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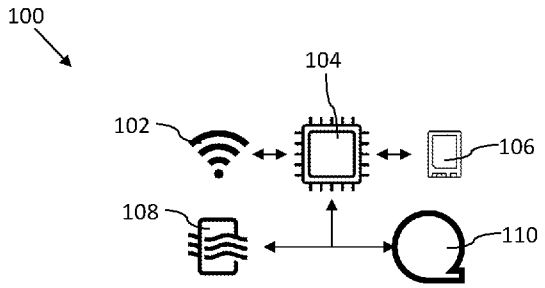

FIG. 1A

(57) Abstract: In one aspect, a system for generating and monitoring an antimicrobial is provided, the system including: a microprocessor and/or a microcontroller; an external communications device; a computational system; an antimicrobial sensor and/or an environmental sensor; and an antimicrobial generator, wherein the external communications device, the computational system, the antimicrobial generator, and the antimicrobial sensor and/or the environmental sensor are operatively connected to the microprocessor and/or the microcontroller. The system may further include a separate sensor sub-system comprising: a sensor sub-system microprocessor and/or a sensor sub-system microcontroller; a sensor sub-system external communications device; a sensor sub-system antimicrobial sensor and/or a sensor sub-system environmental sensor; and a sensor sub-system computational system. The system may further include a separate generation sub- system comprising: a generation sub-system microprocessor and/or a generation sub-system microcontroller; a generation sub-system external communications device; and a generation sub- system antimicrobial generator.

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SYSTEMS, METHODS, AND APPARATUSES FOR DISINFECTION AND DECONTAMINATION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from U.S. Provisional Patent Application No. 63/036,412, filed on June 8, 2020, U.S. Provisional Patent Application No. 63/049,524, filed on July 8, 2020, U.S. Provisional Patent Application No. 63/049,541, filed on July 8, 2020, U.S. Provisional Patent Application No. 63/049,919, filed on July 9, 2020, U.S. Provisional Patent Application No. 63/081,459, filed on September 22, 2020, U.S. Provisional Patent Application No. 63/126,734, filed on December 17, 2020, and U.S. Provisional Patent Application No. 63/157,368, filed on March 5, 2021, each of which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] Infectious diseases such as human immunodeficiency virus and acquired immune deficiency syndrome (HIV/AIDS), tuberculosis (TB), severe acute respiratory syndrome (SARS-CoV-1), Ebola virus disease (EVD), and coronavirus disease 2019 (COVID-19) are contagious diseases transmissible through direct contact from person to person, through indirect contact by breathing airborne droplets spread from an infected person, and through contact with surfaces of contaminated objects.

[0003] With the current COVID-19 pandemic outbreak, facemask or respirator wearing and practicing social distancing may mitigate airborne droplets spread by potential neighboring human carriers. Nevertheless, both of these practices are defensive actions that do not destroy or disinfect the germs or viruses in the airborne droplets. Currently, methods that are used to generate antimicrobial gases or vapor are large and impractical for general household or office use or for personal use in a limited localized space, and methods of generating ClO_2 from liquid and solid precursor chemicals are slow and/or generate low quality ClO_2 solutions.

[0004] Antimicrobial gas, such as chlorine dioxide (ClO_2), has demonstrated capability as an antimicrobial or inactivator for pathogens on hard surfaces. In gas form, ClO_2 has demonstrated capability to disinfect hard surfaces and porous materials within three-dimensional spaces. ClO_2 gas has also been shown to kill or otherwise inactivate airborne pathogens, and even protect against airborne contagion.

[0005] ClO_2 gas is also currently used as a deodorizer in vehicles, rooms, and other enclosed spaces. Typical products used for enclosed space odor removal include placing a cup or container housing one or more dry solid chemical constituents (typically consisting of a chlorite

salt and an activator), adding water to activate the ClO_2 generation process, enclosing the ClO_2 generation materials in the space for an extended period of time before opening up the space, removing the spent ClO_2 solution, and allowing the space to air out to reduce ClO_2 concentration to safe levels.

[0006] The present disclosure relates to a safe and effective system and method for quickly and safely generating antimicrobial gas (e.g., ClO_2 gas). Antimicrobial gas may be generated from small amounts of concentrated liquid and solid precursor chemicals and actively dispersing the antimicrobial gas into an enclosed three-dimensional space. Additionally, the present disclosure relates to a safe and effective system and method for monitoring antimicrobial gas concentration in the enclosed three-dimensional space and generating additional antimicrobial gas as necessary to maintain the desired concentration in the space. When used at higher concentrations, the resultant antimicrobial gas will sanitize or disinfect the air and contact surfaces within the enclosed space. At low concentrations (e.g., < 0.1 ppm), the antimicrobial gas can be used to decrease or otherwise inactivate airborne pathogens and actively protect persons against airborne contagions.

[0007] The present disclosure also relates to a safe and effective system and method of generating and monitoring the concentration of antimicrobial gas on demand.

SUMMARY

[0008] In one aspect, a system for generating and monitoring an antimicrobial gas is provided, the system including: a microprocessor and/or a microcontroller; an external communications device; a computational system; an antimicrobial sensor and/or an environmental sensor; and an antimicrobial generator, wherein the external communications device, the computational system, the antimicrobial generator, and the antimicrobial sensor and/or the environmental sensor are operatively connected to the microprocessor and/or the microcontroller. The system may further include a separate sensor sub-system comprising: a sensor sub-system microprocessor and/or a sensor sub-system microcontroller; a sensor sub-system external communications device; a sensor sub-system antimicrobial sensor and/or a sensor sub-system environmental sensor; and a sensor sub-system computational system. The system may further include a separate generation sub-system comprising: a generation sub-system microprocessor and/or a generation sub-system microcontroller; a generation sub-system external communications device; and a generation sub-system antimicrobial generator. In another aspect, a network of these systems for generating and monitoring an antimicrobial gas is provided.

[0009] In another aspect, a system for generating and monitoring ClO_2 gas is provided, the system comprising: a device housing including an inlet; a microcontroller; one or more reagent

containers containing a reagent; a microfluidic liquid dispensing and metering system; a microfluidic device for generating a ClO_2 gas from the reagent(s); a device for separation of ClO_2 gas and post-generator waste in communication with the air pump air duct and an air duct to one or more outlets; on-device or in-device waste storage prior to disposal; and one or more sensing system for either ClO_2 gas or the environment in which the device is installed.

[0010] In another aspect, a ClO_2 gas generator is provided, comprising: a base including a pressure generator; one or more reagent containers holding liquid reagent(s), the containers being pressurized by the pressure generator; a chamber passage in communication with the pressure chamber and the reagent container; one or more control valves in communication with the pressure generator and reagent container; one or more control valves in communication with the chamber passage and a microfluidic chip; a sensor system for determining the quantity, mass, or volume of the reagents transiting the chamber passage; a microfluidic chip having a generation chamber in communication with a second chamber passage; a second chamber passage in communication with a CLO_2 gas-liquid separation chamber; and, a waste container for storage and/or inactivation of post-CLO_2 generator waste products.

[0011] In another aspect, a network of systems for generating and monitoring ClO_2 gas, is provided, the network comprising: a plurality of systems for generating and monitoring ClO_2 gas, including: a device housing including an inlet; a microcontroller; one or more reagent containers containing a reagent; a microfluidic device for generating a ClO_2 gas from the reagent; and a sensing system; wherein the microcontroller includes a communication device capable of communication between the plurality of systems, and wherein the communication device establishes distributed control of each system's microcontroller, wherein the microcontroller is controlled by machine learning algorithms to alter system performance.

[0012] In another aspect, a network of systems for generating and monitoring an antimicrobial gas is provided, the system including: a microprocessor and/or a microcontroller; an external communications device; a computational system; an antimicrobial sensor and/or an environmental sensor; and an antimicrobial generator, wherein the external communications device, the computational system, the antimicrobial generator, and the antimicrobial sensor and/or the environmental sensor are operatively connected to the microprocessor and/or the microcontroller. The system may further include a separate sensor sub-system comprising: a sensor sub-system microprocessor and/or a sensor sub-system microcontroller; a sensor sub-system external communications device; a sensor sub-system antimicrobial sensor and/or a sensor sub-system environmental sensor; and a sensor sub-system computational system. The system may further include a separate generation sub-system comprising: a generation sub-system

microprocessor and/or a generation sub-system microcontroller; a generation sub-system external communications device; and a generation sub-system antimicrobial generator.

[0013] In another aspect, the microcontroller of the system will have the computational and local data storage ability to enable closed-loop control of the ClO_2 generation system, including but not limited to: local storage and microcontroller operations on data from sensor systems for ClO_2 levels to space environment variables like barometric pressure, humidity, temperature, occupancy, or sounds that may be used to alter generator system performance automatically or via user intervention; measurement, local storage, and microcontroller operations on data from microfluidic subsystems such as mass/volume sensors of reagents, pressure generator performance, microfluidic chip-borne sensors, valve status to any other electronic subsystem to provide control as well as storage of system performance data for maintenance, alert, troubleshooting, inactive modes of operation, active modes of operation, and local setup.

[0014] In another aspect, the system has a communication device connected to the microcontroller and/or electronic components such that data from any electronic component within, on, or connected to the housing can be gathered, locally stored, operated on by the microcontroller, and transmitted to external data gathering systems on mobile to fixed devices.

[0015] In another aspect, machine learning and/or artificial intelligence algorithms can be incorporated into the system microcontroller to alter system performance automatically or by user interactions. An example of local control includes alteration of system performance for detection of a virus or bacteria in the ambient air, altitude, temperature, air changes in the local space measured by changes in concentration in the air of spaces containing ClO_2, changes in occupancy by living beings, alterations for user preference, prediction of cycles of occupancy/vacancy, alerts as to normal or abnormal performance of the system, and the like.

[0016] In another aspect, a plurality of systems within a plurality of spaces which are arranged into a group connected via communication devices described above to each other for distributed control via coordination of each system's microcontroller, centralized unit control, and/or a combination of both local and distributed control.

