Contact Time (min)	Virus (PFU/mL)		pH		TRC (mg/L)		Conductivity (µS)		Chloride (mg/L)*	Flow (mL/min)	Power (Watts)
	Control	Catholyte	Control	Catholyte	Control	Catholyte	Control	Catholyte			
5	1.5 x 10 ⁷	< 1	7.4	9.2	< DL	20	510	-	92.5	300	600
20	1.5 x 10 ⁷	< 1	7.4	9.2	< DL	20	510	-	92.5	300	600

Table VII-B. Series flow - Anolyte --> Catholyte

* Influent

Retention Time (Min)	Cryptosporidium (Organisms/ml)	Infection	Mean MPN (infectious Oocytes)	Confidence Intervals	Normalized MPN
5	1.0875 X 10 ⁵	No	NA	NA	NA
20	3.0 X 10 ⁴	Yes	NA	NA	NA

Table VIII. Series Flow- Influent ⇒ Anolyte ⇒ Catholyte

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More complicated reflow and feedback arrangements than those illustrated in Figs. 1 and 2 may be readily conceived by those skilled in the art. In general, anolyte and catholyte effluent may be cross connected to anolyte or catholyte influent in any proportions to achieve recirculation, series or parallel flow, or any combination thereof. Anolyte and catholyte effluent may also be admixed in any proportions to produce overall device effluent, and optionally a drain stream. The admixture may generally be under automatic control and respond to changing influent conditions in order to maintain effluent properties within a set band. Influent as well as effluent properties can be monitored by a variety of automatic sensors, including but not limited to pH, redox potential, temperature and conductance sensors, whose inputs are fed to a control unit or microprocessor. In the event of excessive variance in influent properties or other conditions leading to a deviation of effluent properties from a target zone, an alarm may be sounded, and the device may optionally undergo an automatic shutdown. It may be especially advantageous in application as an electrochemical sterilizer to run anolyte and catholyte sub-cells in series in order to partially or substantially return treated fluid to a neutral pH before exit from the apparatus, as shown in Fig. 2.

The subjection of flowing fluid to a kill zone comprising moderate biocide concentrations, in this case chlorine, combined with low pH values and strong electric fields, and subsequently returning the treated fluid to a neutral or near-neutral pH prior to emission, qualifies the instant invention for maintenance of a body of fluid in a disinfected or sterile condition without that body being significantly caustic or environmentally hazardous in bulk. The electric fields are naturally confined to a region including the kill zone and substantially lying between a pair of electrodes enclosed in an electrically shielding housing. Throughput of a large volume of fluid per unit time through a high-velocity electrolytic treatment zone accrues anti-fouling and specific coulombic advantages, as well as facilitating dilution of generated chlorine to maintain a low concentration in the effluent. Rapid biocidal effectiveness at low chlorine concentrations is believed to be uniquely and efficiently procured by the synergistic effect of evanescent acidification and electrification in concert with nascent chlorine generation. This synergistic flow-through technique yields inherent advantages over generation of a concentrated chlorine solution and subsequent admixture into the bulk to achieve a given final concentration. These advantages include a more efficient kill for fixed chlorine concentration and exposure time as compared to conventional chlorination techniques, including those using *in situ* electrolytically generated chlorine. Applications include swimming

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pools, spas, fountains, ornamental ponds and fish farms.

Figs. 3 *et seq.* show an electrodialytic pH adjuster wherein an incoming fluid flow is divided into two flowpaths separated by a membrane, one flowpath being along an anode and another flow
5 path being along a cathode. From a generally neutral pH inlet stream, the anodic flowpath produces a disinfected acidic stream. This disinfected fluid stream may be used in manufacturing processes requiring a disinfected acidic solution. As discussed hereinbelow with reference to Figs. 3 *et seq.*, the electrodialytic pH adjuster may incorporate a U-shaped channel in fluid communication with an inlet, where the channel is particularly implemented as a vessel having two interconnected chambers
10 disposed as respective legs of a U. The entire U-shaped channel or vessel is referred to herein as a U-shaped connected vessel. The U-shaped connected vessel includes an inlet accumulating passage or chamber (one leg of the U) in fluid communication with two chambers (both another leg of the U) between the two electrodes. In an action zone defined between the anode electrode and the membrane, a rapidly flowing sheet or water is subjected to an electric field and to associated
15 electrochemical activity to lower the pH of the solution and to generate a disinfecting oxidant species into the solution. The action zone has a volume smaller than that of the accumulating passage, whereby fluid flow from the accumulating passage through the action zones is accelerated in accordance with the physics of hydraulics. In this manner, a novel mechanism is provided for producing a stable fluid of a desired pH and redox potential which is different from the pH and redox
20 potential of the fluid entering the assembly. In particular, the redox potential is adjusted via alteration of the free active chlorine content, or FAC, of a influent fluid containing chlorine essentially only in the form of chloride ion. Unlike prior art assemblies, there is less power consumption due to the increased efficiency gained by the hydrodynamic effect described in detail below. In the electrodialytic pH adjuster of Figs. 3 *et seq.*, a disinfected aqueous solution is
25 produced at the outlet of a low-pH anolyte passageway between the anode and the membrane.

In Fig. 3, a housing 12 is supported within a frame 14. Outside of the housing 12, an inlet
16 from a fluid source is in fluid communication with a pump 18. Preferably, the pump 18 is a centrifugal water pump known to those skilled in the art. As better shown in Fig. 4, the pump 18
30 pumps the fluid through piping 20 to two mechanical filters 22, 24. Filters 22, 24 comprise disk elements and are semi-automatic self-cleaning filters known to those skilled in the art. These filters

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remove particulate matter from the fluid which would otherwise have the potential for clogging the system.

Various regulating valves can be disposed throughout the fluid flow system. For example, a regulating valve 26 is provided downstream from the mechanical filters 22, 24. The regulating valve 26 controls the amount of liquid inlet flow into the housing 12. It also closes liquid passage through the system for the purpose of cleaning the mechanical filters 22, 24. An inline flow meter 28 is used for the conventional purpose of monitoring flow through the system. The meter 28 is in fluid communication with a liquid inlet pipe 30. The inlet pipe 30 has a larger cross-section than the downstream flowpath in order to provide a larger volume of fluid to the entrance of the housing 12.

As best shown in Fig. 3, a control or command unit 32 is mounted on the frame 14. The unit 32 includes a processor, electrical components, and the like well known to those skilled in the art for controlling the automatic operation of the assembly. For example, control or command unit 32 may be programmed to vary the voltage and/or current characteristics to achieve a desired pH change or change in the redox potential. Various aspects of the assembly can be automated, such as the activation state of the pump 18 as well as the electrically controlled valving. As shown in Figs. 3 and 4, the valving is manually controlled but can alternatively or additionally be controlled electrically.

A preferred power supply is generally shown at 48 in Fig. 5. A grounded input plug 50 is connected to a fused input switch 52. A filter 54 coupled to input switch 52 blocks the propagation, through plug 50 into a service line, of radio frequency energy from operation of power supply 48. A bridge rectifier 56 at an output of filter 54 transforms an AC input voltage into a DC voltage, as well understood by those skilled in the art. A cut off device 58 connected to filter 54 and to a filtering capacitor 60 serves to limit a DC current surge on discharge of the capacitor 60 to an acceptable value. Filtering capacitor 60 serves to smooth the DC voltage output of rectifier 56. The smoothed DC voltage is fed to a convector 62, which produces a controlled and floating DC potential at an output plug 64. Convector 62 comprises a power amplifier 66, which takes as an input the smoothed DC voltage and which produces as an output a high frequency AC signal.

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Convector 62 further comprises a high-voltage transformer 68 which takes as input a high-frequency signal at a first voltage from amplifier 66 and produces as an output a high-frequency signal at a second voltage. Reference or center voltages of input and output high frequency signals associated with transformer 68 are electrically isolated, as will be well understood by those skilled in the electrical art.

Convector 62 additionally comprises a second rectifier 70 connected to transformer 68 for rectifying an output thereof. A second filter 72 coupled to rectifier 70 smooths an output thereof. The output of convector 62 at plug or terminals 64 is monitored by a current sensor or ammeter 74 and a voltage sensor or voltmeter 76. Ammeter 74 and voltmeter 76 feed back characteristics of the convector output to a control system 78, which in turn transmits control signals to power amplifier 66 in order to clamp or fix either the output voltage or the output current at plug 64 under conditions of varying load. An input device 80 is operatively tied to control system 78 for enabling a user to set an output voltage or current for convector 62, and hence for overall power supply 48. The user may also optionally control other aspects of an output signal of convector 64. For example, control system 78 or power amplifier 66 may contain circuitry for pulsing the output of amplifier 66. Under these conditions, a pulsed DC signal is realized at terminals 64, whose controllable characteristics may include pulse width and pulse rate.

Fig. 6 shows a cross-section of the housing 12 taken along line IV-IV in Fig. 3. The housing 12 contains an internal channel (not separately designated) in fluid communication with inlet pipe 30, the channel essentially having the form of three interconnected U-shaped flow paths (not separately designated). The second and third U-shaped flow paths are oriented upside down (legs pointed downward), rotated 180° about a horizontal axis with respect to the first U-shaped flow path, and are rotated 90° out of the plane of the first U-shaped path, which is in the plane of the paper of Fig. 6. The second and third U-shaped flow paths are connected to the first U-shaped flow path along a leg common to the three U-shaped flow paths. The overall path of fluid flow is thus vertically downward through an accumulating passage or chamber 36, constituting a first leg of the first U-shaped flow path, and then vertically upward through a second leg of the first U-shaped flow path, which is also a first leg of the second and third U-shaped flow paths. Finally, fluid flows vertically downward through second legs of the second and third U-shaped flow paths, which are

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disposed on opposite sides of a plane substantially containing the first U-shaped flow path. This overall fluid flow arrangement incorporating three interconnected U-shaped flow paths as described above provides several advantages.

