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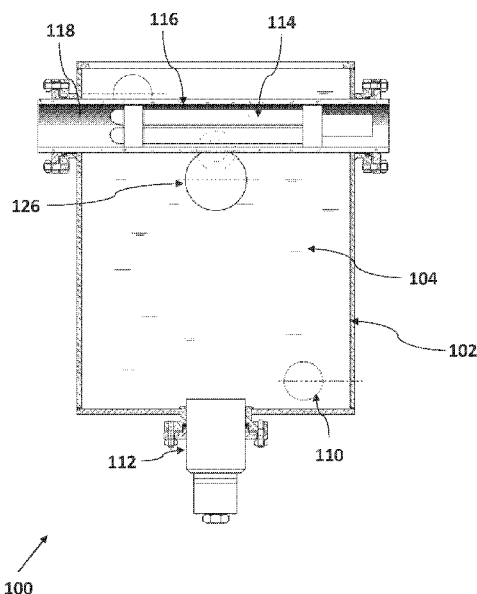


FIG. 1

(57) Abstract: The present invention relates to a system and method for decontamination, sterilization and purification of water. A scalable reactor and method for treatment of contaminated water is disclosed. The reactor simultaneously combines ozone infusion, ultraviolet (UV) irradiation and ultrasound (US) vibration in one reaction zone. The process dramatically increases reaction efficiencies and allows greater volume flow of contaminated water for treatment. The process has been found to reduce contaminants in different types of water and applications, including potable, drinking, recycled for pools or aquariums, oil field, waste or recycled industrial water.

REACTOR FOR WATER TREATMENT AND METHOD THEREOF**CROSS-REFERENCE TO RELATED APPLICATION(S)**

5 This international patent application is based on co-pending US
Provisional Patent Application Serial No. 61/622,613 (Attorney Docket No. AH-
12-1), entitled, "Reactor for Water Treatment and Method Thereof", filed April
11, 2012, the priority of which is hereby claimed and the disclosure of which is
incorporated herein by reference in its entirety.

10

BACKGROUND**Field of the invention**

15 The present invention relates generally to the field of water treatment and
environmental control. More particularly, the present invention relates to a
system and method for decontamination, sterilization and purification of water.

Description of the related art

20

Water treatment systems based on the technologies individually using
ozone, ultraviolet (UV) and ultrasound (US), or a combination of the two, are few
of the most effective approaches used for water treatment and environmental
control. These approaches minimize chemical reagent consumption and
25 environmental load. Further, they replace chlorine as an oxidation agent from
conventional water purification technologies. Chlorine reacts with organic
compounds dissolved in water to produce organo chlorine compounds that are
extremely toxic and carcinogenic. However, limitations of the combined
utilization of ozone, ultraviolet and ultrasound for water treatment make it
30 difficult to implement these technologies on a wide scale. These limitations

further depend upon price and dimensions of treatment equipment used and energy costs.

One such solution that uses a combination of ozone and UV, referred to as
5 advanced oxidation process (AOP) technology, has been developed by Esco
International. The AOP technology effectively removes organic contaminants
largely because of the very high oxidation potential of the hydroxyl (OH) radical
(2.8 eV). For ozone/UV reactions (also known as photolytic ozonation) in
aqueous solution, ozone is energized and combined with water to create OH that is
10 stronger and less selective than chemical oxidants. Ozone effectively reacts with
most organic contaminants and the remaining residual ozone is converted into two
hydroxyl radicals for each ozone molecule. The hydroxyl radicals act on the
remaining targets and enhance the ability of the ozone molecules more effectively.
Some of the stubborn organics are partially oxidized such that they are more
15 readily biodegradable.

The key parameters required for the success of the AOP technology
include ozone dosage, UV irradiation level and pH. For adequate ozone dosage, a
high dissolved ozone rate must be maintained with effective transfer of ozone gas
20 into the aqueous solution. To facilitate this, a pressurized injection secondary mix
UV/O₃ reactor is used. This reactor creates micro bubbles, and provides constant
renewal of gas-to-liquid mixing zone and enhanced gas solubility for better
utilization of UV irradiation. As the pH increases, ozone is readily converted to
hydroxyls, which increases the oxidation rate of contaminants, such as pesticides
25 and cyanides.

For a given ozonation rate, there exists an average radiation power at
which the oxidation efficiency reaches its maximum degree. Below this dose, the
residual ozone dissolves, limits the oxidation efficiency and limits oxidation
30 kinetics. Beyond this dose, oxidation efficiency remains stable; however, the

energy efficiency ratio decreases in relation to the amount of degraded substrate. The ideal radiation strength is the lowest rate at which the dissolved ozone and the ozone in the off gases are entirely consumed.

5 Water treatment for the wastewater from textile manufacturing is a continuing concern based on the dyes, sizing agents, process chemicals, and other components in the water. Some of the dyes in the wastewater are allergenic, toxic and even mutagenic or carcinogenic. Moreover, the dye components can seldom be fully removed with traditional biological, coagulation, and flocculation
10 treatments.

Ozone/UV treatment is able to reduce dye-finishing wastewater by 95%, from 4,000 ADMI units to 200 ADMI units, in an hour. Ozone/UV also shows increased ability to affect mineralization and toxic reduction in some dyes.
15 Ozone/UV treatment in this scenario (800 m³ per day of wastewater) would save 30% on treatment costs per month.

Other components of industrial wastewater include surfactants (surface-active compounds), such as emulsifiers and detergents. Their processing
20 effectiveness and unique chemical structure (both hydrophilic and hydrophobic components) make them difficult to treat, often leading to only partial degradation and high residuals in effluent water, which has potential public health and environmental effects.

25 The application of ozone and UV for surfactants has proved to be more effective than biological treatments for commonly used compounds, such as anionic surfactants. At a low pH, ozone's electrophilic attack decomposes organic compounds, and the hydroxyl radical creates chain reactions that lead to ultimate mineralization. Ozone and UV application has also proved to be an effective pre-
30 treatment step combined with biological treatment.

Phenols are another common component found in wastewater that can be both toxic and hard to break down because of their benzene ring chemical structure. Halogenated aromatics, which are refractory and difficult to remove with conventional biological treatment, can cause severe pollution problems. With ozone/UV treatment, chlorine or nitrogen elements of the benzene ring can be eliminated relatively quickly, allowing the phenol to be more completely decomposed.