[0017] In another aspect, machine learning and/or artificial intelligence algorithms can be incorporated into the distributed network of systems by the aspects described above; example of distributed control include adjusting individual systems to achieve uniform and/or deliberately non-uniform distribution of ClO_2 in each individual generator's location across an entire building floor, multiple floors, or the entire building due to changes in ClO_2 concentration from HVAC, consumption or self-dissipation of ClO_2 gas, control of day/night generation cycles, sensing patterns across time, three-dimensional volumes, seasonal variations, to previously unknown

factors which can be sensed either directly by the sensor systems in/on the system, inferred or traced to the signal measured, or directly traceable to the variations observed in ClO_2 concentrations across a collection of systems installed across distinctly separate to varying interconnection of real world spaces in which control of infectious species is desired.

[0018] In another aspect, the system for distribution and monitoring of ClO2 gas in a three-dimensional space will be designed for a plurality of operating modes; the first operating mode is designed for occupied spaces, the second mode is designed for un-occupied spaces and may include one or more sub-modes to achieve desired outcomes; future user or engineered modes may be added. These modes may be changed by authorized users on the unit, via connected mobile devices, and/or by a centralized distributed control system connected to a plurality of units.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] **FIG. 1A** illustrates a schematic of an example system **100** for generating and monitoring an antimicrobial gas.

[0020] **FIG. 1B** illustrates a schematic of system **100** oriented within a volume under treatment **124**.

[0021] **FIG. 1C** illustrates a schematic of system **100** oriented within a volume under treatment **124**.

[0022] **FIG. 2A** illustrates a schematic of an example complimentary sensing sub-system **120** and generation sub-system **122** for generating and monitoring an antimicrobial gas.

[0023] **FIG. 2B** illustrates a schematic of sensing sub-system **120** and generation sub-system **122** within a volume under treatment **124**.

[0024] **FIG. 2C** illustrates a schematic of sensing sub-system **120** and generation sub-system **122** used in conjunction with an HVAC system.

[0025] **FIG. 2D** illustrates a schematic of sensing sub-system **120** within a volume under treatment **124** engaging with generation sub-system **122** outside of the volume under treatment **124**.

[0026] **FIG. 2E** illustrates a schematic of generation sub-system **122** within a volume under treatment **124** engaging with sensing sub-system **120** outside of the volume under treatment **124**.

[0027] **FIG. 3** illustrates a schematic of an example system **300** for generating and monitoring an antimicrobial gas.

[0028] **FIG. 4** illustrates a schematic of an example system **400** for generating and monitoring an antimicrobial gas.

[0029] **FIG. 5** illustrates an example blueprint of a network **500** of antimicrobial gas systems **300** and sensors distributed in rooms and spaces within a floor of a building.

[0030] **FIG. 6** illustrates a schematic of an example system **600** for generating and monitoring an antimicrobial gas.

[0031] **FIG. 7** illustrates a schematic of an example system **700** for generating and monitoring an antimicrobial gas.

[0032] **FIG. 8** illustrates a cutaway perspective view of a system **800** generating antimicrobial vapor within a sealed environment **810** for disinfecting items therein.

[0033] **FIG. 9** illustrates a system **900** for generation of an antimicrobial gas and/or solution.

[0034] **FIG. 12** illustrates a system **1200** for generation of an antimicrobial gas and/or solution.

[0035] **FIG. 13** illustrates a system **1300** for generation of an antimicrobial gas and/or solution.

[0036] **FIG. 14** illustrates a system **1400** for generation of an antimicrobial gas and/or solution.

[0037] **FIG. 15** illustrates a system **1500** for generation of an antimicrobial gas and/or solution.

[0038] **FIG. 16** illustrates a system **1600** for generation of an antimicrobial gas and/or solution.

[0039] **FIG. 17** illustrates a system **1700** for generation of an antimicrobial gas and/or solution.

[0040] **FIG. 18A** illustrates a plan view of a reactor **1800** for generating an antimicrobial gas.

[0041] **FIG. 18B** illustrates a front perspective view of reactor **1800** for generating an antimicrobial gas.

[0042] **FIG. 18C** illustrates a top perspective view of reactor **1800** for generating an antimicrobial gas.

[0043] **FIG. 18D** illustrates a front perspective view of reactor **1800** for generating an antimicrobial gas.

[0044] **FIG. 19A** illustrates a side perspective view of a reactor **1900** for generating an antimicrobial gas.

[0045] **FIG. 19B** illustrates a side elevational view of reactor **1900** for generating an antimicrobial gas.

[0046] **FIG. 19C** illustrates a plan view of reactor **1900** for generating an antimicrobial gas.

[0047] **FIG. 19D** illustrates an exploded side perspective view of reactor **1900** for generating an antimicrobial gas.

[0048] **FIG. 19E** illustrates an exploded front perspective view of reactor **1900** for generating an antimicrobial gas.

[0049] **FIG. 19F** illustrates a front perspective view of reactor **1900** for generating an antimicrobial gas.

[0050] **FIG. 19G** illustrates a rear perspective view of reactor **1900** for generating an antimicrobial gas.

[0051] **FIG. 19H** illustrates a side perspective view of reactor input mechanism **1962** in a first position.

[0052] **FIG. 19I** illustrates a side perspective view of reactor input mechanism **1962** in a second position.

[0053] **FIG. 20A** illustrates a plan view of a reactor **2000** for generating an antimicrobial gas.

[0054] **FIG. 20B** illustrates a front perspective view of reactor **2000** for generating an antimicrobial gas.

[0055] **FIG. 20C** illustrates a top perspective view of reactor **2000** for generating an antimicrobial gas.

[0056] **FIG. 20D** illustrates a front perspective view of reactor **2000** for generating an antimicrobial gas.

[0057] **FIG. 21A** illustrates a plan view of a reactor **1200** for generating an antimicrobial gas.

[0058] **FIG. 21B** illustrates a top perspective view of reactor **1200** for generating an antimicrobial gas.

[0059] **FIG. 21C** illustrates a rear perspective view of reactor **1200** for generating an antimicrobial gas.

[0060] **FIG. 21D** illustrates a top perspective view of reactor **1200** for generating an antimicrobial gas.

[0061] **FIG. 21E** illustrates a rear perspective view of reactor **1200** for generating an antimicrobial gas.

[0062] **FIG. 22A** illustrates a plan view of a reactor **2200** for generating an antimicrobial gas.

[0063] **FIG. 22B** illustrates a top perspective view of reactor **2200** for generating an antimicrobial gas.

[0064] **FIG. 22C** illustrates a rear perspective view of reactor **2200** for generating an antimicrobial gas.

[0065] **FIG. 22D** illustrates a rear perspective view of reactor **2200** for generating an antimicrobial gas.

[0066] **FIG. 22E** illustrates a front perspective view of reactor **2200** for generating an antimicrobial gas.

[0067] **FIG. 23A** illustrates a sectional view of an example antimicrobial gas generator **2300**.

[0068] **FIG. 23B** illustrates a partial sectional view of antimicrobial gas generator **2300**.

[0069] **FIG. 23C** illustrates a sectional view of antimicrobial gas generator **2300**.

[0070] **FIG. 23D** illustrates a partial sectional view of antimicrobial gas generator **2300**.

[0071] **FIG. 23E** illustrates a sectional view of antimicrobial gas generator **2300**.

[0072] **FIG. 23F** illustrates a partial sectional view of antimicrobial gas generator **2300**.

[0073] **FIG. 23G** illustrates a partial sectional view of antimicrobial gas generator **2300**.

[0074] **FIG. 24** illustrates a sectional view of an example antimicrobial gas generator **2400**.

[0075] **FIG. 25A** illustrates an elevation view of an example antimicrobial gas generator and sensor device **2500**.

[0076] **FIG. 25B** illustrates a perspective view of antimicrobial gas generator and sensor device **2500**.

[0077] **FIG. 25C** illustrates a sectional view of antimicrobial gas generator and sensor device **2500**.

[0078] **FIG. 26A** illustrates a perspective view of an example antimicrobial gas generator and sensor device **2600**.

[0079] **FIG. 26B** illustrates a sectional view of antimicrobial gas generator and sensor device **2600**.

[0080] **FIG. 27A** illustrates an elevation view of an example antimicrobial gas generator and sensor device **2700**.

[0081] **FIG. 27B** illustrates a perspective view of antimicrobial gas generator and sensor device **2700**.

[0082] **FIG. 28A** illustrates an elevation view of an example portable antimicrobial gas reactor **2800**.

[0083] **FIG. 28B** illustrates a schematic view of portable antimicrobial gas reactor **2800**.

[0084] **FIG. 29A** illustrates a plan view of an example packaged antimicrobial gas generator solution and packaged activator solution.

[0085] **FIG. 29B** illustrates a sectional view of packaged antimicrobial gas generator solution and packaged activator solution.

[0086] **FIG. 30A** illustrates an elevation view of an example of an antimicrobial gas generator **3000** in the form of a card shape or a sheet.

[0087] **FIG. 30B** illustrates a sectional view antimicrobial gas generator **3000** containing an antimicrobial generating compound.

[0088] **FIG. 31** illustrates an example of an antimicrobial generator **3100** in the form of a pouch with optional addition of water internal to the pouch.

[0089] **FIG. 32A** illustrates an example of an antimicrobial generator **3200** in the form of a solution treated single or multi-ply porous material.

[0090] **FIG. 32B** illustrates an example of antimicrobial generator **3200** with liquid reactants absorbed or adsorbed on substrates and blended with a porous matrix material with optional addition of an exterior film to control release.

[0091] **FIG. 32C** illustrates an example of antimicrobial generator **3200** with solid reactants blended in a porous material and optional addition of an exterior film to control release.

[0092] **FIG. 32D** illustrates an example of antimicrobial generator **3200** in the form of a perforated pouch.

[0093] **FIG. 32E** illustrates an example of antimicrobial generator **3200** where reactant materials of **FIGS. 32A-32C** are configured side by side with optional materials to support activation and control release.