5 The first leg of the first U-shaped flow path constitutes an accumulating chamber or passage 36, or downcomer, of greater horizontal cross section than the common leg of the three U-shaped flow paths. Thus, fluid moving from the first U-shaped flow path to the second and third U-shaped flow paths is accelerated upwards through the common leg in accordance with the ordinary physics of fluid flow in connected vessels. Fluid feed to the common leg also benefits from gravity aided
10 flow downward in the first leg of the first U-shaped flow path. Flow upward in the common leg is further aided by bubble lift, or the entrainment of fluid by bubbles generated at electrodes contained in this leg. Evolved gas is conveniently separated at the top of the common leg, before processed fluid is returned down second legs of the second and third U-shaped flow paths. The common leg of the three U-shaped flow paths includes the aforementioned action zone, as will be described in
15 greater detail below.

The vertically extending inlet accumulating passage or chamber, or downcomer, 36, has a predetermined volume. Fluid accumulates in this chamber prior to entry into a vertically extending reaction chamber 38. As best shown in Figs. 7 and 8, the reaction chamber 38 includes two
20 electrodes generally shown at 140, 142, supported by current lead connectors in form of rods 144, 146, respectively, and connected thereby to a top plate 148 of the housing 12. Disposed between the electrodes 140, 142 is an electrically neutral semi-permeable membrane 150 well known in the art. The finer the weave of membrane 150 and the thicker the membrane, the better, because there is less flow exchange without affecting ion exchange.

25

Between electrodes 140, 142 are two sub-chambers 141, 143 which are separated by the membrane 150. The sub-chambers 141, 143 in combination have a much smaller cross-section than the inlet accumulating passage 36. Perforce, each or sub-chamber 141, 143 alone has a substantially smaller cross-section than that of the inlet accumulating passage 36. The accumulating passage 36
30 and the sub-chambers 141, 143 together form the first U-shaped flow path or U-shaped connected vessel. Accumulating passage 36 forms one leg of the U-shaped vessel, while sub-chamber 141

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between the electrode 140 and membrane 150 forms another leg of the U-shaped vessel. This sub-chamber between electrode 140 and membrane 150 forms an action zone wherein an aqueous stream is subjected to an electric field and to associated electrochemical activity to lower the pH of the solution and to generate a disinfecting oxidant species into the stream. Due to the relatively large cross-section of the accumulating passage 36 relative to the action zone sub-chamber 141, fluid flowing outwardly through the accumulating passage 36 and around and up through the action zone sub-chamber 141 accelerates through the action zone, in compliance with the physics of fluid flow. This hydrodynamic effect greatly increases the efficiency of the system while requiring less energy consumption as compared with prior art assemblies.

10

As stated above, as the fluid flows through the sub-chambers 141, 143, the electrodes 140, 142 together with the neutral membrane 150 act electrochemically alter the chemistry of anolyte, i.e., fluid adjacent to the anode, and catholyte, or fluid adjacent to the cathode. Relatively electron deficient species, or Lewis acids, are formed at the anode, while relatively electron surfeited species, or Lewis bases, are formed at the cathode. In addition, and particularly if the electrically neutral membrane 150 is chosen from the class known in the art as bipolar membranes, water may be split at membrane 150. In this case hydrogen ions (H^+), a Lewis acid, will generally form and migrate in the catholyte towards the cathode, and hydroxy ions (OH^-), a Lewis base, form and migrate in the anolyte towards the anode. The sense and magnitude of pH changes in anolyte and catholyte thus depend on the balance between these compensatory reactions, and in turn on the prior ionic chemistry of the influent, electrical characteristics of applied power in the electrochemical cell, and duration of treatment. Alteration in concentrations of ionic and other species via redox reactions, and resulting changes in redox potential, particularly those resulting from manipulation of the aqueous chlorine chemistry of interest as discussed hereinabove in the introduction, are dictated by similar process variables.

25

The lead connectors 144, 146 each carry an opposite charge from power source schematically shown at 48 contained within a housing case 154 (Fig. 7) where the rods 144, 146 are connected electrically to the power source at 156, 158 respectively. The charges carried to the respective electrodes 140, 142 oppositely charge those electrodes so that the electrodes 140, 142 and the membrane 150 together act as an electrodialysis system to effectively split the water. In concert with

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oxidation/reduction reactions occurring at the electrodes, this splitting provides an additional means whereby the system affects the ionic chemistry, pH, and redox potential of a treated solution.

As illustrated in Fig. 8, each of the electrodes 140, 142 includes a respective vertically
5 disposed portion 160, 162 each of which is provided at a lower end with a respective bent portion 164, 166 proximate to an entrance from the passage 36 to the upstream sides of subchambers 141, 143. The electrodes 140, 142 further include respective upper horizontal portions 168, 170 connected to power source 48 through respective rods 144, 146. Each electrode 140, 142 has a peripheral edge 172, 174 over or past which all of the fluid with the adjusted pH and redox potential
10 flows. These edges generate an enhanced electrical field and thereby provide a stabilizing mechanism for fluid after a passing thereof through the sub-chambers 141, 143 between electrodes 140, 142 and then over the edges 172, 174, thereby implementing an "edge effect" on the fluid having the adjusted pH and redox potential. The enhanced electrical power and/or electrochemical activity induced in the moving fluid in the area of the edges 172, 174 is believed to stabilized the
15 change pH and redox potential of the fluid, possibly through catalyzing ongoing oxidation/reduction reactions in the disturbed electro-treated fluid exiting the sub-chambers 141, 143. These reactions would then reach completion or equilibrium in a faster time than would otherwise be achieved without effluent from the action zone flowing over the edges. Additionally, flow over constricted orifices partially defined by edges 172, 174 serves to create turbulence and mixing, further
20 facilitating completion of non-equilibrated reactions in solution, and in particular facilitating the attainment of an overall equilibrium in a fluid initially subject to stratification or inhomogeneity in concentrations of reaction products. Catalysis of uncompleted reactions to equilibrium would evidently stabilize a fluid product. In an application of the electrochemical device hereof to the sterilization or disinfection of water, mixing or turbulence induced in fluid product containing
25 nascent chlorine species serves to maximize exposure of biotic burden to freshly produced biocides, in the most potent state of these biocides. It is also known, as discussed above in the Background section of the instant disclosure, that an electric field tends to enhance the effectiveness of aqueous biocidal agents. Carrying of a complete volume of a treated fluid through inter-electrode sub-chamber 141 of the instant apparatus and subsequently past electrode edge 172 is thought to further
30 enhance the biocidal properties of nascent chlorine and result in a thorough kill with lower concentration active chlorine species, and hence of precursor chloride, than would be possible with

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other methods; for example, than would be possible by producing an active chlorine containing solution by electrolysis of a separate batch of brine or saline solution and subsequent admixture of the active chlorine containing solution into a treated volume of water, whereby the treated volume of water is neither exposed to essentially instantly generated nascent chlorine species, nor to intense electric fields, nor yet to both simultaneously. Of course, the correctness of this proposed mechanism is neither essential to the instant description nor limiting to the scope of the instant invention.

It is to be noted that stabilization of the adjusted pH and redox potential may be implemented additionally or alternatively by edges disposed upstream of the peripheral edges 172, 174. For example, holes or perforation may be formed in the electrodes 140, 142, particularly in the downstream portions thereof. (In some cases, the fluid may be constrained to flow through one or more perforations to an outlet of the electrochemical or electrodialytic cell.) Alternatively, each electrode 140, 142 may be formed as a series of electrodes disposed one after the other along the direction of fluid flow. In that case, the trailing edges (and possibly some of the leading edges) of the consecutive electrodes serve to stabilize the change in pH and redox potential.

The stabilizing effect of edges 172, 174 is believed to be enhanced because the pH-adjusted fluid is constrained by gravity to flow partially around the edges, and not merely along a linear flow path past the edges. Thus, the pH and redox potential adjusted water is subjected to an increased extent to the power saturation and enhanced electrochemical activity induced in the water in the region of the edges 172, 174. Of course, the same end result of stabilizing the adjusted pH and redox potential levels is attainable, in a linear flow situation, by increasing the electrical power per unit volume of the pH and redox potential adjusted water. This increase may be effectuated by reducing the flow rate of the fluid or by increasing the electrical current. It is to be noted, however, that constraining the pH and redox potential adjusted water to flow partially around the electrode edges 172, 174 is an especially cost effective way to stabilize the properties of the effluent of the electrodialytic apparatus.

Where the treated liquid is flowing along a linear path past electrode edges, it is desirable for pH and redox potential stabilization purposes to constrain the liquid spatially by restricting the width

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of the flow path in the region of the electrode edges so that the distance of any element of liquid from the edged is limited. The smaller this distance, the larger the minimum electric field experienced by any element of the liquid in passing the edge, and the greater the turbulence creating and mixing effect; hence, the greater the stabilization effect of the edge. A further advantageous spatial constrain is achieved where the flow path induces laminar flow in subchambers 141, 143 between electrode portions 160, 162. To that end, the distance between electrodes 140, 142, particularly between electrode portions 160 and 162 thereof should be no greater than 10 cm.

As demonstrated by experimental evidence set forth below, the electrochemically treated fluid is essentially freed from common pathogens. The present invention provides a method of utilizing aqueous chlorine electrochemistry and possible ozone and hydrogen peroxide to achieve this result with unexpected efficiency, without the admixture of external chemicals, and with low initial chloride levels, as would be found naturally occurring in most sources of potable water. In particular, the instant invention is believed to sterilize or disinfect fluid with a reduced specific power consumption compared to methods known in the prior art. This superior efficiency is believed to arise from the special geometry of the instant apparatus including but not limited to the interconnection of U-shaped vessels in a specific geometric relation and gravitational orientation, relative cross-sectional areas of a feed or accumulating chamber, and a high-velocity action zone, a geometry of the action zone favoring high-velocity laminar flow therein, and a geometry of leading and trailing electrode edges.