Ozone and UV combined present an effective solution to water contamination problems. When engineered correctly, their synergistic reactions create optimum oxidizing and disinfection conditions that break down even some of the most durable and problematic wastewater components.

The disadvantages of ozone/UV systems are analogous with the disadvantages of applications based on ultraviolet (UV) water disinfection without ozone. A significant restriction is associated with the effects of biofouling and deposition of salt crystals on the surfaces of protective quartz-glass sleeves of UV lamps. The deposition causes interruptions in the operation of disinfecting units and makes it necessary to use special technical equipment to clean the sleeves using chemical and physical methods. Another problem is the limitation of exchange process between gas bubbles formed and water. This limitation became especially significant after decreasing reactor dimensions from a reactor used for water treatment by ozone without UV intensification.

25

Another known solution is proposed in the PCT publication number WO 2000/058224, by Kelly, Russell, *et. al.* ("Kelly"). Kelly discloses a device used for water treatment by a combination of UV and ultrasound (US) irradiation. The introduction of elastic vibrations of sufficient power with an ultrasonic frequency into an operative zone achieves disinfection levels that cannot be provided

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otherwise by the use of radiant energy alone. Desired inactivation levels may be achieved at lower total power levels, ensuring fewer costs of disinfection with stable results. Water is subjected to the combined UV/US action that causes the fragmentation of bacterial clusters into smaller units, destruction of

5 microorganisms, and transformation of organic phases. A continuous virucidal action of ultraviolet irradiation takes place, which leads to the microorganisms losing their ability to reproduce. These processes occur simultaneously in one reactor. Therefore, ultrasonic vibrations that can propagate well through aqueous media force all surfaces of inner reactor walls and protective sleeves of ultraviolet

10 lamps to vibrate. This effect prevents the biofouling and salt deposition on the above indicated surfaces. Thus, a number of processes occur simultaneously, maintaining a constant level of inactivation. This makes it possible to increase the effectiveness of water treatment under the commensurable power of UV irradiation by up to 10^3 times and destroy virtually completely all forms (including

15 spore forms) of microorganisms, viruses, and protozoa in large quantities. The effect of complete inactivation in conventional technologies of UV irradiation and ozonation is achieved at very low concentrations of spores and protozoa under prolonged actions and virtually is unable to destroy molds.

20 The limitation of the Kelly approach is low efficiency of oxidation processes stimulated by UV irradiation from mercury UV lamps. Only a small part of total radiant energy of the UV mercury lamp spectrum can dissociate molecules in water and create active particles. Most of UV radiation has a wavelength of about 254 nm. The radiation with such a wavelength can be

25 absorbed only by ozone molecules rather than by water or oxygen molecules – this does not help stimulation of oxidation reactions.

References which may be considered relevant to the subject application include:

The Ozone/UV Combination, *Water Quality Products (WQP)*, February 2007, Vol 12, Number 2 (2007), <http://www.wqpmag.com/The-Ozone-UV-Combination--article7629>;

Water Disinfection Water Treatment and Purification Systems, Specific Features
5 of Intensification of the Process of Water Disinfection by Ultraviolet and
Ultrasound, A.N. Ulyanov, JSC "SVAROG", Stromynka ul.18, Moscow, Russia;
US 5,466,367 and US 5,679,257-disclose industrial waste water treatment;
US 5,683,576 discloses water ozonation treatment apparatus;
US 5,935,431 discloses ultraviolet ozone water purifier for water disinfection;
10 US 7,118,852 discloses methods and apparatus for decontaminating protein-
containing biological fluids;
US 2007/147097 discloses fluid treatment using plasma technology;
US 2010/0219136 discloses fluid treatment using plasma technology;

15 In light of the foregoing, there exists a need to provide a system and
method that overcomes one or more shortcomings of the current conventional
water treatment technologies.

20 SUMMARY

The present invention provides a system and method for water treatment,
decontamination, sterilization and purification.

25 Also provided is a reactor for water treatment that simultaneously
combines ozone, ultrasound and ultraviolet purification techniques in a single
reaction zone, under natural (or non-vacuum) conditions. While the discussion
and drawings depict one ozone inlet, US and UV port, it is understood that more
than one can be configured in the reaction chamber. The number of reactant
30 components will depend on the overall size of the reactor chamber and the desired

effect of maximizing reaction rates with the synchronized use of these components. The reactor can be scaled to the size desired by the user, and can be constructed of various materials provided the materials are sufficient to maintain the components and withstand pressure, ultrasound vibrations, and the oxidative effects of ozone, as well as the degradation effects of ultraviolet radiation. Stainless steel and polymers such as lexan have been found to be beneficial materials for the construction of the reactor.

Another object of the present invention is to provide a reactor for water treatment that is effective and can be scaled as needed including to the smaller dimensions, and yet maintain an aggressive reaction among components. The present inventive system and reactor allow for a smaller size reactor than current conventional water treatment reactors, since greater volumes and rates can pass through the reactor.

Yet another object of the present invention is to provide a reactor for water treatment that increases the reaction efficiency by bursting the bubbles formed at the surfaces of the reactor and its components.

Embodiments of the invention provide a system for treating contaminated water. The system includes a casing that forms a reaction chamber having an inlet for injecting or infusing ozone gas, and an outlet for removing the treated water, an ultraviolet radiation source, and, an ultrasound vibration source. As used herein, injecting and infusing relative to ozone is used interchangeably and intended to mean an infusion of ozone into the reaction liquid. While it is believed essentially that any shape of reactor would accomplish the invention, the axisymmetrically shaped reactor allows for greater movement and flow of water, and hence is the preferred shape for the present inventive method. A mixture of the contaminated water and ozone is injected in the reactor chamber through an

inlet nozzle (i.e., injection or infusion system of gas in water). Ultraviolet radiations are introduced in the mixture of the contaminated water and ozone by way of an ultraviolet (UV) radiation source. Sound vibrations of ultrasound frequencies are simultaneously introduced in the reaction chamber. The contaminated water is treated by virtue of one or more chemical reactions occurring in the reaction chamber. The system further includes an outlet nozzle (outlet pipe) for carrying the treated water outside the reaction chamber.