[0094] **FIG. 33A** illustrates a cutaway view of an aerosol container **3386** including an interrupted dip tube **3390**.

[0095] **FIG. 33B** illustrates a cutaway view of aerosol container **3386** including reactor **2100**, **2200** engaged with dip tube **3390**.

[0096] **FIG. 33C** illustrates a cutaway view of aerosol container **3386** including reactor **2100** engaged with dip tube **3390**.

[0097] **FIG. 33D** illustrates a cutaway view of aerosol container **3386** including reactor **2200** engaged with dip tube **3390**.

[0098] **FIG. 34** illustrates a cutaway view of an aerosol container **3486** including a flexible bladder **3492** connected to a dip tube **3490**.

[0099] **FIG. 35A** illustrates a cutaway view of an aerosol container **3586** including a plurality of flexible bladders **3594**.

[00100] **FIG. 35B** illustrates a cutaway view of aerosol container **3586** including a plurality of flexible bladders **3594**.

[00101] **FIG. 36** illustrates a schematic diagram of an apparatus **3600** for generating antimicrobial gas or vapor external to a sealed environment for disinfecting items therein.

[00102] **FIG. 37** illustrates a schematic diagram of a system **3700** generating antimicrobial gas or vapor external to a sealed environment for disinfecting items therein.

[00103] **FIG. 38A** illustrates a schematic diagram of a system **3800** generating antimicrobial gas or vapor within a sealed environment for disinfecting items in the sealed environment.

[00104] **FIG. 38B** illustrates a schematic diagram of apparatus **3800** generating antimicrobial gas or vapor within a sealed environment for disinfecting items in the sealed environment.

[00105] **FIG. 39A** illustrates an apparatus **3900** generating antimicrobial vapor within a sealed environment for disinfecting items therein.

[00106] **FIG. 39B** illustrates apparatus **3900** generating antimicrobial vapor within a sealed environment for disinfecting items therein.

[00107] **FIG. 39C** illustrates apparatus **3900** generating antimicrobial vapor within a sealed environment for disinfecting items therein.

[00108] **FIG. 40** illustrates methods of generating antimicrobial gas or vapor within a sealed environment or external to the sealed environment to disinfect items within the sealed environment.

[00109] **FIG. 41A** illustrates ClO_2 efficacy test data on controlled samples.

[00110] **FIG. 41B** illustrates ClO_2 efficacy test data on controlled samples.

[00111] **FIG. 42** illustrates an example of an apparatus **4200** that generates antimicrobial gas or vapor for disinfecting items in three-dimensional space.

[00112] **FIG. 43** illustrates an example of an apparatus **4300** that generates antimicrobial gas or vapor for disinfecting items in three-dimensional space.

[00113] **FIG. 44** illustrates an example procedure **4400** for the use of apparatus **4300** in **FIG. 43** to generate antimicrobial gas.

[00114] **FIG. 45** illustrates a table showing temperature effects to solubility of ClO_2 gas in water and in air and required amount of ClO_2 gas for a defined room size.

[00115] **FIG. 46** illustrates a uniformity of ClO_2 gas concentration distributed within a room.

[00116] **FIG. 47** illustrates gas concentration profiles in room setting with furniture.

[00117] **FIG. 48** illustrates relative humidity and generated ClO_2 gas concentration from a ClO_2 solution.

[00118] **FIG. 49** illustrates a correlation of increase in disinfection efficacy with elevated humidity.

[00119] **FIG. 50** illustrates a method for generating an antimicrobial gas and dispersing the gas via an apparatus.

[00120] **FIG. 51A** illustrates the time (minutes) to equilibrium for a target concentration of 0.1 ppm of ClO_2 to air.

[00121] **FIG. 51B** illustrates the concentration (ppm of ClO_2 to air) measured at five ports over time (minutes).

[00122] **FIG. 52A** illustrates the time (minutes) to equilibrium for a target concentration of 350 ppm of ClO_2 to air.

[00123] **FIG. 52B** illustrates the concentration (ppm of ClO_2 to air) measured at 12 ports over time (minutes).

[00124] **FIG. 53A** illustrates a diagram of an example system **5300** for generating ClO_2 vapor from small volumes of high concentration liquid precursors.

[00125] **FIG. 53B** illustrates a diagram of example system **5300** for generating ClO_2 vapor from small volumes of high concentration liquid precursors.

[00126] **FIG. 54A** illustrates results of ClO_2 generation using system **5300** or similar systems.

[00127] **FIG. 54B** illustrates results of ClO_2 generation using system **5300** or similar systems.

[00128] **FIG. 54C** illustrates requirements for ClO_2 generation using system **5300** or similar systems.

[00129] **FIG. 55A** illustrates the mean D-values (hours) from replicate tests per organism performed at the range of 0.11 ± 0.04 ppmv.

[00130] **FIG. 55B** illustrates the mean D-values (hours) from replicate tests per organism performed at the range of 5.3 ± 2.4 ppmv.

DETAILED DESCRIPTION

Closed Loop Antimicrobial Concept

[00131] A system is provided including an interconnection of platform component elements described below. **FIGS. 1A-1C** illustrate a system **100** for generating and monitoring an antimicrobial gas. **FIGS. 2A-2E** illustrate a system **200** for generating and monitoring an antimicrobial gas. Platform component elements may be used individually or in combination to implement a system and device to create, maintain, optimize and/or document the presence of a concentration of an antimicrobial agent in a volume under treatment **124**.

[00132] The system (such as systems **100**, **200**) is capable of maintaining an antimicrobial agent in the atmosphere of volume under treatment **124**, and may include: (1) controlled release of antimicrobials to maintain a target antimicrobial concentration in volume under treatment **124**; (2) at least one type of sensor **108**, within volume under treatment **124**, and possibly several sensors **108** or several types of sensors **108**, are used to sense the concentration of the antimicrobial; (3) a computational system **106** that can compare the measured difference between the antimicrobial concentration sensing and a target antimicrobial concentration in volume under treatment **124**; (4) an antimicrobial generator **110** (which may be connected to computational system **106**) capable of initial establishment and maintenance of a target antimicrobial concentration in volume under treatment **124**; (5) where a computed difference between a target antimicrobial concentration and a sensed antimicrobial concentration is determined, a target control may adjust antimicrobial generation to maintain the target antimicrobial concentration; (6) at least one base safety assurance implementation at the physical components of system **100**, **200**, electronic hardware, and firmware to software levels of the product.

[00133] System **100**, **200** may be designed for modes of operation to prevent transmission or infection between humans in occupied spaces, as well as modes of operation wherein unoccupied rooms can be treated. To maintain target antimicrobial concentrations, system **100**, **200** may separate the durable reusable components from disposable components to maintain refill and physical-digital control across deployed system elements.

[00134] Regarding the antimicrobials, the self-degradation kinetics and kinetics of inactivation to log-kill microbes may depend upon more than just the concentration of the antimicrobials in the volume under treatment **124**. Thus, system **100**, **200** may include a broad spectrum of environment sensing to enable system **100**, **200** to use machine learning and artificial intelligence, including for example, enhanced target control, automated volume estimation, humidity measurement, and programmatic antimicrobial cycles.

[00135] Antimicrobial generator **110** designs may use matter displacement (including positive displacement pumps) to activate systems, many of which may have an electronic signal that can be harvested to enable enhanced safety assurance utilizing signals collected by a microprocessor/microcontroller **104** that may be part of computational system **106**.

[00136] System **100**, **200** may use external communication **102** to form a connectivity network designed to utilize distributed system data of the aforementioned variables of interest to enable the network coordination of distributed product nodes, and the correspondingly required strategy of spatial and temporal identification constants durably and/or variably assigned to system **100**, **200** products.

[00137] System **100**, **200** may use a combination of platform components, to create an antimicrobial dashboard system. System **100**, **200** may provide real-time as well as historical data on infection control, either for safety and health in a user's own spaces, or in high requirements markets such as healthcare facilities. The antimicrobial dashboard system may be used to map a data lake of environment sensing, target antimicrobial concentrations, and use of the connectivity network to deliver distributed system data on the distributed product nodes, which may be identified by unique spatial and temporal identifications, and combine all of this data into human-meaningful information.

[00138] Distributing the intelligence (e.g., computational system **106**), sensing (e.g., sensor **108**), and generation (e.g., antimicrobial generator **110**) may enable the development of a digital twin of space for antimicrobial control. This concept may enable additional network safety assurance implementations and may contain all of the information required to develop and deploy proactive strategies in system **100**, **200** products such as a predictive antimicrobial control.

[00139] System **100**, **200** includes the ability to combine platform components in multiple ways to achieve product implementation options that are designed specifically for rooms in buildings and provide digital control to low-concentration of an airborne antimicrobial. This antimicrobial may be used to fight transmission and infection caused by microbe-emitting beings and microbes that are circulated through the air currents in rooms, adjacent rooms via open infiltration/exfiltration passages, and shared HVAC systems.

[00140] As illustrated in **FIGS. 1A-1C**, system **100** may include platform components including external communications **102** devices, microprocessors/microcontrollers **104**, computational system **106**, antimicrobial and/or environmental sensors **108**, and antimicrobial generator **110**. System **100** may be entirely contained inside of volume under treatment **124**. Optionally, system **100** may be contained within volume under treatment **124** and supplemented

with one or more additional sensor sub-systems **120** configured to provide additional data, including antimicrobial concentration and/or environmental data.

[00141] As illustrated in **FIGS. 2A-2E**, system **200** may include both a sensor sub-system **120** and a generation sub-system **122**. Sensor sub-system **120** may include external communication **102** devices, a microprocessor/microcontroller **104A**, computational system **106**, and antimicrobial and/or environmental sensors **108**. Generation sub-system **122** may include external communication **102** devices, a microprocessor/microcontroller **104B**, and antimicrobial generator **110**. System **200** may be entirely contained inside of volume under treatment **124**.