As shown in Figs. 7 and 8, at least one of the electrodes 140 can include a substantially vertical downward extension 176 for providing a further stabilizing effect on the electrochemically altered aqueous oxidation reduction chemistry. Arrows 178, 180 in Fig. 7 show the fluid flow pattern as the fluid falls from horizontal surface 168 to contact the edge 172 of the extension 176 of the electrode 140. either one of the electrodes, the anode or the cathode, or both electrodes or neither electrode, can be so extended.

As best shown in Fig. 7, electrode extension 176 is inclined inwardly toward the vertical electrode portions 160, 162. Electrode extension 176 is provided at a downstream end with an outwardly extending surface or lip 182. Electrode edge 172 defines the downstream end of lip 182,

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which acts to catch the fluid flow as shown by an arrow 180 so that all of the fluid flowing over the horizontal surface 168 of the electrode 140 passes in close proximity to edge 172, thereby ensuring implementation of the edge effect.

5 As best shown in Fig. 8, the flow of the fluid over the horizontal surface 168, 170 of the electrodes 140, 142 brings the fluid in direct contact or close proximity with the lead connectors 144, 146. The lead connectors 144, 146 are not insulated, and preferably are made from the same material as the electrode portions 160, 162. Current carried by the lead connectors 144, 146 can affect the fluid flowing nearby. It has been found that the lead connectors 144, 146 provide
10 additional power saturation for increasing the net rate of reaction induced by maintenance of the electrodes at a given DC potential difference.

 Preferably, lead connectors 144, 146 are streamlined with respect to the fluid flow. Both the electrodes 140, 142 and lead connectors 144, 146 are preferably made from electrically conductive
15 material insoluble in liquid of anticipated pH value and concentration of chlorine containing species, and in particular impervious to electrolytically induced corrosion under these conditions, such electrodes being known in the art as "dimensionally stable". Suitable materials for the connectors include stainless steel, titanium and carbon composites. The electrode extension 176 is preferably made from chemically more inert material. Example of such material are titanium, titanium with
20 platinum coating, titanium with palladium coating, and other materials known in the electrode manufacturing art.

 Preferably, the distance between the electrode portions 160, 162 is equal to one to two millimeters while operating without a membrane, and four to six millimeters while operating with
25 a membrane. Such a distance allows for acceleration of the fluid flow through the action zone between the electrodes 140, 142 to a speed of two meters per second. Additionally, it is preferred that the bent portions 164, 166 of electrodes 140, 142 are oriented at an angle of 30° to 45° relative to the vertical portions 160, 162 of the electrodes.

30 Gas and aerosol outlet ports 184, 186 are provided in the housing 12 at a location above the horizontal portions 168, 170 of the electrodes 140, 142, as illustrated in Fig. 8. The ports 184, 186

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are located so as to be able to remove the gases from above the sub-chambers 141, 143 in a direction perpendicular to the direction of the fluid movement in the sub-chambers 141, 143. As shown in Fig. 9A, a filter assembly 187 is in fluid communication with the outlet 184. Assembly 187 includes a housing 188 provided with air pressure piping 190 and vacuum piping 192 for extracting gases
5 from the treatment zone within the housing 188.

The housing 188, shown on a larger scale in Fig. 9B, contains a filter including aluminosilicate granulated material. More specifically, natural granulated clinoptilolite is used as a filler, indicated at 194. The filler is contained within cylinders 196, 198. The gases and aerosols
10 are guided to cylinders 196, 198 in a tangential direction, through conical settling basins 197, 199, with a vortical effect. The assembly 187 can also contain a cloth filter (not shown) for conventional filtration of the air, aerosols, and fluids therethrough.

As shown in Fig. 10, after passing over the edges 172, 174 of the electrodes 140, 142, the
15 fluid is collected and exits through outlets 200, 202. Appropriate valving 204, 206, 208, 210 controls outlet fluid flow. The fluid can be controlled to exit separately by closing valves 206 and 208 and opening valves 204 and 210. Alternatively, valves 204 and 210 can be closed and valves 206 and 208 opened to various degrees to provide a combined flow through outlet 212. Of course, in case it is contemplated to reliably produce various relative mixtures of output from outlets 200
20 and 202, valves 206 and 208 will be replaced by units allowing finer flow control than the 90° on/off valves pictured in Fig. 10 by means of illustration, as will be well understood by those versed in the hydraulic arts. Valve 214 controls the combined flow through outlet 212, and does have an on/off effect. Thus, anolyte and catholyte can be removed separately through outlets 216 and 218 or combined at various ratios by controlling valves 206 and 208 for exit through outlet 212.

25

It is to be noted that a disinfection process may be carried out through essentially chemical processes, without the use of an electrodialytic cell as described hereinabove. In such a process, a pH neutral aqueous solution is acidified to a pH lower than approximately 4.0, and more preferably lower than approximately 3.0, by the addition of a chemical species such as a protic acid. A
30 disinfecting chemical oxidant species such as a chlorine containing composition is also added to the solution. The disinfecting oxidizing agent may be added in the form of an aqueous solution of the

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disinfecting oxidizing agent, the aqueous solution having a pH of less than approximately 4.0 (more preferably 3.0). Subsequently, the acidified solution with the disinfecting oxidizing agent is treated to raise the pH to a neutral level. This treatment may comprise the addition of a basic solution.

5 Although the invention has been described in terms of particular embodiments and applications, one of ordinary skill in the art, in light of this teaching, can generate additional embodiments and modifications without departing from the spirit of or exceeding the scope of the claimed invention. Accordingly, it is to be understood that the drawings and descriptions herein are proffered by way of example to facilitate comprehension of the invention and should not be
10 construed to limit the scope thereof.

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WHAT IS CLAIMED IS:

1. A disinfected solution produced by a process comprising:
supplying a fluid through a channel to an inlet of an action zone between two electrodes;
accelerating the fluid flow from said inlet through said action zone so that the fluid flowing through the action zone has a velocity substantially greater than the velocity of the fluid flowing through said channel; and
applying an electrical potential difference across said electrodes during the supplying of said fluid and the accelerating of the fluid flow.
2. A solution as defined in claim 1 wherein said fluid is aqueous.
3. A solution as defined in claim 1 or 2 wherein the fluid at an outlet of said action zone has a total residual chlorine content sufficient to prevent reinfection of said fluid.
4. A solution as defined in claims 1-3 wherein the fluid at an outlet of said action zone has a chlorine content sufficient to use that fluid as a disinfectant.
5. A solution as defined in claims 1-4 wherein said electrodes are at least partially vertically oriented, said inlet being disposed at a lower end of said action zone, the accelerating of the fluid flow including directing the fluid flow in a vertically upward direction.
6. A solution as defined in claims 1-5 wherein a membrane is disposed between said electrodes to divide an interelectrode space into two chambers, further comprising dividing the fluid flow into two portions and directing one such portion into one of said two chambers and the other such portion into the other of said two chambers.
7. A solution as defined in claims 1-6 wherein at least one of said electrodes has a horizontally oriented extension at an upper end, further comprising directing fluid flow at an outlet of said action zone substantially horizontally over said horizontally oriented extension.
8. A solution as defined in claims 1-7 wherein physical dimensions of said action zone and

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said velocity substantially greater than the velocity of the fluid flowing through said channel are such that said fluid flow from said inlet through said action zone is substantially laminar.

9. A disinfected solution produced by a process comprising:
supplying a first stream of fluid through a channel to one of two sub-chambers disposed in a space between two electrodes;
feeding a second stream of fluid to another of said two sub-chambers during the supplying of said first stream; and
during the supplying of said first stream and the feeding of said second stream, applying an electrical potential difference across said electrodes.
10. A solution as defined in claim 9 wherein said first stream of fluid is aqueous.
11. A solution as defined in claims 9 or 10 wherein the fluid at an outlet of said space has a residual chlorine content sufficient to prevent reinfection.
12. A solution as defined in claims 9 or 10 wherein the fluid at an outlet of said space has a chlorine content sufficient to use that fluid as a disinfectant.
13. A disinfected solution produced by a process comprising:
electrochemically adjusting the pH and redox potential of an aqueous flowable fluid; and
stabilizing the adjusted pH of the fluid,
the adjusting of the pH and redox potential of said fluid including guiding the fluid through an action zone between two electrodes,
the stabilizing of the adjusted pH and redox potential including guiding the fluid over and partially around an edge located outside of said action zone and projecting into a fluid flow path extending from an outlet side of said action zone.
14. A method for treating water, comprising:
providing a continuously flowing stream of water; and
continuously operating on said stream in a continuous flow process to generate a disinfectant

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species in said stream and to simultaneously lower the pH of said stream below approximately 4.0.

15. The method defined in claim 14 wherein the operating on said stream comprises passing said stream through an electrodialytic cell and applying an electric potential difference across electrodes of said cell during passing of said stream through said cell.
16. The method defined in claims 14 or 15 wherein the providing of said stream includes guiding said stream through a channel upstream of said cell, the passing of said stream through said cell includes accelerating said stream so that said stream when flowing through said cell has a velocity substantially greater than said stream when flowing through said channel.
17. The method defined in claim 16, further comprising, after the passing of said stream through said cell, operating on said stream to raise the pH of said stream to a neutral range.
18. The method defined in claims 14-17 wherein the operating on said stream to raise the pH of said stream to a neutral range includes passing said stream between differentially charged electrodes.
19. The method defined in claims 14-18 wherein electrodes are part of said cell, the passing said stream between differentially charged electrodes including guiding said stream back to an inlet of said cell after operating on said stream to generate said disinfectant species and to simultaneously lower the pH of said stream below approximately 4.0.
20. The method defined in claim 16-18 wherein said cell has at least partially vertically extending electrodes, the accelerating of said stream including directing said stream in a vertically upward direction.
21. The method defined in claims 14-20 wherein said stream is passed in a thin sheet through said electrodialytic cell.