Hence, the present invention provides a method for treating contaminated water using ozone gas, ultraviolet radiation, and ultrasound vibrations in one system or reactor. For purposes herein, use of the word treatment shall also mean pretreatment of water, wherein pretreatment is considered before the water is passed through a filtration media. A mixture of the contaminated water and ozone is injected in a reaction chamber, and is contacted with or exposed to ultraviolet radiation, forming water containing dissolved ozone, and gas bubbles containing the excess or remaining ozone, along with ultrasound vibrations. The contaminated water is treated by virtue of one or more chemical reactions occurring in the reaction chamber. The method includes using a sensor for sensing an intensity of the ultraviolet radiations to maintain correct reaction dynamics, and regulating the dose of introduced ozone and the flow of treated water through the chamber. Dimensions and the motion pattern of bubbles in the reaction chamber can be visually inspected. The treated water is withdrawn from the reaction chamber and the flocculated or coagulated colloidal by-products of the reaction are filtered. Ultrasound irradiation of UV lamp jacket prevents scale formation on its surface, which causes UV efficiency drop. A mirror in the lamp jacket can be installed for reflecting the UV radiation in the direction of the ultrasound transducer in order to make the interaction between the two more effective.

BRIEF DESCRIPTION OF DRAWINGS

The features of the present invention are set forth with particularity in the appended claims. Embodiments of the present invention will hereinafter be described in conjunction with the appended drawings provided to illustrate and
5 not to limit the scope of the claims, wherein like designations denote like elements, and in which:

Fig. 1 illustrates a cross sectional front view of the reactor for water treatment, in accordance with various embodiments of the present invention;
10

Fig. 2 illustrates a cross sectional side view corresponding to the cross sectional front view of **Fig.1**, of the reactor for water treatment, in accordance with various embodiments of the present invention; and

15 **Fig. 3** illustrates a flowchart, illustrating a method for water treatment, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

20 As used in the specification and claims, the singular forms “a”, “an” and “the” include plural references unless the context clearly dictates otherwise. For example, the term “an article” may include a plurality of articles unless the context clearly dictates otherwise.

25 Those with ordinary skill in the art will appreciate that the elements in the **Figures** are illustrated for simplicity and clarity and are not necessarily drawn to scale. For example, the dimensions of some of the elements in the **Figures** may be exaggerated, relative to other elements, in order to improve the understanding of the present invention.

30

There may be additional components described in the foregoing application that are not depicted on one of the described drawings. In the event such a component is described, but not depicted in a drawing, the absence of such a drawing should not be considered as an omission of such design from the
5 specification.

Broadly, this invention may be employed in residential, municipal, or industrial settings and can be powered by conventional or solar treated sources. Before describing the present invention in detail, it should be observed that the
10 present invention utilizes a combination of method steps and system components related to a method for treating water, wherein different types include but are not limited to: potable, drinking, recycled for pools or aquariums, oil field, waste or recycled industrial water. Accordingly, the system components and the method steps have been represented where appropriate by conventional symbols in the
15 drawings, showing only specific details that are pertinent for an understanding of the present invention so as not to obscure the disclosure with details that will be readily apparent to those with ordinary skill in the art having the benefit of the description herein.

20 While the specification concludes with the claims defining the features of the invention that are regarded as novel, it is believed that the invention will be better understood from a consideration of the following description in conjunction with the drawings, in which like reference numerals are carried forward.

25 The disclosed embodiments are merely exemplary of the invention, which can be embodied in various forms. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention in virtually any appropriately detailed

structure. Further, the terms and phrases used herein are not intended to be limiting but rather to provide an understandable description of the invention.

Referring to **FIGS. 1** and **2**, cross sectional front and corresponding cross
5 sectional side views of the reactor for water treatment respectively, are shown.

Described herein is a system for treating contaminated water comprising:

- a) an outer housing forming a reaction chamber therein for holding contaminated water;
- 10 b) at least one inlet nozzle for injecting an ozone-containing gas with the contaminated water in the reaction chamber;
- c) at least one ultraviolet (UV) radiation source for introducing ultraviolet radiation in the mixture of the contaminated water and ozone;
- d) at least one ultrasound (US) transducer for generating ultrasound vibrations in
15 the reaction chamber,
- e) simultaneously contacting the ozone gas, UV radiation and US vibrations with the contaminated water within the reaction chamber, and;
- e) removing the treated water through at least one outlet nozzle to the outside of the reaction chamber.

20

The inventive system further comprises an ultraviolet sensor which is required to be located on the walls of the reactor. The sensor can be of a type for sensing an intensity of the ultraviolet radiations that maintain correct reaction dynamics.

25

The time of the reaction can vary from seconds to minutes and in some cases even for hours depending on what substance is required to be removed. One can consider the constants of chemical reactions, which are common knowledge (reference is made to the NIST data base) as a basis to help determine time of the
30 reaction. The reaction constants of ozone are different for different materials, but

in general, are a few orders of magnitude higher when ozone reacts with UV than without the use of UV radiation. The volume of the reaction chamber depends on the flow rate of treated water where treatment by ozone in combination with UV is much faster, because it is believed that OH radicals are produced that work much faster than the ozone (by a few orders of magnitude) thus allowing to make the chamber smaller than conventional chambers, yet obtain similar results. The size of the reaction chamber can vary but cannot be too small so that there is enough time (for the given flow rate) for UV to be absorbed by the ozone. The reaction chamber can be scaled to a desirous size based on the needs of the user.

10

In order to regulate the dose of introduced ozone and a flow of treated water through the chamber, the system can optionally contain a visual inspection window for visually inspecting the one or more reactions occurring in the reaction chamber. Through the visual inspection window, the dimensions and the motion pattern of bubbles in the reaction chamber can be inspected. The ultraviolet sensor registers an intensity of the ultraviolet radiations to maintain the correct reaction dynamics, and to regulate the dose of introduced ozone and the flow of treated water through the chamber. Generally, the size of the bubbles and their number assist in monitoring the effectiveness of UV and the process of absorbing (or sucking-in) the gas. Typically, it is difficult to quantify or count the number of bubbles, therefore no numbers can easily or generally be assigned to this monitoring process. An ultraviolet sensor registers the intensity of the ultraviolet radiations to maintain the correct reaction dynamics, for the dose of introduced ozone and the flow of treated water through the chamber.