[00142] As illustrated in **FIG. 2C**, system **200** may, in a first aspect, include sensor sub-system **120** within volume under treatment **124**, and generation sub-system **122** outside of volume under treatment **124**. In the first aspect, generation sub-system **122** generates an antimicrobial and via a fluid connection to an HVAC air supply **126**, directs antimicrobial into the interior of volume under treatment **124**. The concentration of antimicrobial within volume under treatment **124** is sensed by sensor sub-system **120**.

[00143] As illustrated in **FIG. 2C**, system **200** may, in a second aspect, include generation sub-system **122** within volume under treatment **124,** and sensor sub-system **120** outside of volume under treatment **124**. In the second aspect, generation sub-system **122** generates an antimicrobial within volume under treatment, and via a fluid connection to an HVAC air return **128**, sensor sub-system **120** senses the concentration of antimicrobial within volume under treatment **124**.

[00144] As illustrated in **FIG. 2D**, system **200** may include a sensor sub-system **120** within volume under treatment **124**, and generation sub-system **122** outside of volume under treatment **124**, wherein generation sub-system **122** is in fluid communication within volume under treatment **124** to place generated antimicrobial within volume under treatment **124**.

[00145] As illustrated in **FIG. 2E**, system **200** may include a sensor sub-system **120** outside of volume under treatment **124**, and generation sub-system **122** within volume under treatment **124**, wherein sensor sub-system **120** is in fluid communication within volume under treatment **124** to sense generated antimicrobial concentrations within volume under treatment **124**.

[00146] Volume under treatment **124** is conceptually a volume in which a user seeks to distribute an antimicrobial. The volume may be sealed permanently or temporarily to isolate the volume for a period of time. The volume may have openings through which atmosphere can be allowed to infiltrate and/or exfiltrate before, during, or after distributing an antimicrobial. The infiltration/exfiltration can be a characteristic of the volume that is either an uncontrolled variable due to consequence of the volume configuration, or active control strategies of infiltration/exfiltration of atmosphere.

[00147] The target volumes may be the living spaces where human beings gather for work, activities, entertainment, and/or their domiciles. Therefore, product targets may be volumes that can be termed rooms, with groups of rooms forming floorplans, collections of floorplans that form a building, and collections of buildings that comprise a facility.

[00148] Modular platform components may be extended into other volumes under treatment **124**, including for example: (1) mobile vehicles such as the interiors of cars, trains, subways, airplanes, recreational vehicles, ride share vehicles, autonomous vehicles, cabins in ships, and the like; (2) leisure spaces such as restaurants, nightclubs, bars, churches, community centers, libraries, and the like; (3) hospital spaces such as hospital rooms, operating rooms, procedure rooms, patient examination rooms, vivariums, morgues, and the like; and (4) business spaces such as offices, conference rooms, hallways, cafeterias, coffee and lounge areas, and the like.

[00149] Target antimicrobial concentrations may be a setpoint desired for antimicrobial release into a volume under treatment **124**. The concentration of an antimicrobial in the air can be expressed in relative ratios such as percentages, parts-per-million ("ppm"), or parts-per-billion ("ppb"), and similar terms. As the term is used herein, ppm and ppb are based upon volume.

[00150] International standard terms are often used to describe antimicrobial concentrations similar to how industrial chemicals are regulated. Important to system **100**, **200** product designs is to treat the air in rooms where people live, work, and play. Regulatory terminology for antimicrobial concentrations in the air in volume under treatment **124** include: (1) recommended/permitted exposure limit, abbreviated "REL/PEL," are concentration and time exposure limits safe for human occupation based upon historical studies and evidence; (2) immediately dangerous to life or health, abbreviated "IDLH," is a concentration at which human exposure can begin to quickly cause an adverse reaction; (3) lethal concentration with 50% mortality, abbreviated "LC-50," is a concentration at which a time-based exposure to an airborne concentration shown to have a mortality rate of 50% in animals exposed in a trial of time at concentration; and (4) lethal dose with 50% mortality, abbreviated "LD-50," is an immediate dose extrapolated from animal trials where a mortality rate of 50% is observed from a single large dose, including air measured as near-immediate mortality at an airborne concentration.

[00151] The first target antimicrobial concentrations include:

[00152] (1) prevention mode in occupied volumes: simple target number typically predicated upon, but not necessarily constrained to, known and published REL/PEL from regulatory bodies. The objective of the prevention mode is to maintain a known-safe concentration of an antimicrobial in the air in which humans can occupy for a meaningful length

of time, typically defined by safety regulators in the context of a "work shift" between 8 to 10 hours. The objective of the concentration is to limit and/or eliminate the transmission potential and/or infection potential of microbes that are already present in a room, or are being emitted into the room by other living beings or room systems like HVAC;

[00153] (2) decontamination mode in unoccupied volumes: simple target number typically predicated on, but not necessarily constrained to, known and published IDLH from regulatory bodies. One objective of decontamination mode is to enable the use of higher concentration levels of an airborne antimicrobial that can shorten the time required to inactivate/kill microbes that need elimination faster, are more difficult to kill organisms (such as spores) or are typically easier to kill but that are partially protected in nutrient rich soils, fluids in obvious to hidden locations, and are suspected or confirmed in a specific volume under treatment **124**. Targeting the range near to or below the IDLH includes a likelihood that a person who accidently or purposefully walks into volume under treatment **124** will notice effects associated with the IDLH such as watery eyes, nasal irritation, and other immediately dangerous but not lethal concentrations;

[00154] (3) emergency decontamination volumes: target number potentially selected where a highly dangerous concentration of and/or highly resistant species of microbe require an emergency decontamination of volume under treatment **124**. Once volume under treatment **124** is isolated and evacuated, system **100**, **200** products could be set by authorized users to perform higher concentration "civil defense mode" concentrations that are at or exceed the LC-50 and LD-50, therefore requiring a degree of user interaction and implementing physical safety safeguards that such a mode will not be an automated mode.

[00155] Sensors **108** and sensor sub-system **120** can include a broad range of sensing technologies to determine the concentration of the antimicrobial in volume under treatment **124**.

[00156] Any one or a combination of these sensing technologies may be utilized for many different species of antimicrobials, including for example ClO_2, which is part of the class of oxidizing antimicrobials, which may additionally include: hydrogen peroxide, dry hydrogen peroxide, ozone, nitric oxide.

[00157] System **100**, **200** may incorporate any combination of the following sensors **108** to achieve digital control: (1) electrochemical sensors that utilize a depletable chemical which reacts with the antimicrobial, and an electrical circuit that measures the effect of this chemical reaction using measures of charge, voltage, current, conductivity, resistivity, and the like to provide a signal that is in proportion to the known capable range of the sensors. An example of electrochemical sensors for ClO_2 include sensors from Analytical Technologies, Inc.; (2) MOx sensors (metal oxide semiconductor sensors) are widely used in air quality measurement, typically

for airborne pollutants such as H2S, volatile organic compounds, and are known to work to sense gaseous oxidizing species. Two examples of these MOx sensors include the Sensirion SGP40 and the Renesas ZMOD4410 family of sensors.

[00158] Advantages of MOx sensors over electrochemical sensors may include: (a) 10-year lifetimes with no chemicals to deplete; (b) calibration and training values last the lifetime of the sensor; (c) sensors can be "trained" to gas species of interest. The number of gases the sensor can be trained to is not limited by choices of chemical species in the sensor, therefore, as opposed to electrochemical sensors, one MOx sensor can be used to sense multiple antimicrobial species of interest, as well and complementary and potentially interfering gases, without requiring use of different chemicals, membranes, or other interaction/barrier methods to provide species specificity.

[00159] Alternative sensing solutions may be able to sense an antimicrobial species to the parts-per-billion to parts-per-trillion levels of concentration expected in the prevention mode in occupied volumes. These alternatives may include: (1) Colorimetry: using a chemical "dye" that interacts with the antimicrobial species of interest and causes a reaction that can be observed be electronic color sensors. The "color" can be in the spectrum of visible, infrared, UV, and other wavelengths of light. The fundamental output of such a system would be an electronic signal that is proportional to the "color change" expected for known chemical interactions that underpin such sensing technologies; (2) Fluorescence: if the antimicrobial species fluoresces, or can be bound to a chemical species that is selective and can be sensed via fluorescence, the magnitude of the fluorescence can be sensed and calibrated to known sources to translate fluorescence levels sensed into and electronic signal that is proportional to said fluorescence.

[00160] Electronic and/or computational controls (computational system **106**) act as the "heart" and "brains" of a system **100**, **200** product. While there are electronic analog, field-programmable gate array ("FPGA"), and discrete circuitry methods that may work for control, the digital solutions designed for low power battery-powered connected products are particularly beneficial for wireless system **100**, **200** products.

[00161] Microprocessors or microcontrollers **104** may form the control intelligence backbone of system **100**, **200** products. Microprocessors may be used as these may be required for the embodiments of certain simple safety assurance systems.

[00162] Microprocessor unit **104** may be the central processing core electrically connected to all of the elements of the system **100**, **200** platform components.

[00163] Antimicrobial generator **110** is any of a variety of subcomponents responsible for the generation and/or dispersion of an antimicrobial into volume under treatment **124**. A large variety of antimicrobial generators **110** is discussed herein, including:

[00164] (1) compressed matter release: an antimicrobial stored in a compressed state is released by a pressure reducing regulator. For example, a canister of antimicrobial gas connected to a pressure reducing regulator, which when opened, allows compressed antimicrobial gas to flow out of the canister to an uncompressed state. A mass flow controller in the path of the matter being transformed from a compressed to an uncompressed state can provide quantitative measurement of the quantity of antimicrobial released;

[00165] (2) two or more chemical activation: two or more precursors are combined to cause a chemical reaction that generates the desired antimicrobial. The two or more precursors can be mixed in passive or active structures, including microfluidic structures to accelerate reaction kinetics. Examples of systems contained herein utilizing this concept include, without limitation: reactors **1800**, **1900**, **2000**, **2100**, and **2200**; gas generators **2300**, **2400**, and **3000**; gas reactor **2800**; antimicrobial generators **3100** and **3200**; and aerosol containers **3486** and **3586**;

[00166] (3) electrochemical activation: voltage potential and/or current can be varied to control species release and kinetics of antimicrobial generation. In one aspect, termed a flow-through electrochemical cell, $NaClO_2$ can be flowed over electrodes and recycled until depleted by the electrochemical cleaving of Na from $NaClO_2$. In another aspect, the precursor material can be contained in a static volume into which electrodes are co-located to generate the electrochemical cleaving of Na from $NaClO_2$ until the bulk fluid is depleted. In another aspect, ClO_2 is electrochemically generated from a solution of $NaClO_2$ as the anolyte that is separated from a catholyte by a membrane. Each anolyte and catholyte is in communication with at least one electrode, and a membrane plays an active role in increasing the yield or desired species of antimicrobial (e.g., ClO_2) while sequestering undesired species in the catholyte like Na (in this example for ClO_2). In another aspect, a thin layer of sodium chlorite is flowed in a closed, open, or one-sided membrane channel where material could be introduced to an electrochemical cell designed to generate ClO_2 only from the small quantity of $NaClO_2$, after which the depleted precursor is transferred to a waste container and the processed is repeated.