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22. The method defined in claims 14-21 further comprising subsequently operating on said stream to raise the pH of said stream to a neutral range.
23. The method defined in claim 22 wherein the operating on said stream to raise the pH of said stream to a neutral range includes passing said stream between differentially charged electrodes of an electrodialytic cell.
24. A disinfected solution produced by the method of claims 14-22.
25. A disinfectant solution produced by the method of claim 23.
26. The method defined in claims 14-23, further comprising subsequently using said stream as a sanitizing solution in an application taken from the group consisting essentially of rinsing a kitchen surface, rinsing a bathroom surface, rinsing a wound, rinsing a surgical operating site, rinsing a stomach *in vivo*, rinsing an intestine *in vivo*, rinsing a medical instrument, rinsing a foodstuff, rinsing a hand, and rinsing an article of clothing.
27. The method defined in claims 14-23, further comprising subsequently using said stream in as water taken from the group consisting essentially of potable water, swimming pool water, spa water, cooling tower disinfection water, sterile water.
28. A method for disinfecting water, comprising:
 - providing an influent stream of water having an approximately neutral pH;
 - feeding said influent stream to an electrodialytic cell in a continuous flow operation to produce a first effluent stream at an outlet of said cell, said first effluent stream having a pH below about 4.0;
 - guiding said first effluent stream back to an inlet of said cell; and
 - passing said first effluent stream through said cell to produce a second effluent stream having an approximately neutral pH.
29. The method defined in claim 28 wherein the providing of said influent stream includes

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guiding said influent stream through a channel upstream of said cell, the feeding of said influent stream through said cell includes accelerating said influent stream so that said influent stream when flowing through said cell has a velocity substantially greater than the velocity of said influent stream flowing through said channel.

30. The method defined in claim 28 or 29 wherein the guiding of said first effluent stream includes directing said first effluent stream through a feedback channel, the passing of said first effluent stream through said cell includes accelerating said first effluent stream so that said first effluent stream when flowing through said cell has a velocity substantially greater than the velocity of said first effluent stream flowing through said feedback channel.
31. A method for disinfecting water, comprising:
providing water having pH of less than approximately 4.0; and
adding to said water a disinfecting oxidizing agent.
32. The method defined in claim 31 wherein the providing of said water includes acidifying an aqueous sample having a pH of about 4.0 or less.
33. The method defined in claim 31 or 32 wherein the acidifying of said aqueous sample includes adding a protic acid to the aqueous sample.
34. The method defined in claims 31-33 wherein the adding of said disinfecting oxidizing agent includes combining said water with an aqueous solution of said disinfecting oxidizing agent, said aqueous solution having a pH of less than approximately 4.0.
35. The method defined in claims 31-34, further comprising raising the pH of said water after the adding of said disinfecting oxidizing agent.
36. The method according to claims 31-35 wherein said acid is selected from the group consisting of hydrochloric, sulfuric, sulfamic, nitric, citric, fumaric, glycolic, lactic, malic, propionic, acetic, mandelic, tartaric acid, sodium bisulfate, potassium bisulfate,

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benzenesulfonic acid, phosphoric acid, ethylenediamine tetracetic acid and maleic acid.

37. The method according to claims 31-36 wherein said disinfecting oxidizing agent is selected from the group consisting of molecular chlorine, hypochlorous acid, hypochlorite, chlorine dioxide, ozone, and peroxide.
38. The method defined in claims 31-37 wherein the adding of said disinfecting oxidizing agent is effectuated by passing said water in a continuous stream through an action zone between two electrodes and applying a voltage across said electrodes during the passing of said water through said action zone.
39. A method for disinfecting a fluid comprising:
providing a stream of fluid;
feeding said stream of fluid through an electrodialytic-cell anodic section to produce a first effluent stream having a pH below about 3;
guiding said first effluent stream past an ultraviolet disinfecting station to produce a second effluent stream; and
guiding said second effluent stream from said ultraviolet disinfecting station through an electrodialytic-cell cathode section to produce a third effluent stream.
40. The method defined in claim 39 wherein said fluid is water.
41. The method defined in claim 39 or 40 wherein said ultraviolet disinfecting system emits radiation of a wavelength between about 200 and 300 nanometers.
42. The method defined in claims 39-41 wherein said first effluent stream is held for a short contact period in said anodic section.
43. The method defined in claims 39-42 wherein said third effluent stream has a residual chlorine content.

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44. A method for disinfecting vapor, comprising:
mixing a vapor with a liquid to produce a vapor-liquid mixture;
guiding said vapor-liquid mixture through an electrodialytic-cell anodic section to produce a first effluent stream having a pH of less than about 3;
guiding said first effluent stream through an electrodialytic-cell cathodic section to produce a second effluent stream;
operating on said second effluent stream to separate vapor from liquid in said second effluent stream.
45. The method defined in claim 44 wherein the mixing of the vapor with the liquid is effectuated by using a line mixer device.
46. The method defined in claim 44 or 45 wherein the operating on said second effluent stream includes passing said second effluent stream through a vapor separator.
47. The method defined in claims 44-46 wherein said vapor is air.
48. The method defined in claims 44-47 wherein said fluid is water.
49. The method defined in claims 44-48 wherein said first effluent stream is held for a short contact period in said anodic section.
50. The method defined in claims 44-49, further comprising delivering the separated vapor to a room.
51. A method of disinfecting a surface contaminated with at least one organism selected from the group consisting of protozoa, bacteria, viruses or fungi comprising exposing said surface to the composition according to any of claims 1-13 for a period effective to disinfect said surface.
52. The method according to claim 51 wherein said protozoa is a *Cryptosporidium* protozoa

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53. The method according to claim 51 wherein said bacteria is a fecal coliform bacteria.

54. The method according to claim 53 wherein said fecal coliform bacteria is *E. coli*.

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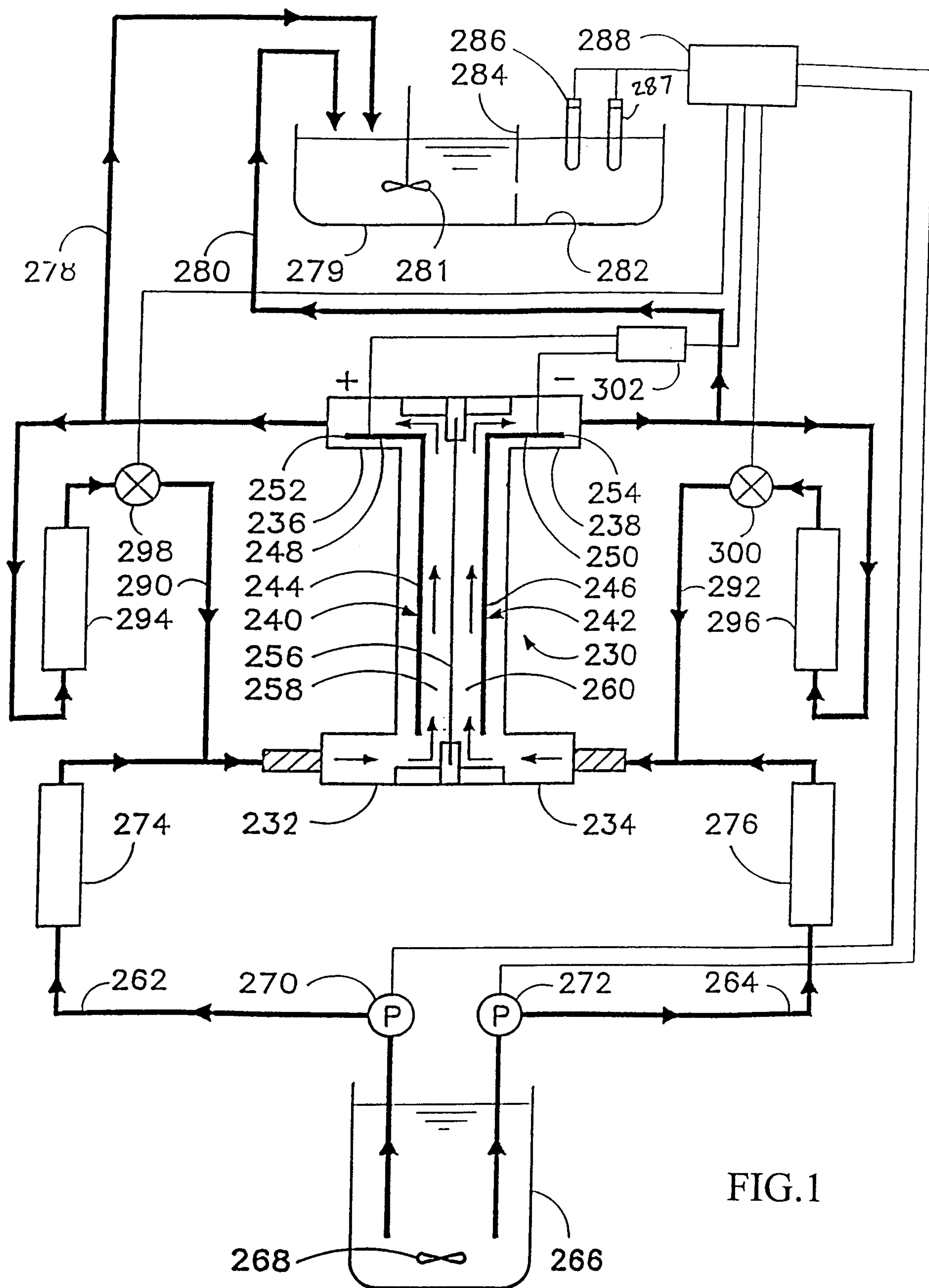