25

The inlet nozzle of the reactor includes a water inlet nozzle, and gas containing ozone inlet nozzle. The contaminated water, and ozone introduced in the water, are in a quantity or amount sufficient to complete the interaction (or reaction) between the ozone and the UV radiation. The amount of ozone employed will vary based on the degree of contamination of the water. The

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amount of ozone must be sufficient for the direct oxidation reaction and for creation of the dissolved ozone concentration in water for absorption of UV.

A water treatment reactor **100** or a water treatment system **100** according to an illustrative embodiment of the disclosure is shown in **FIG. 1** and **FIG. 2**. The reactor **100** includes an outer housing **102** in which the water treatment reactions are carried out. The outer housing **102** is cylindrical in shape and forms a reaction chamber **104**. While the cylinder shape is preferred, any shape allowing for thorough mixing of the water with the reactants, or wherein the contaminated water is exposed to the reactants can be employed. The reaction chamber **104** is fitted with a water input nozzle **106** at the bottom in a substantially horizontal direction, through which untreated water enters the reaction chamber **104**. The reaction chamber **104** may also contain more than one input nozzle **106**. The water input nozzle **106** is fitted with an ozone input nozzle **108**. The water input nozzle **106** and the gas containing ozone input nozzle **108** form the inlet nozzle **110**. Gas containing ozone is drawn by the untreated water forming an emulsion. Part of the ozone is dissolved in water and the remainder is in the bubbles. This generally occurs inside the inlet nozzle **110** before they enter the reaction chamber. The configuration of the inlet and outlet nozzles to the reactor is not critical provided they are configured to maximize contact of the reactants with the contaminated water as they enter the reactor.

The ultrasound transducer **112** is fitted at the bottom of the reaction chamber in a substantially vertical direction as shown in **FIG. 1**. The transducer does not have to be at the bottom of the chamber, and can be located anywhere within the reactor to allow for effective mixing within the solution and exposure/penetration of US to the reactor chamber surfaces. The ultrasound transducer **112** generates sound waves or ultrasonic vibrations in the ultrasonic range, above about 18,000 hertz, by converting the electrical energy into sound. For example, the ultrasound transducer may be a piezoelectric transducer that

generates sound frequencies in the range of about 20kHz to 1Mhz. Appropriate hydrodynamic, mechanical or magnetostrictive ultrasound transducers may also be used. The ultrasound transducer **112** creates an ultrasound field zone that covers the entire volume of the reaction chamber **104**, thus enabling an effective
5 reaction and preventing scaling within the surfaces of the chamber.

The water treatment reactor **100** further includes an ultraviolet (UV) lamp **114**, located herein at the top of the outer housing **102**. The UV lamp **114** is protected by a quartz glass sleeve **116**, which surrounds the UV lamp **114**. It
10 should be appreciated that any other quartz glass which is transparent for the UV rays of 253.7 nm wavelength may be used for this application. While the UV lamp herein is located at the top of the reactor, it may be located anywhere convenient depending upon the design of the reactor chamber and water flow provided it maximizes penetration into the solution.

15

The quartz glass sleeve **116** also includes a reflective mirror **118** for enabling a complete utilization of the ultraviolet rays produced by the UV lamp **114**, and an ultraviolet (UV) sensor **120**. The reflective mirror **118** reflects the UV rays produced by the UV lamp **114**, such that the UV rays cover the entire
20 reaction chamber **104**.

The dimensions of the outer housing **102**, the ultrasound transducer **112** and the quartz glass sleeve **116** are chosen such that maximum process effectiveness is achieved. The time of the reaction can vary from seconds to
25 minutes and in some cases even for hours depending on what substance is required to be removed. It was found that generally the oxidation reaction was complete within about 10 seconds. The volume of the reaction chamber **104** depends on the flow rate of treated water where treatment by ozone in combination with UV is much faster because it is believed that OH radicals are
30 produced that work much faster than the ozone (by a few orders of magnitude)

thus allowing one to make the chamber smaller. The inactivation, destruction and oxidation are maximized by providing a large surface area for the reaction, at the same time, precipitation of the contaminants on the surface of the quartz glass sleeve **116** is minimized.

5

The UV lamp **114** generates electromagnetic radiations in the ultraviolet wavelength range of about **250** nm to about **260** nm. More specifically, in an example, the UV lamp **114** generates the electromagnetic radiation of **253.7** nm wavelength. The quartz glass sleeve **116** with reflector makes it possible for these radiations to cover the entire volume of the reaction chamber **104**.

10

Another embodiment of the invention involves a method for treating contaminated water comprising:

- a) injecting an ozone containing gas through an inlet nozzle into a reaction chamber having contaminated water, wherein the injection results in the formation of water containing dissolved ozone and bubbles with residual ozone in the reaction chamber;
- b) introducing ultraviolet (UV) radiation in the water containing dissolved ozone;
- c) generating ultrasound (US) vibrations in the reaction chamber, and maintaining the vibrations for a period of time sufficient to complete the reaction between the water, ozone, and UV radiation resulting in removal of a majority percentage of the contaminants from the water; and
- d) removing the now treated water out of the reaction chamber through an outlet nozzle.

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The inventive method further comprises sensing an intensity of the ultraviolet radiations to maintain correct reaction dynamics, regulating the dose of introduced ozone and the flow of treated water through the chamber, as well as

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inspection of the dimensions and the motion pattern of bubbles in the reaction chamber **104**. The method still further includes the contaminated water and ozone introduced in an amount sufficient to drive the reaction to completion.

5 A person skilled in the art will understand that the intensity of the UV lamp **114** is varied on a case by case basis and the intensity is selected such that the reaction between the contaminated water and ozone results in virtually all contaminants to be affected by the process.