[00167] Systems **100**, **200** may be a platform that includes durable reusable components and disposable components. The disposable components may include refill cartridges. The refill cartridges may include precursors or direct antimicrobial in a concentrated form. Refill cartridges may include a reservoir. Refill cartridges may include platform components that are prone to failure from wear, including for example, pumps, sensors, and the like.

[00168] Systems **100**, **200** may include digital and physical signals to achieve the changing of modes as described above. System **100**, **200** may be used either in occupied or unoccupied volumes under treatment **124**.

[00169] As such, one class of refill cartridges can incorporate a mechanism (physical, electrical/digital, or both) to limit the base unit into which it is installed to operate in an occupied volume under treatment **124** mode (e.g., prevention mode in occupied volumes) and REL/PEL concentration levels.

[00170] Another class of refill cartridges can incorporate a mechanism (physical, electrical/digital, or both) to allow the base unit into which it is installed to operate in a decontamination mode (e.g., decontamination mode in unoccupied volumes). Additional features may include a mechanism limiting installation to a subset of users who are authorized to install the decontamination mode cartridge. These features may include a requirement to enter an appropriate electronic or digital authorization (e.g., a code, swipe a keycard, enter a biometric pass, or the like) to unlock a decontamination mode that would be inappropriate for occupied spaces. Such a decontamination mode may utilize IDLH or higher concentration levels and may be suitable for regular or exceptional "deep-clean" scenarios.

[00171] System **100**, **200** may use a combination of platform components, to create an antimicrobial dashboard system. The dashboard system may combine distributed intelligence, distributed data across the system, and other platform components to enable beneficial system features, including for example: (1) a room, floor, building control dashboard for antimicrobial treatment; (2) provide notifications to phones that are nearby a base unit; (3) system **100**, **200** coordination in physically adjacent volumes under treatment **124**; (4) antimicrobial output coordination of multiple units in a single contiguous volume (e.g., a large open space such as a concert hall); (5) data portability for integration into building management systems, such as hospital command centers; and (6) civil defense alert network for biological threats or attacks.

[00172] Each system **100**, **200** unit may securely connect (IoT connections), for purposes of data collection and storage, software and firmware updates, and/or user interactions, to assign: (1) unique identifiers for each hardware unit; (2) unique identifiers for each refill unit; (3) and/or two different types of refill units (one for when in low-concentration occupied mode, and another for authorized user to change to unoccupied decontamination mode).

[00173] Additionally, each system **100**, **200** unit may securely connect to each other (via external communication **102**) and may pass identification validation data as well as recorded operational performance data along to a data gathering point. Each unit may record its own data, and if necessary for redundancy and safety, neighboring unit data. In one aspect, each unit may

connect to a WiFi hub to achieve interconnectivity. In another aspect, all units may be required to connect to a central identification validation and data gathering point.

[00174] Computational system **106** may include local storage mediums for each system **100**, **200** unit. Alternatively, one unit can have storage capability and may act as an accumulator for multiple units in a logical grouping. All units or all accumulators may be required to report up into a central data gathering point, which may also be a point of connection into cloud data.

[00175] In one aspect, system **100**, **200** units may have safety features including: (1) input received from each unit, including location, environmental sensor suite, antimicrobial sensor data, quantity of antimicrobial generated, and/or corresponding time stamps; (2) output to user and/or system controls including possible safety signal generation based upon: (i) operational parameters that do not make sense and thus that particular unit may be malfunctioning, (ii) recognition that a neighboring unit has experienced an error can initiate "alert status" among a local group of units, and a group or region of units could be powered off if airflow-dictated interactions between two local units cause interference, (iii) client and/or host operations control: the control system will watch for signals of parameters that do not make sense, across the entire installation of units.

[00176] System **100**, **200** may include machine learning algorithms. For example, machine learning algorithms may use a multi-sensor suite to both measure and classify at least two fundamental characteristics of airborne microbial concentration in volume under treatment **124**.

[00177] System **100**, **200** may include the capability to automatically measure the volume of any given volume under treatment **124**. Sensor array **108** may be utilized to automatically measure room volume so that generator **110** closed-loop performance can be translated from a concentration in the air to a value of required make up antimicrobial that will move the concentration from a measured value to the target concentration within volume under treatment **124**. System **100**, **200** units may generate and emit a known test quantity of the antimicrobial upon initialization. The unit may initiate continuous antimicrobial sensor **108** readings while generator **110** is kept idle for a period of time between 1 min to 4 hours. On-unit computation capability measures peak concentration and uses machine learning aspect 1 ("ML1") to measure room kinetics. Understanding that concentration = mass (derived from sensed dispensed antimicrobial volume, directly or indirectly sensed precursor utilization, mass flow measurement of antimicrobial gas, or any other value that can be traced back to quantity) of antimicrobial divided by volume of volume under treatment **124**. The volume of volume under treatment **124** is determined by using the measured quantity of antimicrobial generated and antimicrobial concentration reading at a time appropriate to the room kinetics measured with ML1. System **100**, **200** may iterate with each antimicrobial gas emission to update ML1 room kinetics estimates,

while cataloging changes by time stamp. As machine learning aspect 2 ("ML2") "learns" from the data lake or direct verification experiments, future algorithms may be designed to provide input data to the generator to predict the specific quantity of antimicrobial needed to achieve the desired concentration based upon environment conditions within volume under treatment **124**. Alternatively, or as a backup method, system **100**, **200** may use a three-dimensional laser measuring system, or a tone emitter and microphone on units to ping the volume of volume under treatment **124** with a CHIRP acoustic signal. Measuring time of flight and collision of sound waves, system **100**, **200** may build a characteristic volume estimate of volume under treatment **124**.

[00178] **FIGS. 3** and **4** illustrate schematics of example systems **300** and **400** for generating and monitoring an antimicrobial gas (including a disinfection gas and/or decontamination gas). The antimicrobial gas may be a ClO_2 gas. Systems **300** and **400** may include a microfluidic liquid dispensing and metering system. Systems **300** and **400** may be used to both generate antimicrobial gas (e.g., ClO_2 gas) and dispense the antimicrobial gas (e.g., ClO_2 gas) to the ambient environment, and to sample the ambient air to identify antimicrobial gas concentration therein and generate more or less antimicrobial gas as necessary to maintain a desired antimicrobial gas concentration. Systems **300** and **400** may be used to test air in a particular environment (e.g., a three-dimensional enclosed space) to determine the concentration of antimicrobial gas (e.g., ClO_2 gas) in parts per billion ("ppb") of air. Systems **300** and **400** may be used to maintain a desired antimicrobial gas concentration in ambient air surrounding devices housing systems **300** and **400** by regularly sampling the ambient air, determining the concentration of antimicrobial gas in the ambient air, and via closed-loop control of the device, generating more or less antimicrobial gas to maintain the desired antimicrobial gas concentration in the ambient air.

[00179] Systems **300** and **400** may include wired connections to a computer network, cloud storage, or the like. Systems **300** and **400** may include wireless connections to a computer network, cloud storage, or the like. Systems **300** and **400** may document time-based tracking of system use, product maintenance, target concentration performance, and environmental parameters of interest. This documentation may be in the form of files, logs, or other records stored locally within a device housing system **300** and/or **400** or transmitted via wired connection or wirelessly to a computer network, cloud storage, or the like. Systems **300** and **400** may have cloud and/or IoT connectivity to enable user personas to effectively set up, train, manage, and maintain devices housing systems **300** and/or **400** in the three-dimensional enclosed spaces under treatment, view real-time and stored performance and environment data, and/or export data to compare validation tests such as animal and human exposure trials.

[00180] Systems **300** and **400** may be used to decontaminate (that is, to inactivate or destroy pathogens) a three-dimensional enclosed space (e.g., a hospital room) through high concentrations of antimicrobial gas (e.g., ClO_2 gas) (when unoccupied by humans), or through low concentrations of antimicrobial gas (e.g., ClO_2 gas) (when occupied by humans). In one aspect, systems **300** and **400** generate antimicrobial gas in a concentration of 1,000 ppb to 5,000 ppb or 50,000 to 300,000 ppb to decontaminate an unoccupied three-dimensional enclosed space. Systems **300** and **400** may destroy the COVID-19 within a three-dimensional enclosed space.

[00181] Systems **300** and **400** may be used to prevent the spread and/or survival of a virus in a three-dimensional enclosed space (e.g., a hospital room) through low concentrations of antimicrobial gas (e.g., ClO_2 gas) (whether occupied by humans or not). In one aspect, systems **300** and **400** generate antimicrobial gas in a concentration of less than 100ppb, for example 50 ppb, to prevent the spread and/or survival of a virus in an occupied three-dimensional enclosed space. Systems **300** and **400** may reduce aerosolized virus transmission and infection of viruses including COVID-19. Systems **300** and **400** may inactivate and/or kill airborne pathogens, and even protect against airborne contagions.