FIG.1

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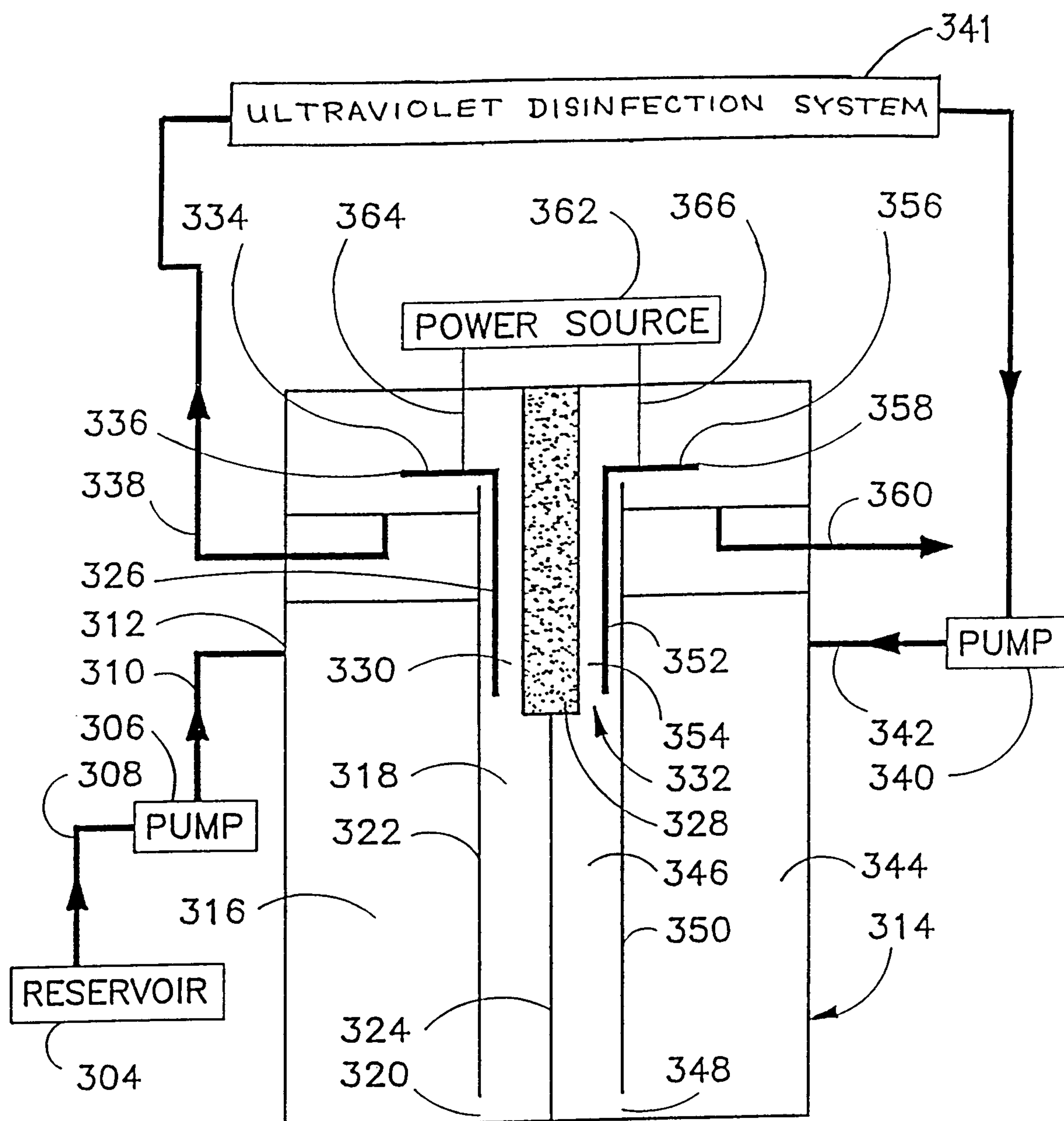


FIG. 2

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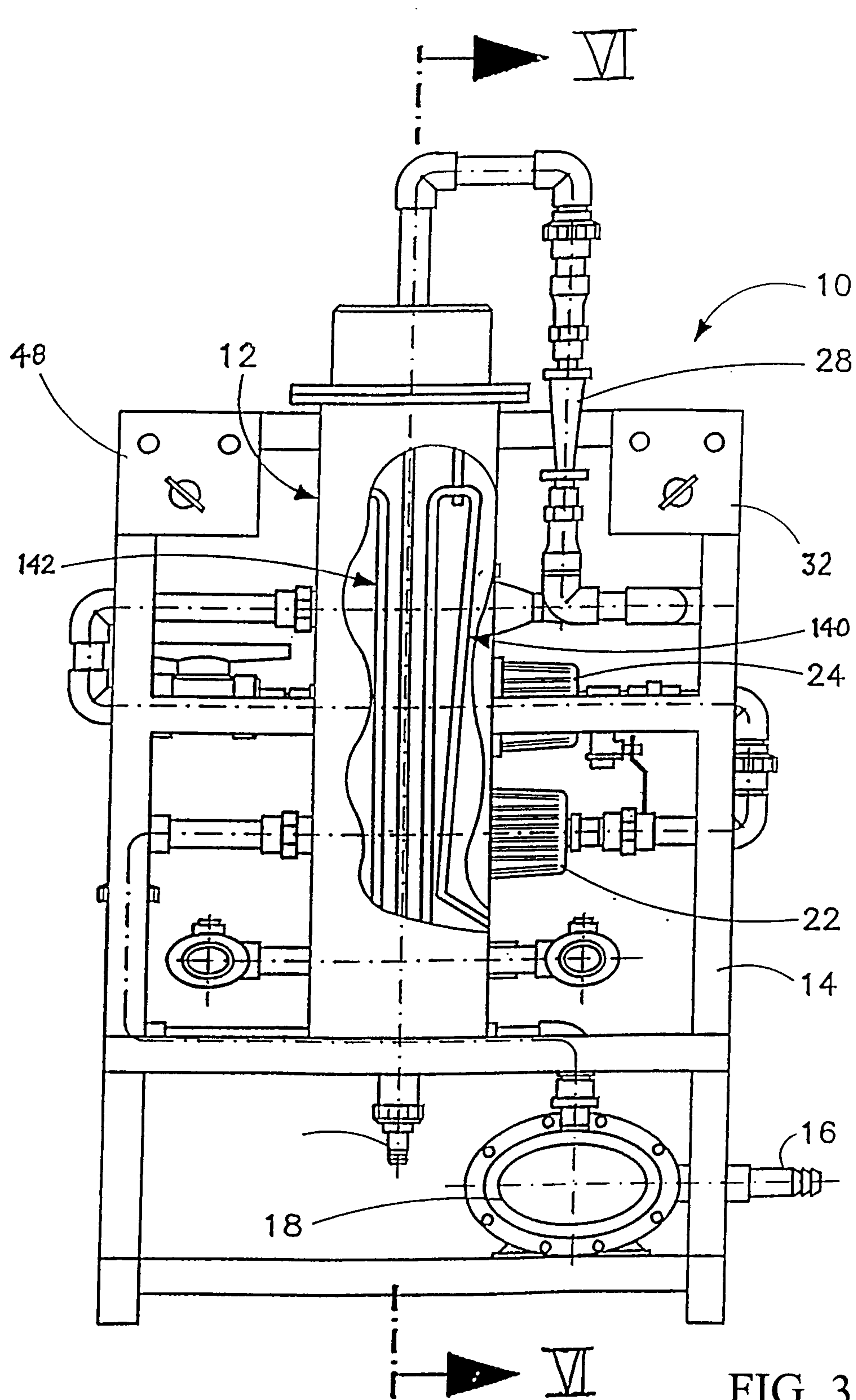