10 The treated water is removed from the reaction chamber **104** via outlets **122**. While shown herein, the outlets are located at the top and at the bottom of the reaction chamber **104**, their location may be anywhere convenient on the reactor. A water outlet pipe **124** of appropriate length may be provided for this purpose. Further, a visual inspection window **126** may be provided to facilitate
15 visual inspection of the reaction conditions. A UV controller **128** is also provided. The UV sensor **120** senses the intensity of the UV rays and the UV controller **128** allows control of the UV intensity such that optimum water treatment conditions can be maintained in the reaction chamber **104**. While a manual UV controller may be employed, it is preferred to utilize an automatic UV controller in the
20 inventive process.

 The untreated water entering from the inlet nozzle **110** is mixed with ozone in appropriate quantity. When the ozonized water enters the reaction chamber **104**, the reaction chamber **104** and the UV lamp **114** are irradiated by the
25 ultrasound. The ozone dissolved in untreated water absorbs the UV radiations and dissociates with the formation of OH radicals. Ultrasound irradiation of the surface of the quartz glass sleeve **116** keeps the surface clean and transparent for maximized UV radiation, crushes the gas bubbles formed, and further agitates the entire mixture thus accelerating the gas-liquid exchange process.

30

FIG. 3 is a flowchart **300**, illustrating a method for water treatment, in accordance with an embodiment of the present invention. It can be carried out in batch or continuous reaction mode. References will be made to **FIGS. 1** and **2** during the description of **FIG. 3**. At step **302**, a mixture of ozone and
5 contaminated water is injected in the reaction chamber **104** of the reactor **100**, through the inlet nozzle **110**. At step **304**, ultraviolet radiations of a predetermined intensity are introduced in the reaction chamber **104** by using the UV lamp **114** and the quartz glass sleeve **116** with reflector. At step **306**, ultrasound vibrations are introduced in the reaction chamber by way of the
10 ultrasound transducer **112**. The water treatment reaction occurs between the contaminated water and ozone in the presence of the UV radiations and ultrasound vibrations, and the water is treated to remove the contaminations. At step **308**, the treated water is taken out of the reaction chamber **104**.

15

For clarity, the inventive process combines all reactants essentially simultaneously, as opposed to a step-wise system. In an embodiment, steps **304** and **306** may be carried out simultaneously. The steps **302** and **308** are continuous processes, *i.e.*, the mixture of the contaminated water and ozone is introduced
20 continuously to replenish the treated water that is being continuously taken out of the reaction chamber. In general, the present method is able to remove organic compounds, chloro organic compounds, biological contaminants etc from water or a fluid of primarily water. The time period of the treatment is dependent on the type of contaminants in the water and the degree of contamination. The following
25 examples illustrate the results of the tests carried out by using the reactor and method of the present invention.

EXAMPLES

30 Example 1:

In this test, the following equipment and conditions were employed:

Natural water (by natural water it is meant water from natural sources, i.e., springs, rivers, lakes, etc., with no specific impurities but containing the usual organic compounds, salts, etc.; the amount is quantified as “COD” in the table below) with admixture of solvable organic compounds was purified by the reactor of the present invention. Injected ozone amount was 2 g/hour. Treated water flow was 0.5 m³/hour. UV intensity (without ozone) was more than 60 W/m² in all reactor points. The custom made reactor employed was of cylindrical shape, made from stainless steel, about 1/10th of an inch thick, 150mm diameter and 200mm high. There were no ozone, UV or US sensors employed. The ozone level was visually monitored within the reactor. Ultrasound radiation at frequency 28 kHz was more than 1 W/cm² on the surface of UV lamp jacket (quartz glass sleeve 102). In all tests, the UV lamp jacket was observed to be clean. As characteristic of solvable organic concentration chemical oxygen demand (COD) was measured. In the table, initial COD of water and COD of treated water with different combination of effect factors are presented. The following table represents the results of the tests conducted by using combinations of ozone, ultrasound and ultraviolet methods:

20

The standard COD test was employed, and the data in the tables herein represents an average set of data found.

Legend:

25 O₃: Ozone

UV: Ultraviolet

US: Ultrasound

30

Table 1: Results of Test or Example 1

	Initial	O ₃	US	UV	O ₃ +UV	O ₃ + US	UV+US	O ₃ +UV+US
COD (g/m ³)	8.3	7.5	8.3	8.2	3.3	7.1	8.2	1.8

As can be seen from Table 1, the combination of ozone, ultraviolet and
 5 ultrasound gave the best results as compared to other combinations. Use of pure
 UV and US irradiation resulted in practically no effect on the resultant COD.
 O₃+US combination proved to be effective (but less effective than the present
 invention) for the clean UV lamp jacket, but this situation was observed to be
 unstable. Without ultrasonic protection of the UV lamp jacket against scale
 10 deposition, UV intensity drops and efficiency of this combination decreases up to
 the efficiency of the pure ozone case.

Example 2:

15 In this example, the equipment and conditions of test 1 or example 1 were
 reproduced except that chlorinated tap water with an admixture of chloro organic
 compounds was purified by using the reactor of the present invention. Ozone
 containing gas was injected in an amount of 1 g/hour (gram/hour). Treated water
 flow was 0.5 m³/hour. UV intensity (without ozone) was greater than 60 W/m² in
 20 all reactor points. Ultrasound radiation at frequency 28 kHz was more than 1
 W/cm² on the surface of the UV lamp jacket. In the table below, the
 concentrations of some chloro organic compounds in initial and treated water are
 presented.

Table 2: Results of test or Example 2

	Initial	O ₃ +UV+US
Chloroform mg/m ³	89.1	<0.1
Perchloroethylene mg/m ³	18.5	3.2
Perchloromethane mg/m ³	8.3	0.5

As can be seen from Table 2, high purification rate was observed for all measured chloro organic substances. For all substances, the final concentration of admixtures for treated water was lower than maximum allowable concentration for drinking water. For allowable concentration values, the reader is referred to website: www.EPA.gov/safewater/hfacts.html. It is found that acceptable levels of contaminants differ per contaminant, however, generally for all contaminants, the range is between 0 and 10 (mg/L)².

Example 3:

The reactor and conditions of example 1 were reproduced except as noted. In this example, biologically contaminated natural water was treated. The injected ozone amount was 1 g/hour. Treated water flow was 1 m³/hour. UV intensity (without ozone) was greater than 60 W/m² in all reactor points. Ultrasound radiation at frequency 28 kHz was more than 1 W/cm² on the surface of the UV lamp jacket. In the table, the total bacterial count and coliform bacterial count in initial and treated water are presented. A high sterilization ability of water treatment can be observed by using the reactor of the present invention.