[00182] System **300** and/or **400** may be contained within a device housing **304**. Ambient air **302** may enter one or more inlet in device housing **304**. Ambient air **302** may pass through a particulate filter within device housing **304**. The particulate filter may not exclude any atmospheric molecules.

[00183] Ambient air **302** passes from device housing **304** into one or all of air pumps **308A**, **308B**, and **308C** via one or more air ducts. System **300** includes air pumps **308A**, **308B**, and **308C**, while system **400** only includes air pumps **308A** and **308C**, as will be further explained below.

[00184] A microcontroller **306** may control all on-board functions of system **300** and **400**. Microcontroller **306** includes software that can be written to change system **300** and **400**'s functions where necessary. Microcontroller **306** is operatively connected to various elements (described further below) of systems **300** and **400** via wired or wireless connection.

[00185] Microcontroller **306** is connected to air pumps **308A**, **308B**, and **308C** as illustrated, and controls the function of **308A**, **308B**, and **308C**, including one or more of start, stop, velocity, flow rate, pressure, and the like. Air pumps **308A**, **308B**, and **308C** may be disc pumps. In one aspect, air pumps **308A**, **308B**, and **308C** may be capable of producing pressure in excess of 270 mbar, flow rates in excess of 0.55 L/min, and vacuum in excess of 220 mbar. Air pumps **308A**, **308B**, and **308C** may include separate motor control units. Air pumps **308A**, **308B**,

and **308C** may include integrated motor control units. It is understood that system **400** does not include air pump **308B**.

[00186] Air pumps **308A** and **308B** in system **300** are connected to pressure relief valves **310A** and **310B**, such that excess or unnecessary pressure produced by air pumps **308A** and **308B** may be routed out of system **300**. System **400** likewise includes a pressure relief valve **310A** having the same function but does not include a pressure relief valve **310B**. Alternatively, as illustrated in **FIGS. 6** and 7, systems **600** and **700** eliminate at least air pumps **308A** and **308B** as reagent containers **312A** and **312B** may be pressurized prior to assembly of systems **600** and **700**, and thus air pumps **308A** and **308B** are unnecessary.

[00187] System **300** includes reagent containers **312A** and **312B**, each containing a different liquid reagent **314A** and **314B**. Reagents **314A** and **314B** may be combined within a microfluidic mixer **320** to generate ClO_2 gas. One of reagents **314A** and **314B** may be a liquid precursor such as $NaClO_2$ (sodium chlorite). The other of reagents **314A** and **314B** may be a liquid activator such as an acid/H+ activator.

[00188] With respect to system **300**, air pump **308A** pressurizes reagent container **312A**, thus causing reagent **314A** to travel from reagent container **312A**, through a passage into an electronically operated normally closed valve **316A** (which is connected to a controlled by microcontroller **306**). From valve **316A** reagent **314A** travels through a microfluidic flow sensor **318A** (which is used for closed loop control signals and is connected to and provides data to microcontroller **306**), and into microfluidic mixer **320**. It is contemplated that any pressure generator may be used in lieu of air pump **308A** to pressurize reagent container **312A**. In one aspect, reagent container **312A** may be pressurized by an external source during assembly of system **300**, and a valve connected to reagent container **312A** (e.g., valve **316A**) may open to permit the passage of a quantity of pressurized reagent to exist reagent container **312A** and proceed into microfluidic mixer **320** as described above. Such a system is illustrated in **FIG. 6**.

[00189] With respect to system **300**, air pump **308B** pressurizes reagent container **312B**, thus causing reagent **314B** to travel from reagent container **312B**, through a passage into an electronically operated normally closed valve **316B** (which is connected to and controlled by microcontroller **306**). From valve **316B** reagent **314B** travels through a microfluidic flow sensor **318B** (which is used for closed loop control signals and is connected to and provides data to microcontroller **306**), and into microfluidic mixer **320**. It is contemplated that any pressure generator may be used in lieu of air pump **308B** to pressurize reagent container **312B**. In one aspect, reagent container **312B** may be pressurized by an external source during assembly of system **300**, and a valve connected to reagent container **312B** (e.g., valve **316B**) may open to

permit the passage of a quantity of pressurized reagent to exist reagent container **312B** and proceed into microfluidic mixer **320** as described above. Such a system is illustrated in **FIG. 6**.

[00190] Microfluidic mixer **320** may be a planar chape designed for low dead space volume and effective mixing to increase reaction kinetics of precursors.

[00191] The mixture of reagents **314A** and **314B** in microfluidic mixer **320** creates an antimicrobial gas, including for example, ClO_2 gas. Antimicrobial gas may pass via a passage into an off-gas and waste chamber **322**. Chamber **322** may include an absorber material, an evaporator, or the like. Within chamber **322**, any waste from the creation of antimicrobial gas may be absorbed in an absorber material. Chamber **322** may include a membrane. Antimicrobial gas may exit chamber **322** into the ambient atmosphere. In one aspect, antimicrobial gas exits chamber **322** through the membrane. System **300** and **400** may include a device for separation of antimicrobial gas (e.g., ClO_2 gas) and post-generator waste in communication with one or more air pumps and air ducts to one or more outlets, and on-device or in-device waste storage prior to disposal. Chamber **322** may act as the device for separation of antimicrobial gas and post-generator waste. Chamber **322** may act as the device for on-device or in-device waste storage prior to disposal. Chamber **322** may act as both the device for separation of antimicrobial gas and post-generator waste and the device for on-device or in-device waste storage prior to disposal.

[00192] With respect to system **400**, system **400** does not include an air pump **308B**, pressure relief valve **310B**, reagent container **312B**, reagent **314B**, valve **316B**, or a microfluidic flow sensor **318B**. Further, system **400** substitutes microfluidic mixer **320** with a microfluidic electrochemical generator **434**. In system **400**, air pump **308A** pressurizes reagent container **312A**, thus causing reagent **314A** to travel from reagent container **312A**, through a passage into an electronically operated normally closed valve **316A** (which is connected to and controlled by microcontroller **306**). From valve **316A** reagent **314A** travels through a microfluidic flow sensor **318A** (which is used for closed loop control signals and is connected to and provides data to microcontroller **306**), and into microfluidic electrochemical generator **434**. An electrical current, provided by and controlled by microcontroller **306** within microfluidic electrochemical generator **434** causes a reaction with reagent **314A** within microfluidic electrochemical generator **434** that produces an antimicrobial gas, such as ClO_2 gas. Antimicrobial gas passes from microfluidic electrochemical generator **434** into chamber **322** and ultimately into the ambient environment as described with respect to system **300**.

[00193] It is contemplated that any pressure generator may be used in lieu of air pump **308A** to pressurize reagent container **312A**. In one aspect, reagent container **312A** may be pressurized by an external source during assembly of system **300**, and a valve connected to reagent container

312A (e.g., valve **316A**) may open to permit the passage of a quantity of pressurized reagent to exist reagent container **312A** and proceed into microfluidic mixer **320** as described above. Such a system is illustrated in **FIG. 7**.

[00194] Electronically operated normally closed valve **316A, 316B** may be controlled by microcontroller **306**, and may be oriented such that when no power is provided, valve **316A, 316B** is closed. Likewise, when power is provided, valve **316A, 316B** is open.

[00195] Microfluidic flow sensor **318A, 318B** may sense the flow of reagent **314A, 314B**, respectively, and may provide data regarding that flow to microcontroller **306**. Such data may include flow rate, flow volume, flow time, mass, and the like.

[00196] Systems **300** and **400** may include a barometric sensor **328**. Barometric sensor **328** may sense the pressure within the three-dimensional enclosed space that systems **300** and **400** operate. Upon sensing a negative pressure (indicating that a HVAC return system is pulling air out of the room, a door or window is open, or the like), barometric sensor **328** may communicate the negative pressure via its connection with microcontroller **306**, upon which microcontroller **306** may pause antimicrobial gas (e.g., ClO_2 gas) generation until a neutral and/or positive pressure is sensed by barometric sensor **328**. Upon sensing a neutral or positive pressure, barometric sensor **328** may communicate the neutral or positive pressure to microcontroller **306**, at which point microcontroller **306** may once again initiate gas generation (e.g., ClO_2 gas).

[00197] Systems **300** and **400** may include an air quality sensor **330**. Air quality sensor **330** may sense any of a variety of ambient air **302**'s characteristics, including for example, humidity, temperature, and the like. Data regarding air quality may be recorded for evaluating the effectiveness of systems **300** and **400**. Alternatively, as antimicrobial gas (e.g., ClO_2 gas) may be more effective at destroying pathogens in more humid environments, humidity data, for example, may be communicated via air quality sensor **330**'s connection with microcontroller **306**, upon which microcontroller **306** may adjust the target concentration of antimicrobial gas in ambient air **302** based upon humidity readings.

[00198] The above-described aspects, methods, and processes of systems **300** and **400** demonstrate the generation of antimicrobial gas by each of systems **300** and **400**. Below is described the aspects of systems **300** and **400** that sample ambient air **302** to determine the concentration of antimicrobial gas (e.g., ClO_2 gas) within ambient air **302**.

[00199] In both systems **300** and **400**, ambient air **302** may be ducted to air pump **308C**, which causes a sample of ambient air **302** to enter a concentrator **324**. Concentrator **324** may separate antimicrobial gas (e.g., ClO_2 gas) from the mostly diamagnetic other components of ambient air **302**. One aspect of a concentrator is illustrated in **FIGS. 8A** and **8B**. Concentrator

324 may separate and concentrate a very low concentration of antimicrobial gas (e.g., ClO_2 gas) so that a more accurate measurement of its concentration may be obtained. Concentrator **324** may utilize magnets to separate diamagnetic gases from antimicrobial gas, thus permitting the testing of a concentrated and amplified level of antimicrobial gas. Diamagnetic gases may be passed back into the ambient environment after separation. In one aspect, antimicrobial gas may be amplified at least 100 times prior to further concentration testing.