FIG. 3

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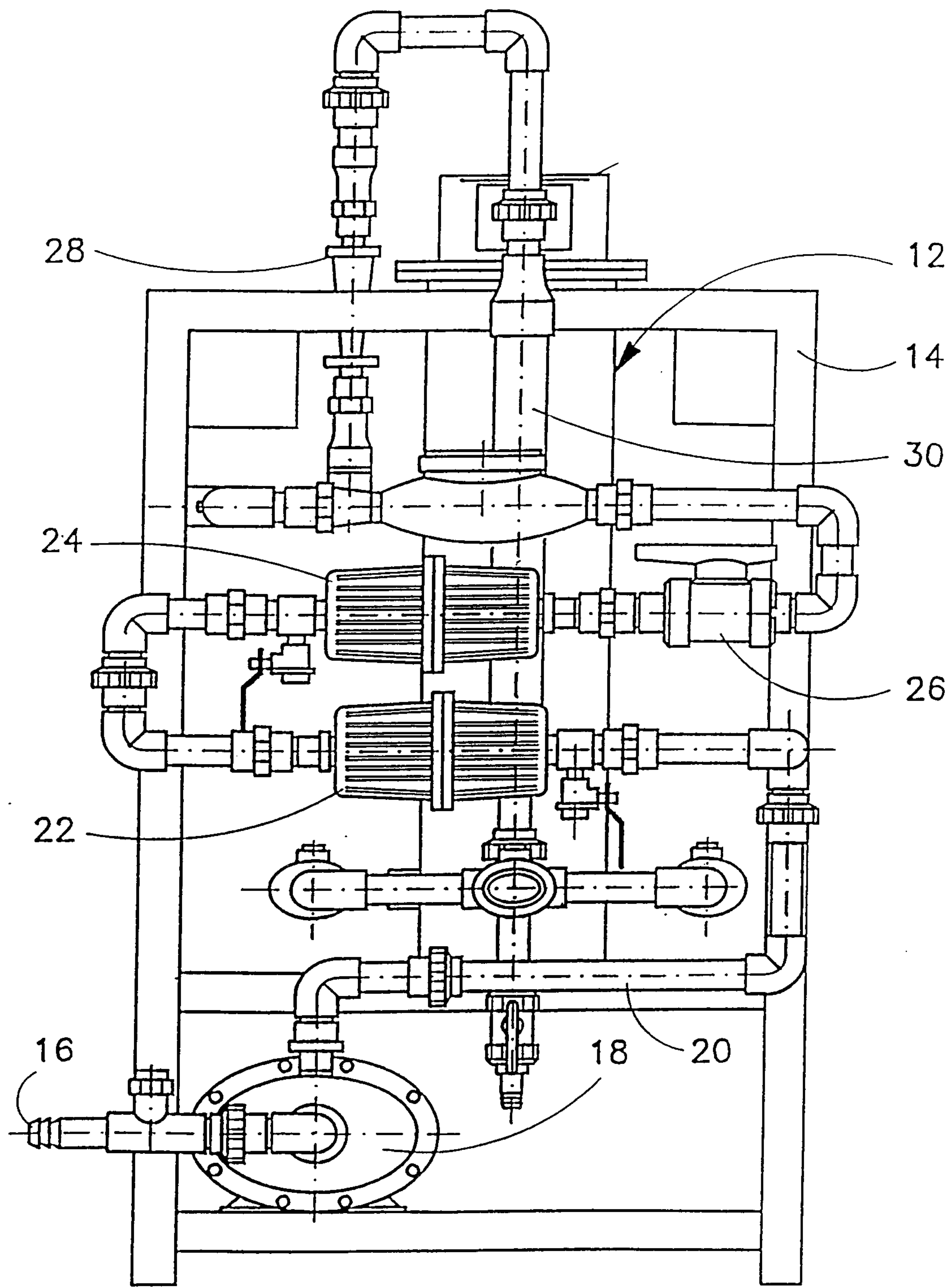
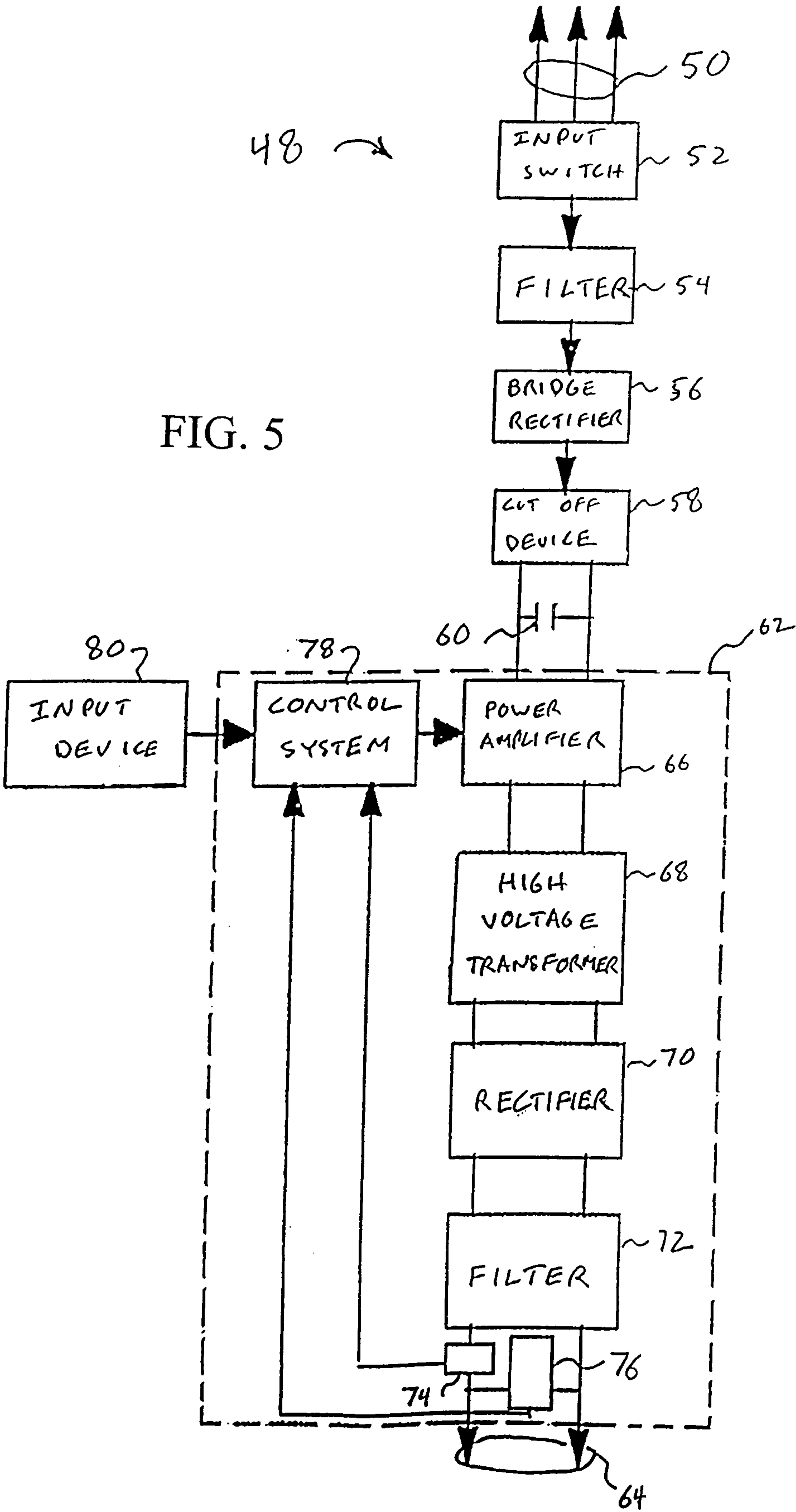