Table 3: Results of test or Example 3.

	Initial	O ₃ +UV+US
Total Bacterial Count CFU/100ml	320	0
Coliform Bacterial Count CFU / 100ml	180	0

It has been found that the inventive process generally will not oxidize
5 metals or non-organic contaminants to the point of removing them in solution (or
from the contaminated water) at the time of the reaction. However, the process
will coagulate these contaminants making it easy to remove the contaminants by
ultrafiltration. This occurs without any additional agents or additives to the
process, making the ozone-UV-US process advantageous to purification of these
10 heavy contaminants over current traditional methods for their removal.

The present invention has been described herein with reference to a
particular embodiment for a particular application. Although selected
embodiments have been illustrated and described in detail, it may be understood
15 that various substitutions and alterations are possible. Those having ordinary skill
in the art and access to the present teachings may recognize additional various
substitutions and alterations are also possible without departing from the spirit and
scope of the present invention, and as defined by the following claims.

WHAT IS CLAIMED IS:

1. A system for treating contaminated water comprising simultaneously
5 contacting contaminated water in a reaction chamber with an ozone containing gas, ultraviolet radiation, and ultrasound vibrations.
2. The system of claim 1 in the absence of vacuum.
- 10 3. A system for treating contaminated water comprising:
 - a) an outer housing forming a reaction chamber therein for holding contaminated water;
 - b) at least one inlet nozzle for injecting an ozone-containing gas with the contaminated water in the reaction chamber;
 - 15 c) at least one ultraviolet (UV) radiation source for introducing ultraviolet radiation in the mixture of the contaminated water and ozone;
 - d) at least one ultrasound (US) transducer for generating ultrasound vibrations in the reaction chamber,
 - e) simultaneously contacting the ozone gas, UV radiation and US vibrations
20 with the contaminated water within the reaction chamber, and;
 - e) removing the treated water through at least one outlet nozzle to the outside of the reaction chamber.
4. The system of claim 3, further comprising an ultraviolet sensor.
25
5. The system of claim 3, further comprising a visual inspection window.
6. The system of claim 3, wherein the contaminated water and ozone-containing gas are added to the system in an amount sufficient for the direct oxidation

reaction and creation of the dissolved ozone concentration in water for absorption of UV.

7. The system of claim 3, wherein the system further comprises at least one of a
5 UV lamp, a quartz glass sleeve, and a reflective mirror.

8. The system of claim 3 further comprising a UV controller configured to control the intensity of the UV radiation source.

10 9. The system of claim 3 further comprising the US transducer creating sufficient vibrations to sufficiently agitate the water and prevent scale build-up on the interior of the reactor.

10. The system of claim 9 further comprising lack of scale build up on the quartz
15 glass sleeve, and other surfaces of the reaction chamber.

11. A method for treating contaminated water comprising:

- a) injecting an ozone containing gas through an inlet nozzle into a reaction chamber having contaminated water, wherein the injection results in the
20 formation of water containing dissolved ozone and bubbles with residual ozone in the reaction chamber;
- b) introducing ultraviolet (UV) radiation in the water containing dissolved ozone;
- c) generating ultrasound (US) vibrations in the reaction chamber, and
25 maintaining the vibrations for a period of time sufficient to complete the reaction between the water, ozone, and UV radiation resulting in removal of a majority percentage of the contaminants from the water; and
- d) removing the now treated water out of the reaction chamber through an outlet nozzle.

30

12. The method of claim 11, further comprising monitoring UV radiations passed through layers of water.

13. The method of claim 11, further comprising visually inspecting the interior of
5 the reaction chamber to view the dimensions and the motion pattern of the bubbles formed in the reaction chamber.

14. The method of claim 11, further comprising means for controlling the intensity of UV radiations.

10

15. The system and method of any of the above claims for the removal of contaminants from potable water, drinking water, recycled water, oil field water, waste water, or recycled industrial water.