[00200] Systems **300** and **400** may include a sensing system **326**. Sensing system **326** may sense the concentration of antimicrobial gas (e.g., ClO_2 gas) (which may be amplified 100 times or more following processing in concentrator **324**). Sensing system **326** may measure a time weighted average of the concentration of antimicrobial gas (e.g., ClO_2) in ambient air **302**. Data regarding the concentration is passed to microcontroller **306**, and if necessary, microcontroller **306** causes system **300** or **400** to generate more or less antimicrobial gas based upon the concentration measured in sensing system **326**.

[00201] After sensing in sensing system **326**, the sampled gas passes via a passage to off-gas and waste chamber **322** and is ultimately passed into the ambient atmosphere with the generated antimicrobial gas.

[00202] Thus, systems **300** and **400** may measure the concentration of antimicrobial gas (e.g., ClO_2 gas) in ambient air **302**, and if the concentration is below the target concentration, microcontroller **306** can cause system **300** or **400** to generate more antimicrobial gas to raise the concentration of antimicrobial gas (e.g., ClO_2 gas) in ambient air **302** until the sampled ambient air **302** meets the target concentration threshold.

[00203] All microcontrollers referenced herein (including microcontroller **306**), may have the computational ability and local data storage ability to enable closed-loop control of the antimicrobial gas generation system (including systems **300**, **400**, **600**, and **700**), including but not limited to: (1) local storage and microcontroller operations on data from sensor systems for antimicrobial gas (e.g., ClO_2) levels to the space environment variables such as barometric pressure, humidity, temperature, occupancy, or sounds that may be used to alter generation system (including systems **300**, **400**, **600**, and **700**) performance automatically or via user intervention; (2) measurement, local storage, and microcontroller operations on data from microfluidic subsystems such as mass/volume sensors of reagents, pressure generator performance, microfluidic chip-borne sensors, valve status and/or any other electronic subsystem to provide control as well as storage of system performance data for maintenance, alert, troubleshooting, inactive modes of operation, active modes of operation, and local setup.

[00204] In another aspect, the system (including systems **300**, **400**, **600**, and **700**) has a communication device connected to the microcontroller and/or electronic components such that data from any electronic component within, on, or connected to the systems (including systems **300**, **400**, **600**, and **700**) or housing **304** can be gathered, locally stored, operated on by the microcontroller, and transmitted to external data gathering systems on mobile and/or fixed devices.

[00205] In another aspect, machine learning and/or artificial intelligence algorithms can be incorporated into the system (including systems **300**, **400**, **600**, and **700**) microcontroller (including microcontroller **306**) to alter system performance automatically or by user interactions. An example of local control includes alteration of system performance for detection of a virus or bacteria in the ambient air, altitude, temperature, air changes in the local space measured by changes in antimicrobial gas (e.g., ClO_2) concentration in the air of spaces containing antimicrobial gas (e.g., ClO_2), changes in occupancy by living beings, alterations for user preference, prediction of cycles of occupancy/vacancy, alerts as to normal or abnormal performance of the system, and the like. In one aspect, microcontroller **306** is controlled by machine learning algorithms to alter system performance. In another aspect, microcontroller **306** is controlled by artificial intelligence algorithms to alter system performance. Microcontroller **306** may alter system performance automatically. Microcontroller **306** may alter system performance by control by a user. Microcontroller **306** may alter the system performance based upon at least one of: a detection of a virus or bacteria in the ambient air; an altitude of the system; a temperature of the system; changes in the ambient air measured by changes in a concentration of antimicrobial gas (e.g., ClO_2) in ambient air; changes in occupancy by living beings of an area containing the system; alterations for a user's preferences; prediction of cycles of occupancy and vacancy by living beings of the area containing the system; and a diagnosis of normal or abnormal performance of the system.

[00206] In another aspect, the system (including systems **300**, **400**, **600**, and **700**) for distribution and monitoring of antimicrobial gas (e.g., ClO2 gas) in a three-dimensional space will be designed for a plurality of operating modes. A first operating mode may be designed for occupied spaces, while a second operating mode may be designed for un-occupied spaces. Future user or engineered operating modes may be added. These operating modes may be changed by authorized users on the system (including systems **300**, **400**, **600**, and **700**) network (e.g., network **300**) connected to a plurality of system (including systems **300**, **400**, **600**, and **700**).

[00207] **FIG. 5** illustrates an example blueprint of a network **500** of disinfecting gas (e.g., ClO_2 gas) generator systems **300** and sensors **536** distributed in rooms and spaces in a floor of a

building. Network **500** illustrates a floor of a building bounded by exterior walls **538** and divided by interior walls **540**. Gas generator systems **300** may operate with the configuration and method of systems **300** or **400** described above, or **600** or **700** described below, and thus may include disinfecting gas (e.g., ClO_2 gas) concentration sensors. As illustrated, gas generator systems **300** may be oriented in each individual room of the floor, as well as in open spaces between the individual rooms. Standalone sensors **536** (configured simply to sense the concentration of disinfecting gas, such as ClO_2 gas, in the ambient air) supplement network **500** to ensure that the target concentration is achieved throughout network **500**.

[00208] The various gas generator systems **300** may operate to generate disinfecting gas (e.g., ClO_2 gas) independent of one another, and at different concentration target values depending upon the desired function of a particular gas generator systems **300**.

[00209] For example, where a room is occupied by a patient (e.g., in a hospital or nursing facility), employee (e.g., in an office), a guest (e.g., in a hotel), or the like, the gas generator system **300** in that particular room may have a target disinfecting gas (e.g., ClO_2 gas) concentration of about 50 ppb. After the room is no longer occupied (e.g., patient is moved from the room for a set period of time, employee is gone for the night, guest checks out, etc.), the gas generator system **300** in that room may increase its target disinfecting gas (e.g., ClO_2 gas) concentration to about 1,000 ppb to about 5,000 ppb for a set period of time. In this manner, the room can be decontaminated (1,000 ppb to 5,000 ppb concentration level, or 50,000 ppb to 300,000 ppb concentration level for extreme pathogens) between its use by particular individuals, or on a regular time schedule, and maintain a lower safe (to humans) concentration of 50 ppb for prevention or mitigation of virus spreading while occupied.

[00210] In another aspect, a plurality of systems **300** within a plurality of spaces which are arranged into network **500** can be connected via communication devices (as described above) to each other for distributed control via coordination of each system's microcontroller (e.g., microcontroller **306**), centralized unit control, and/or a combination of both local and distributed control.

[00211] In another aspect, machine learning and/or artificial intelligence algorithms can be incorporated into the distributed network **500** of systems **300** by the aspects described above. Examples of distributed control include adjusting individual systems **300** to achieve uniform and/or deliberately non-uniform distribution of disinfecting gas (e.g., ClO_2) in each individual generator system **300**'s location across an entire building floor to the entire building due to changes in disinfecting gas (e.g., ClO_2) concentration from HVAC, consumption or self-dissipation of disinfecting gas, control of day/night generation cycles, sensing patterns across

time, three-dimensional volumes, seasonal variations, and/or previously unknown factors that can be sensed either directly by the sensor systems **300** in/on the network **500**, inferred or traced to the signal measured, or directly traceable to the variations observed in disinfecting gas (e.g., ClO_2) concentrations across a collection of systems **300** installed across distinctly separate and/or varying interconnection of real world spaces in which control of infectious species is desired.

[00212] **FIGS. 6** and **7** illustrate schematics of example systems **600** and **700** for generating and monitoring antimicrobial gas (e.g., ClO_2 gas). Systems **600** and **700** are substantially similar to systems **300** and **400**, respectively, except that air pumps **308A** and **308B** and pressure relief valves **310A** and **310B** are replaced with check valves **609A** and **609B**. These check valves are one-way, directional flow valves that permit the passage of fluid through check valves **609A**, **609B** toward reagent containers **312A**, **312B**, but prevent the passage of fluid away from reagent containers **312A**, **312B** through check valves **609A**, **609B**.

[00213] Such an arrangement may be used where reagent containers **312A**, **312B** are pressurized by an external source before or during assembly of systems **600**, **700**. Thus, reagent containers **312A**, **312B** may be pressurized containers housing reagents **314A**, **314B**, and as such do not need air pumps **308A**, **308B** to cause reagent **314A**, **314B** to flow to microfluidic mixer **320**. The flow of pressurized reagent **314A**, **314B** may be controlled by a valve, such as valves **316A**, **316B**. When valves **316A**, **316B** are opened, pressurized reagent **314A**, **314B** may flow from pressurized reagent containers **312A**, **312B**, through microfluidic flow sensors **318A**, **318B**, and into microfluid mixer **320**.

Antimicrobial Generation Systems and Devices

[00214] **FIG. 9** illustrates a schematic for a system **900** for generating a disinfecting gas and/or solution. The disinfecting gas and/or solution may be ClO_2 gas and/or solution. System **900** may be used to generate a pure disinfecting gas (e.g., ClO_2 gas). System **900** may create a disinfecting gas (e.g., ClO_2 gas), which may be immediately vented, swept, or evacuated out of a reaction chamber **906** and either used as a disinfecting gas **908** in an end use application or dissolved into water to create a pure disinfecting solution (e.g., ClO_2) **910**.

[00215] System **900** may use a concentrated liquid precursor **902**. Liquid precursor **902** may be $NaClO_2$ (sodium chlorite).

[00216] System **900** may include an activator **904**. Activator **904** may be an acid/H+ activator. Activator **904** may be a concentrated liquid activator.

[00217] Liquid precursor **902** and activator **904** may be brought into contact with one another in reaction chamber **906**. At least one of liquid precursor **902** and activator **904** may be conveyed into reaction chamber **906** via at least one of a gravity feed, a metered gravity feed,

pressurization via a pump, pressurization via a syringe, pressurization via any mechanism, vacuum/low pressure, microfluidics, or the like. At least one of liquid precursor **902** and activator **904** are conveyed into reaction chamber **906** in correct proportions and rates to meet antimicrobial gas and/or solution (e.g., ClO_2) production requirements.