FIG. 4

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FIG. 5



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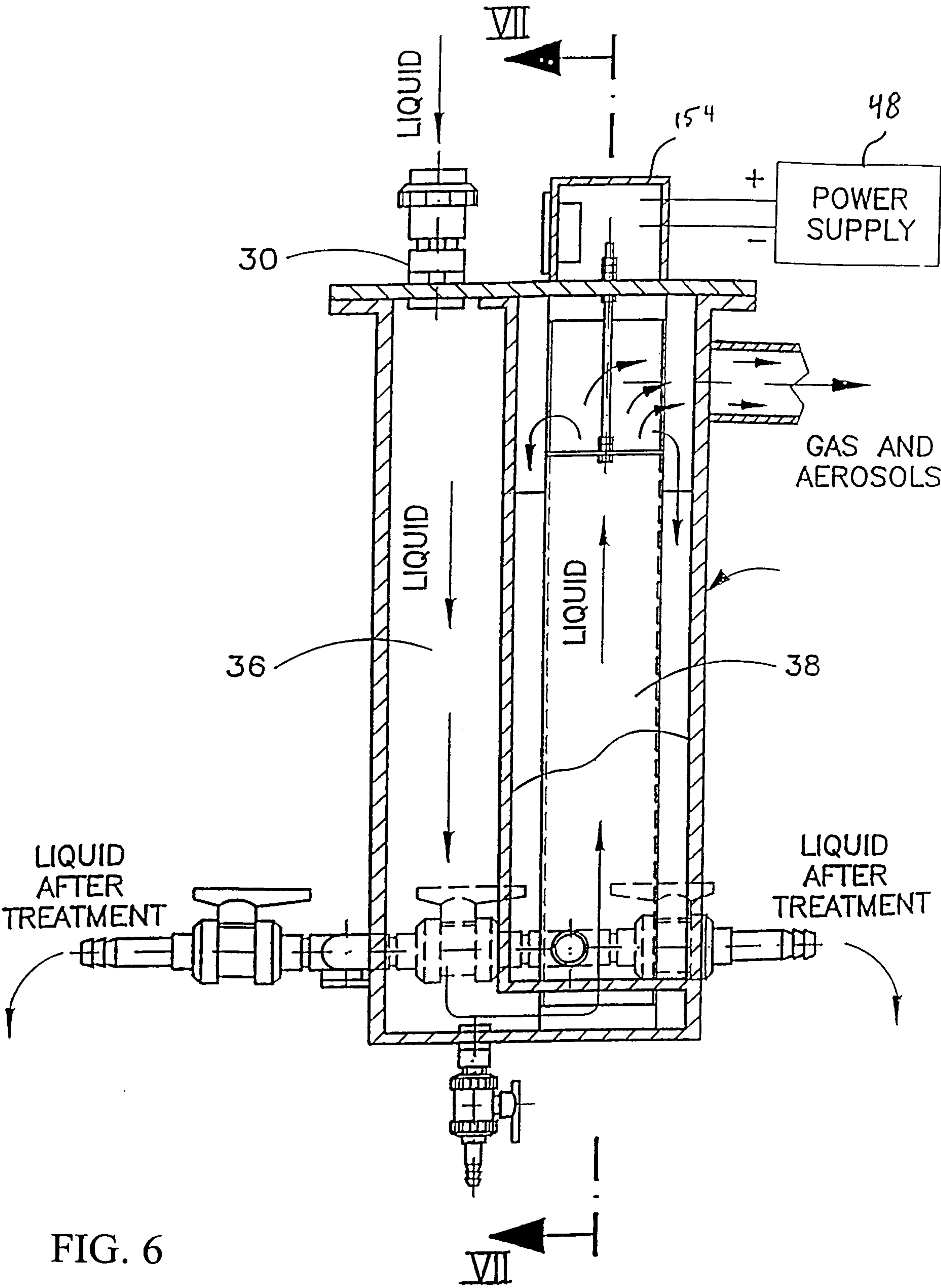
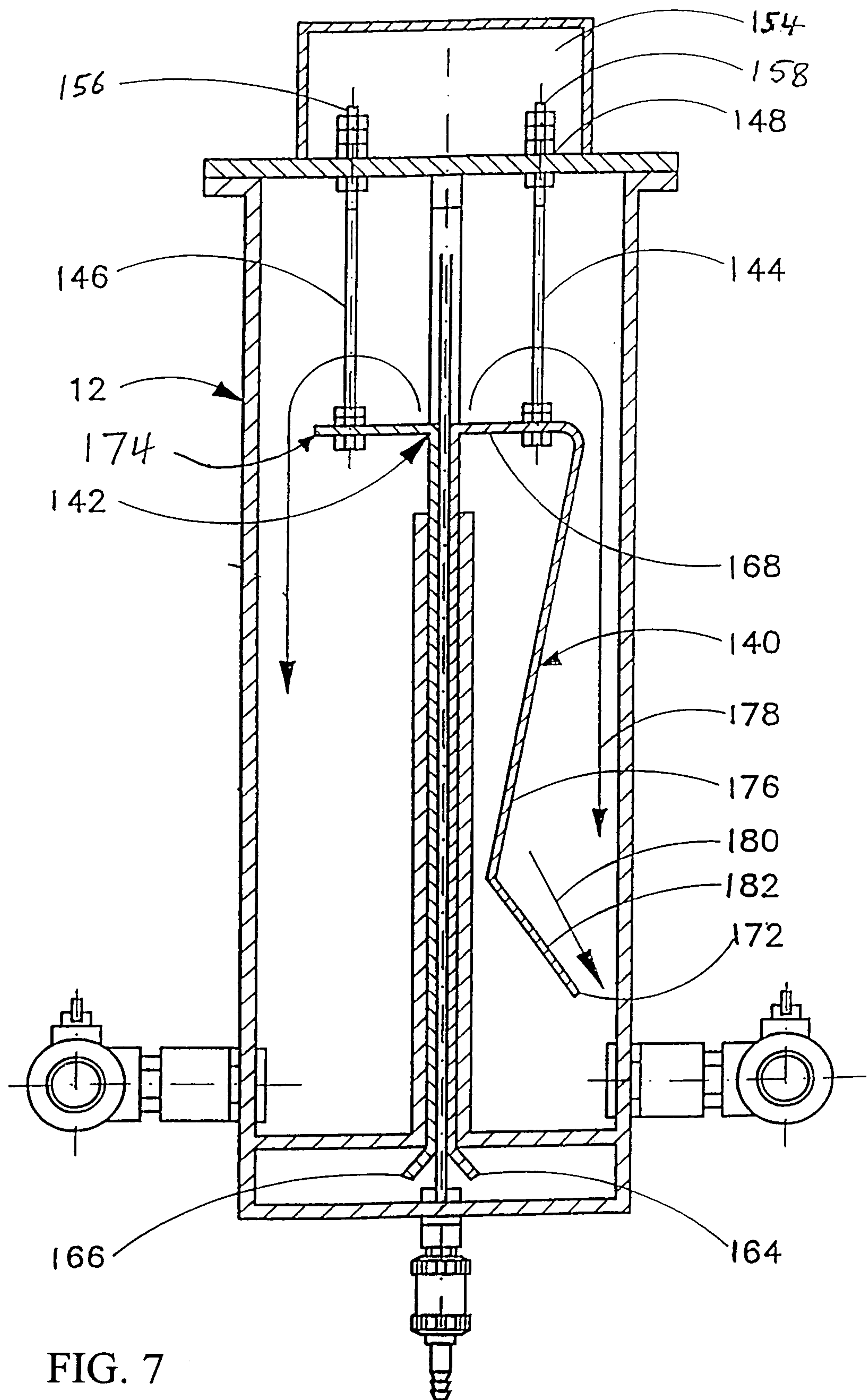


FIG. 6

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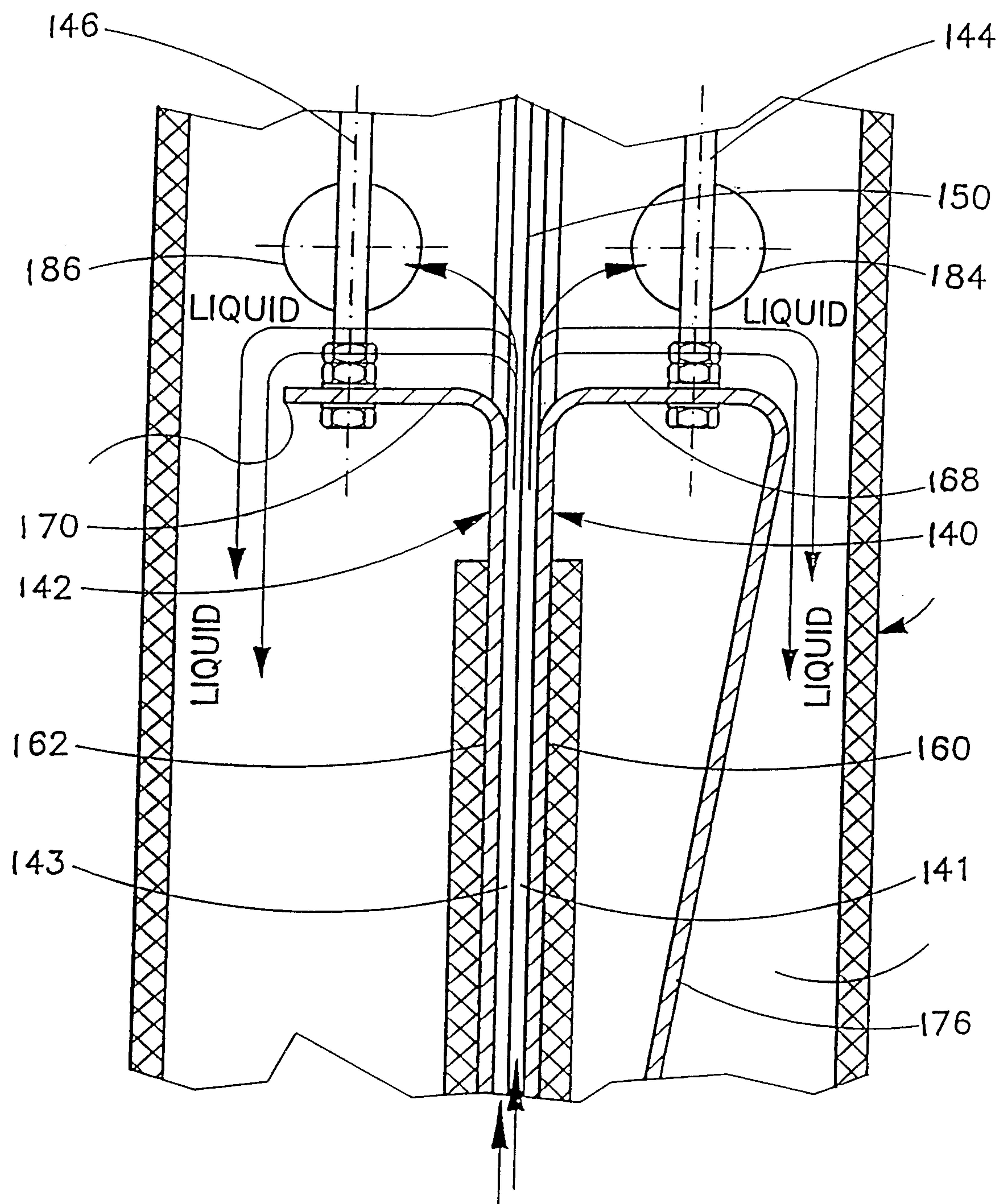