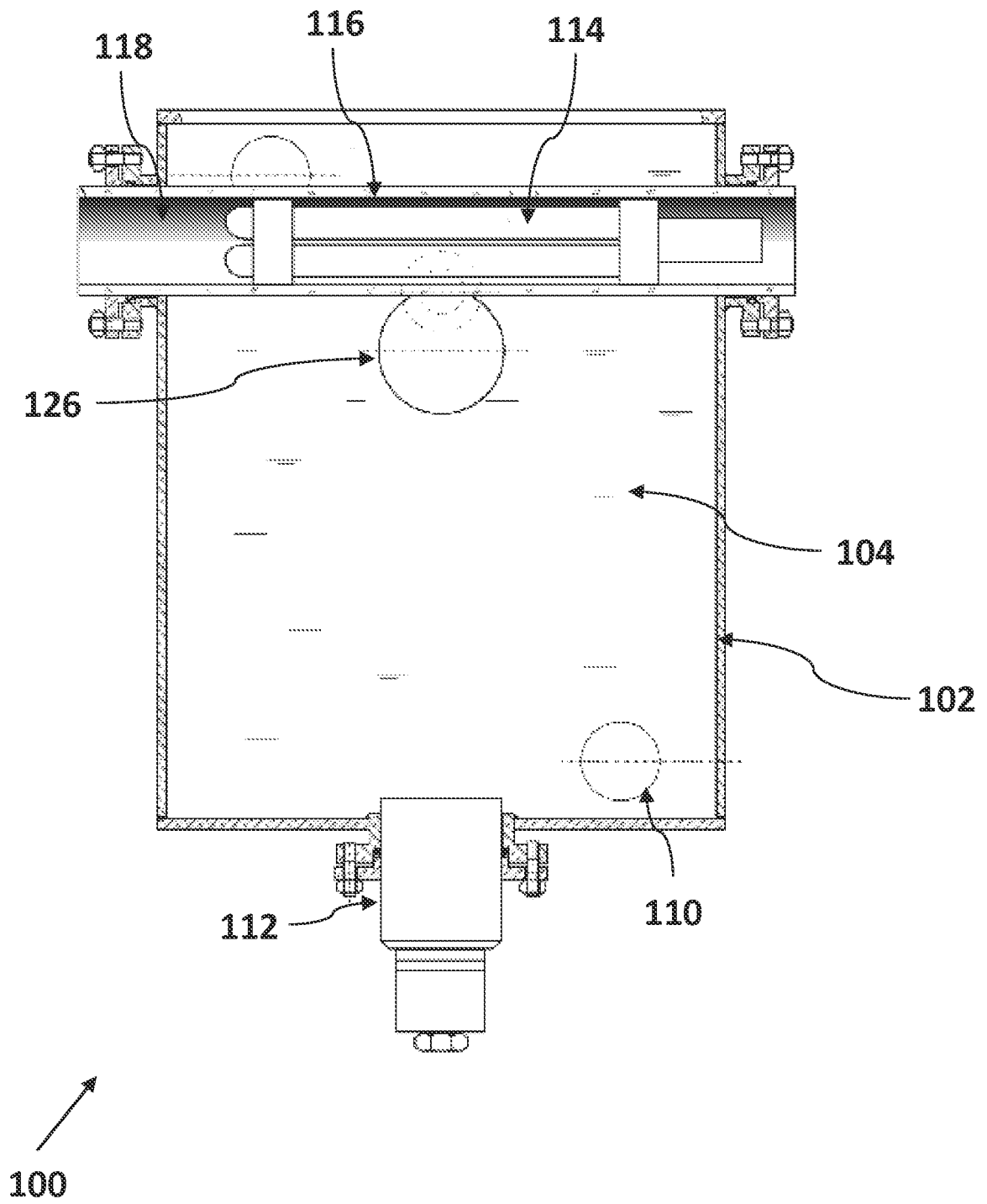


FIG. 1

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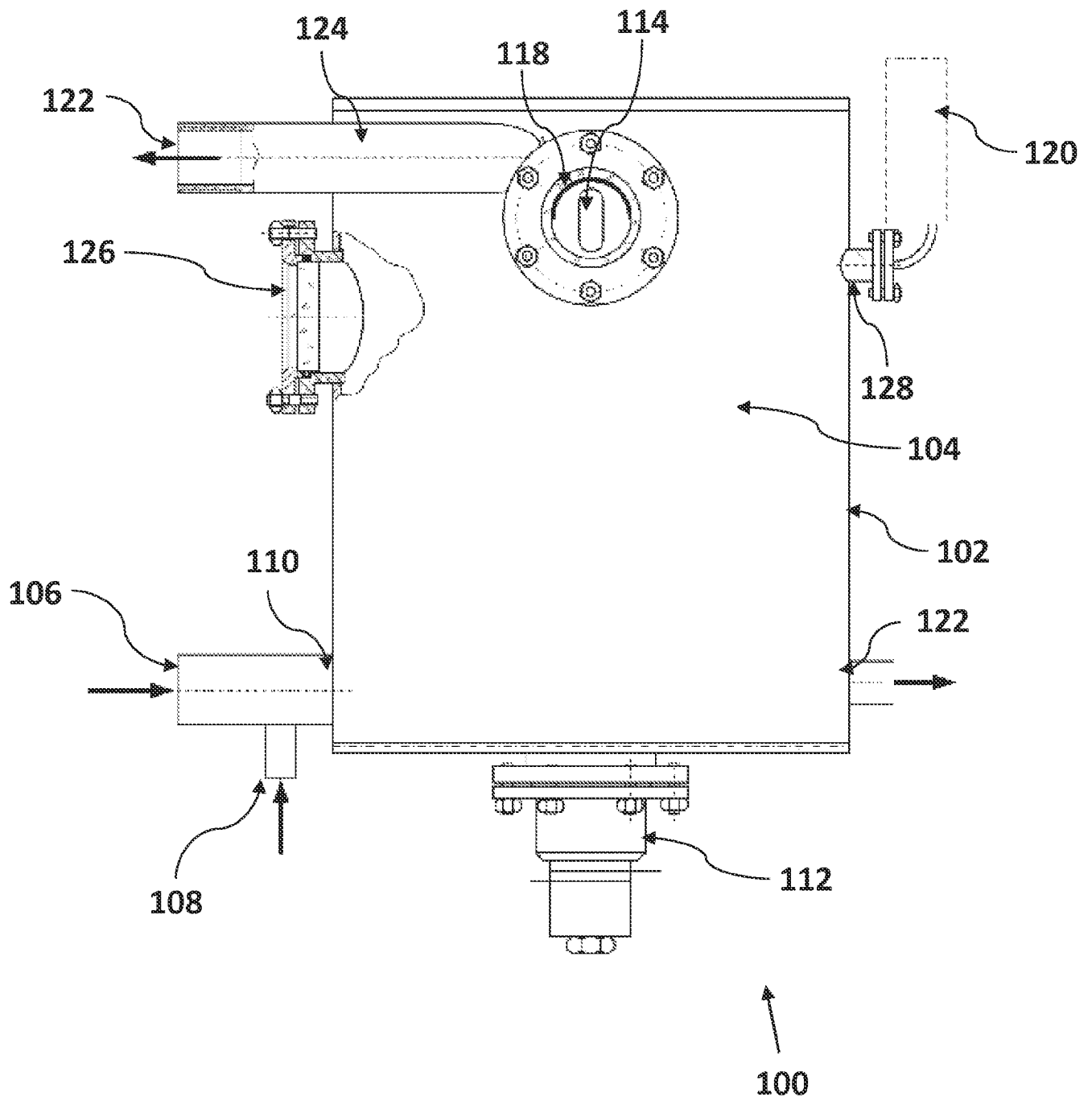
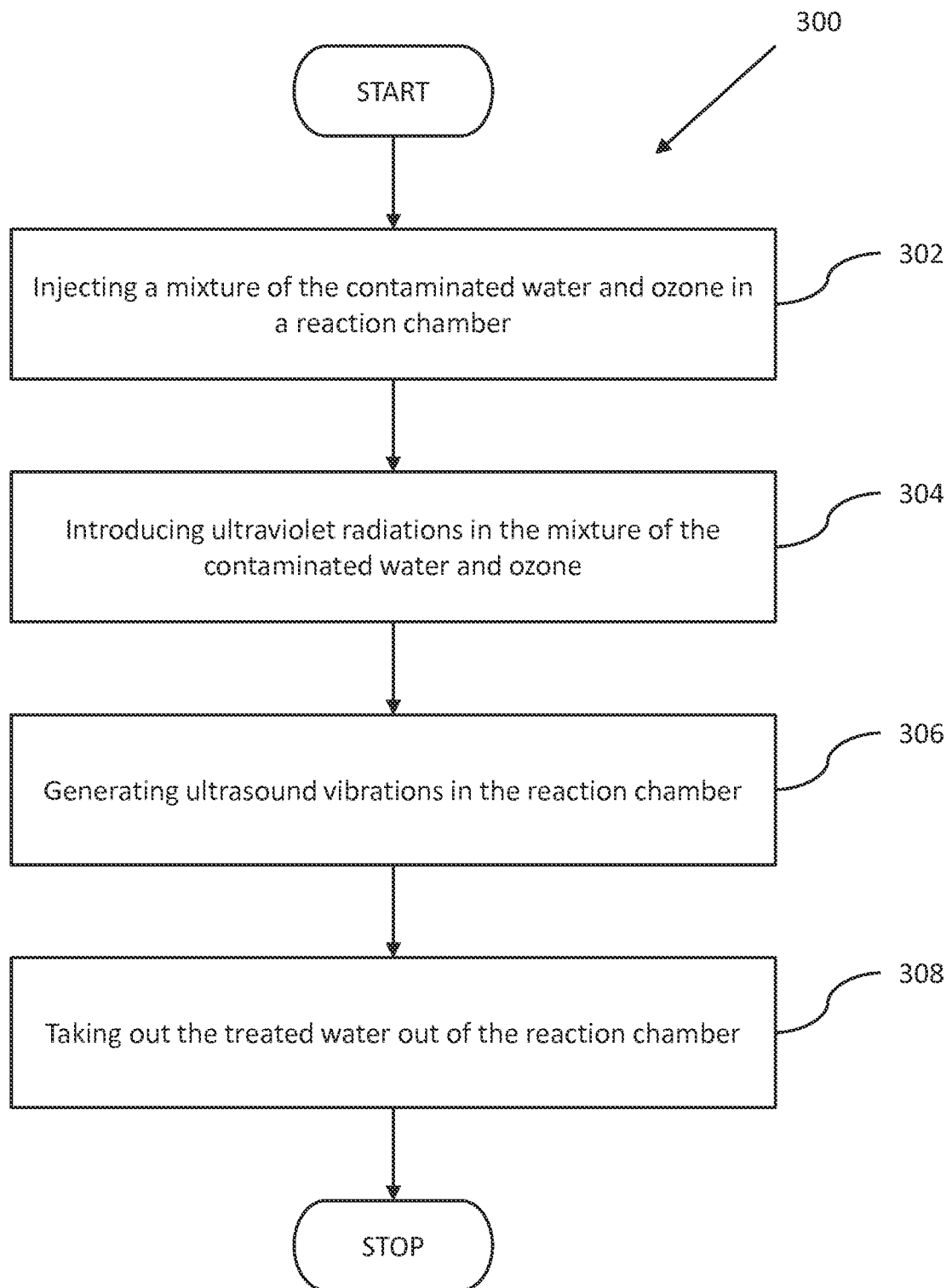