FIG. 8

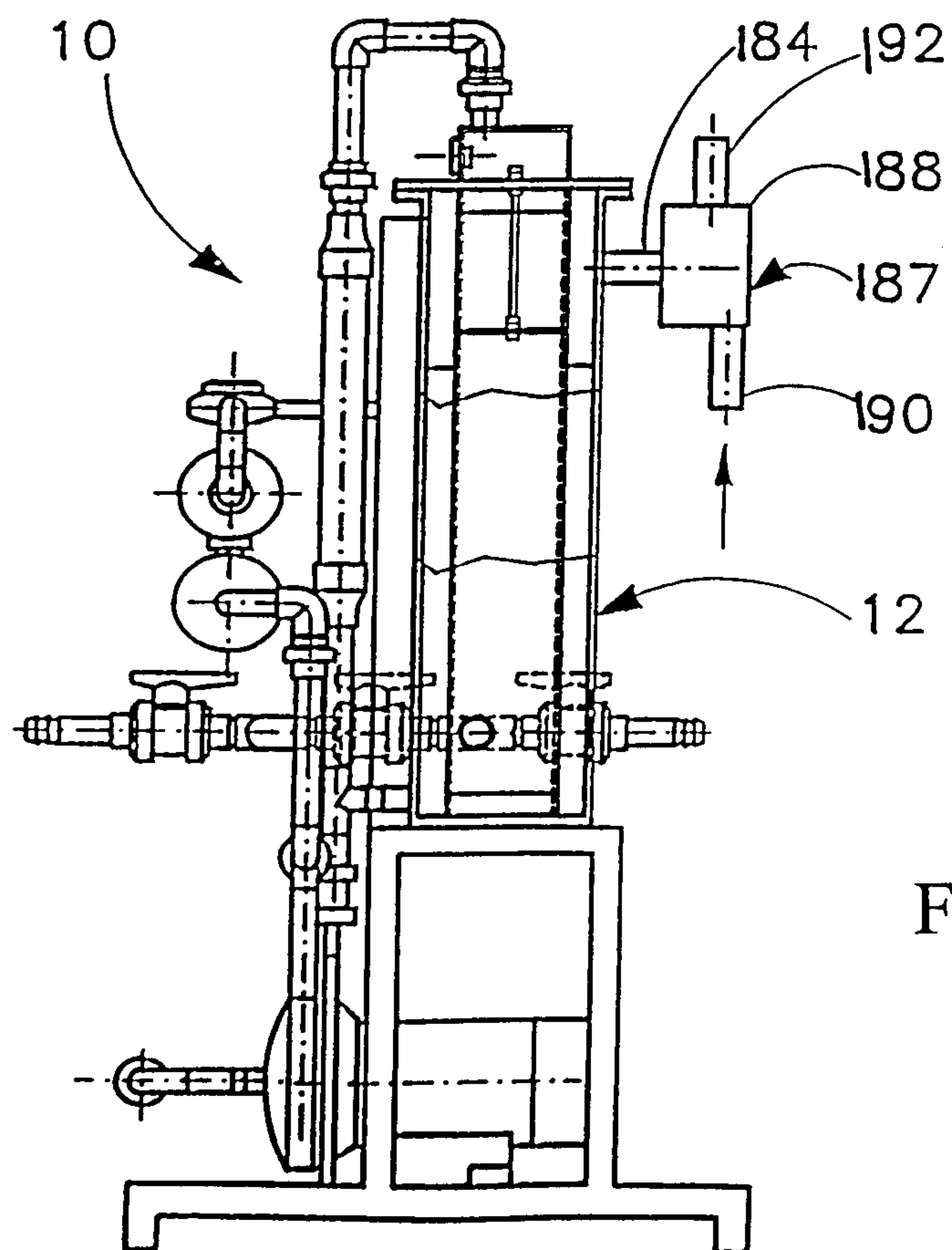
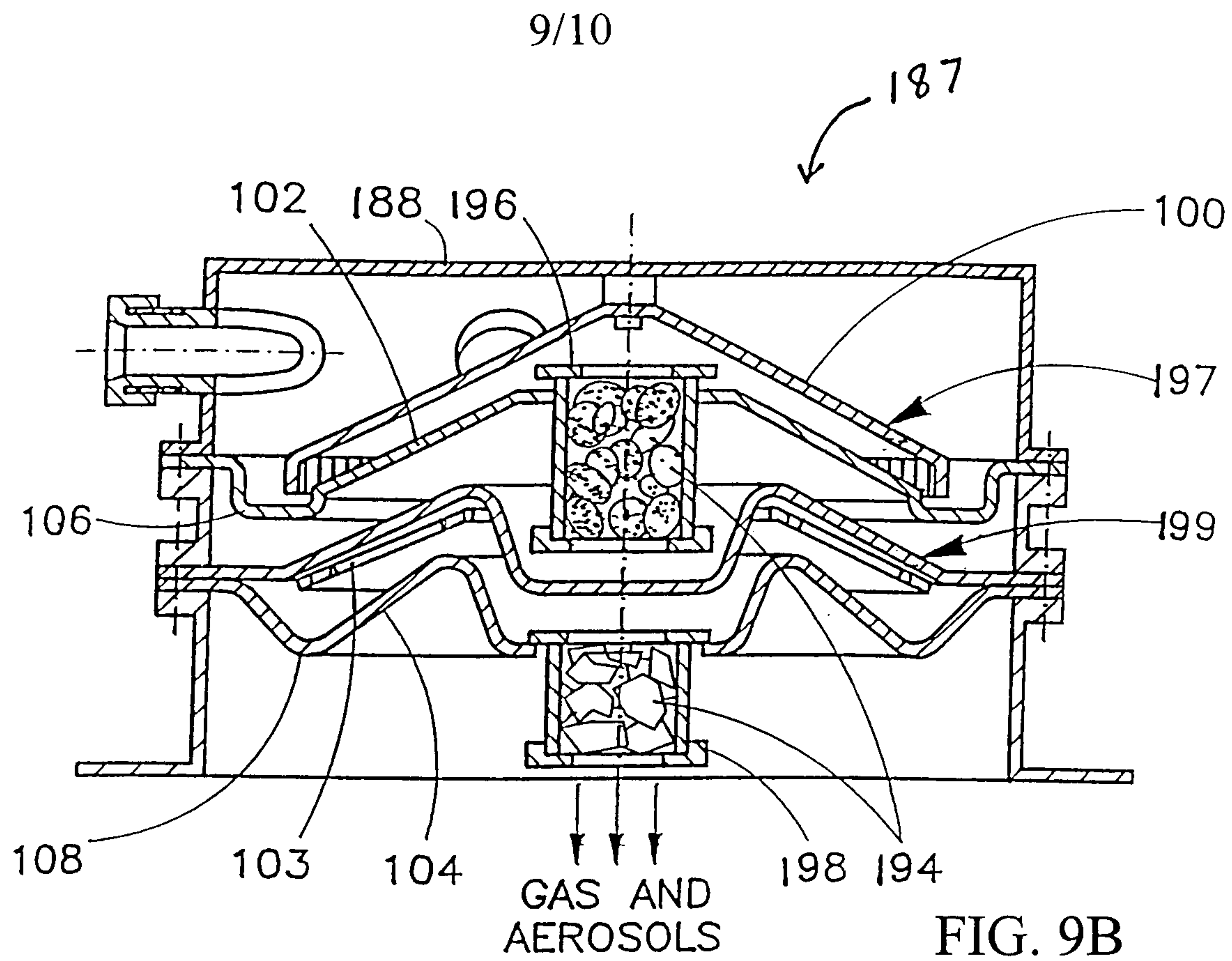


FIG. 9A

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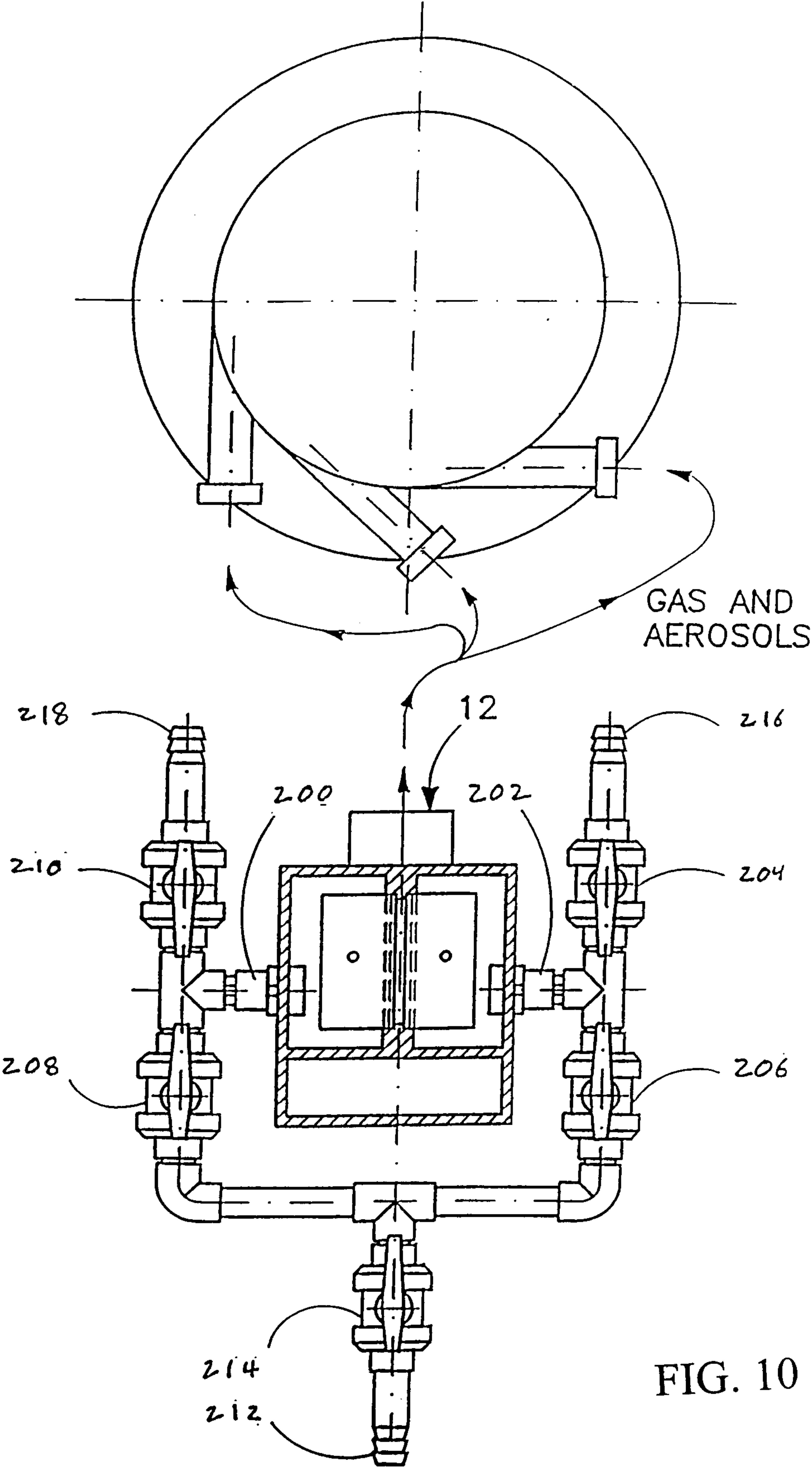


FIG. 10