FIG. 2

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**FIG. 3**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US13/36145

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - C02F 1/32, 1/36, 1/78 (2013.01)

USPC - 210/748.04, 748.13, 760

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8): B01J 19/08, 19/10; C02F 1/32, 1/36, 1/78, 9/00 (2013.01)

USPC: 210/748.04, 748.1, 748.13, 758, 760, 764; 422/186.3

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

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

MicroPatent (US-G, US-A, EP-A, EP-B, WO, JP-bib, DE-C,B, DE-A, DE-T, DE-U, GB-A, FR-A); DialogPRO; Google; Google Scholar; IP.com; water*, aqueous*, wastewater*, contamin*, decontamin*, steriliz*, purif*, treat*, pretreat*, clean*, disinfect*, ozone*, ultraviolet*, ultrasound*, simultaneous*, chamber*, reaction*, housing*, reactor*

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---	US 2009/0162258 A1 (JANSSEN, RA et al.) June 25, 2009; abstract; figure 1; paragraphs [0002]-[0003], [0010]-[0013], [0016], [0018]-[0019], [0027]-[0029], [0033], [0037]-[0039], [0042]-[0047], [0049]-[0055], [0057]-[0059], [0061]	1, 15/1 ---
Y	US 7371323 B1 (SPIELMAN, RB et al.) May 13, 2008; abstract; figure 3; column 4, lines 54-61; column 9, lines 48-60	2-14, 15/2-14
Y	US 7371323 B1 (SPIELMAN, RB et al.) May 13, 2008; abstract; figure 3; column 4, lines 54-61; column 9, lines 48-60	3-10, 13-14, 15/3-10, 15/13-14
Y	US 6361697 B1 (COURY, WS et al.) March 26, 2002; abstract; column 12, lines 52-65	2, 15/2
Y	US 2003/0194692 A1 (PURDUM, HE) October 16, 2003; abstract; paragraphs [0311]-[0313], [0563]-[0564], [0575]	4, 11-12, 15/4, 15/11-12
Y	US 6071473 A (DARWIN, LC) June 6, 2000; abstract; column 4, lines 36-48; column 5, lines 21-45	9-10, 15/9-10
Y	US 2010/0247390 A1 (TANAKA, K et al.) September 30, 2010; abstract; figures 2-3; paragraphs [0104], [0194]-[0199], [0211], [0291]	5, 13, 15/5, 15/13
Y	US 6555011 B1 (TRIBELSKY, Z et al.) April 29, 2003; abstract; figure 4; column 4, lines 65-67; column 14, lines 27-67	8, 14, 15/8, 15/14

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

* Special categories of cited documents:

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

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

29 July 2013 (29.07.2013)

Date of mailing of the international search report

02 AUG 2013

Name and mailing address of the ISA/US

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