[00218] Disinfecting gas (e.g., ClO_2 gas) **908** may be created in reaction chamber **906** and allowed to escape into the environment within an enclosed space (e.g., a room in a building) for treatment of the air and/or surfaces within the enclosed space; optionally, a polymer membrane may be used to control the rate of antimicrobial (e.g., ClO_2) release. Antimicrobial gas **908** may be dissolved into a liquid to create pure antimicrobial solution (e.g., ClO_2 solution) **910**.

[00219] Antimicrobial solution (e.g., ClO_2 solution) **910** may be at least one of: (a) transferred to a dispensing device **912** (e.g., a spray bottle), which may be diluted with water **914**, or (b) transferred to a waste liquid container **916**. Solution **910** transferred to a dispensing device **912** may be diluted with another liquid **914**, including for example, liquid water. Where solution **910** is not desired (e.g., a user of system **900** only desires the creation of antimicrobial gas (e.g., ClO_2 gas) **908**), or more solution **910** than desired is produced, all or some of solution **910** is moved to waste liquid container **916**.

[00220] Additionally, any waste liquid created in reaction chamber **906** may likewise be ducted directly to waste liquid container **916**. Waste liquid can be removed from system **900** and properly disposed of via a waste liquid outlet **920**.

[00221] **FIG. 10** illustrates a system **1000** for generation of an antimicrobial gas and/or solution (e.g., ClO_2 gas and/or solution). System **1000** is substantially similar to system **900** described above, where like reference numbers indicate like elements. System **1000** additionally includes a neutralizing agent **1018** that is ducted to waste liquid container **916**. Neutralizing agent or process **1018** may be any agent or process capable of neutralizing the antimicrobial (such as ClO_2) or the reaction between $NaClO_2$ and the activator that is combined in reaction chamber **906**. Neutralizing agent **1018** may include, for example, a chemical agent or a physical process wherein ultraviolet light, carbon, or the like is used for neutralizing an antimicrobial (such as ClO_2) or the reaction between $NaClO_2$ and the activator. Neutralizing agent **1018** may be used to neutralize an antimicrobial solution (such as ClO_2 solution) (either solution **910** or from reaction chamber **906**) to render the solution safe for disposal via waste liquid outlet **920**.

[00222] **FIG. 11** illustrates a system **1100** for generation of an antimicrobial gas and/or solution (e.g., ClO_2 gas and/or solution). System **1100** is substantially similar to system **900** described above, where like reference numbers indicate like elements. System **1100** additionally includes an air pressurization device **1122** (e.g., a fan or blower) and an optional air meter **1124**.

Air pressurization device **1122** and air meter **1124** may control a flow of air into reaction chamber **906** to safely evacuate antimicrobial gas (such as ClO_2 gas) **908** from reaction chamber **906**, or both. Air meter **1124** may control the volume of air fed into reaction chamber **906**, the amount of time that air is fed into reaction chamber **906**, or both. Air meter **1124** may include a valve to control air flow.

[00223] **FIG. 12** illustrates a system **1200** for generation of an antimicrobial gas and/or solution (e.g., ClO_2 gas and/or solution). System **1200** is substantially similar to systems **1000** and **1100** described above, where like reference numbers indicate like elements. System **1200** is a combination of systems **1000** and **1100**, including a neutralizing agent or process **1018**, an air pressurization device **1122**, and an air meter **1124**.

[00224] **FIG. 13** illustrates a system **1300** for generation of an antimicrobial gas and/or solution (e.g., ClO_2 gas and/or solution). System **1300** is substantially similar to system **900** described above, where like reference numbers indicate like elements. However, liquid activator **904** is replaced with a solid activator **1330**. Activator **1330** may include an acidic chemical powder like citric acid or sodium persulfate, a bed of cationic ion exchange resin/polymer with optional metal-oxide catalyst. Liquid precursor **902** may be exposed to solid activator **1330** via gravity feed, active pumping, etc., as discussed above with respect to system **900**. Liquid precursor **902** may flow through solid activator **1330**.

[00225] **FIG. 14** illustrates a system **1400** for generation of an antimicrobial gas and/or solution (e.g., ClO_2 gas and/or solution). System **1400** is substantially similar to system **1300** described above, where like reference numbers indicate like elements. System **1400** includes a neutralizing agent or process **1018** as described above in system **1000**.

[00226] **FIG. 15** illustrates a system **1500** for generation of an antimicrobial gas and/or solution (e.g., ClO_2 gas and/or solution). System **1500** is substantially similar to system **1300** described above, where like reference numbers indicate like elements. System **1500** additionally includes an air pressurization device **1122** and an air meter **1124** as described above in system **1100**.

[00227] **FIG. 16** illustrates a system **1600** for generation of an antimicrobial gas and/or solution (e.g., ClO_2 gas and/or solution). System **1600** is substantially similar to systems **1400** and **1500** described above, where like reference numbers indicate like elements. System **1600** is a combination of systems **1400** and **1500**, including a neutralizing agent or process **1018**, an air pressurization device **1122**, and an air meter **1124**.

[00228] **FIG. 17** illustrates a system **1700** that is substantially similar to system **900** illustrated in **FIG. 9** and described above, where like reference numbers indicate like elements.

System **1700** additionally includes pressurized aerosol containers **1786A** and **1786B**. Aerosol container **1786A** may contain liquid precursor **902**, while aerosol container **1786B** may contain liquid activator **904**. Liquid precursor **902** and liquid activator **904** may be delivered to a reaction chamber **906** using the pressure within containers **1786A** and **1786B** to cause the delivery. Such an embodiment may eliminate the need for electrically powered components for antimicrobial generation and dispersal.

[00229] **FIGS. 18A-18D** illustrate a reactor **1800** for generating an antimicrobial gas (e.g., ClO_2 gas). Reactor **1800** may be a prepackaged device loaded with a liquid precursor **902** and a liquid activator **904** within containers inside reactor **1800**. Liquid precursor **902** may be sealed within its container and may require pressurized air to flow into reaction chamber **906**. Liquid activator **904** may be sealed within its container and may require pressurized air to flow into reaction chamber **906**.

[00230] Reactor **1800** may include a housing **1840** containing liquid precursor **902**, activator **904**, a reaction chamber **906**, and a waste liquid container **916**, wherein device elements are machined or otherwise formed out of a housing material, as in common in the production of microfluidic devices. Reactor **1800** may be a microfluidic device.

[00231] Reactor **1800** may include a pressure input **1841** capable of applying an air pressure to liquid precursor **902** and activator **904** to break seals within their respective containers and/or cause them to travel to reaction chamber **906**. Pressure input **1841** may receive pressure from a pump, a syringe, or the like.

[00232] Reaction chamber **906** may include a capillary filter **1842** that permits waste liquid to travel into waste liquid container **916** via capillary action. Waste liquid container **916** may include an inactivator, neutralizing agent, or the like capable of rendering waste liquid from reaction chamber **906** into a safe state.

[00233] Reaction chamber **906** may include a gas permeable membrane **1844**, which allows an antimicrobial gas (e.g., ClO_2 gas) created in reaction chamber **906** to pass through membrane **1844** at a controlled rate but prevents a waste liquid from reaction chamber **906** from passing through membrane **1844**. Antimicrobial gas (e.g., ClO_2 gas) may exit reactor **1800** via a gas outlet **1843**. Gas outlet **1843** may permit antimicrobial gas (e.g., ClO_2 gas) to exit reactor **1800** and enter the surrounding area, including for example an enclosed space (e.g., a room within a building).

[00234] As illustrated in **FIG. 18D**, reactor **1800** may include a cover **1846** that seals the above-referenced contents (e.g., liquid precursor **902**, activator **904**, reaction chamber **906**, and waste liquid container **916**) within housing **1840**.

[00235] **FIGS. 19A–19I** illustrate a reactor **1900** for generating a disinfecting gas (e.g., ClO_2 gas). Reactor **1900** may include a housing **1950** having an upper surface **1952**. Housing **1950** may include a container **1970** and a reaction chamber **1972** connected to one another by a chamber duct **1976**, wherein device elements are machined or otherwise formed out of a housing material, as in common in the production of microfluidic devices. Reactor **1900** may be a microfluidic device.

[00236] Container **1970** may include a solid container cover **1954** oriented on or near upper surface **1952**. Reaction chamber **1972** may include a reaction chamber cover **1956** oriented on or near upper surface **1952**. Reaction chamber cover **1956** may include an outlet **1960** having an aperture **1958** in fluid communication with the interior of reaction chamber **1972**. Aperture **1958** may include a gas permeable membrane that allows a gas (e.g., ClO_2) to pass through, but prevents a liquid (e.g., waste liquid) from passing through.

[00237] Chamber duct **1976** may include a valve **1980**. Valve **1980** may be a check valve, backflow valve, seal, or the like that prevents the contends of container **1970** and the contents of reaction chamber **1972** from coming into contact with one another until a user selectively causes the contents of container **1970** to be transferred to reaction chamber **1972**.

[00238] Container **1970** may contain a liquid activator as described above, while reaction chamber **1972** may contain a liquid or solid precursor (e.g., liquid $NaClO_2$ or solid $NaClO_2$). Alternatively, container **1970** may contain a liquid precursor (e.g., $NaClO_2$) as described above, while reaction chamber **1972** contains a solid activator or liquid activator.

[00239] Housing **1950** may include an end **1964** including a pressurization device **1962**. Pressurization device may include any device capable of pressurizing the contents of container **1970**, thereby causing the contents of container **1970** to overcome and pass valve **1980** and enter reaction chamber **1972**. Pressurization device **1962** may include a plunger device including a hollow body **1966** extending from end **1964** and in fluid communication with container **1970** via a pressurization duct **1974**, and a plunger **1968** extending into hollow body **1966**. As illustrated in **FIGS. 19H** and **19I**, plunger **1968** may be actuated by a user and pressed into hollow body **1966**, thus causing pressurization of the contents of container **1970**, which overcome and pass valve **1980** and flow into reaction chamber **1972**. Antimicrobial gas (e.g., ClO_2 gas) is allowed to escape aperture **1958** via an optional gas permeable membrane, while waste liquid is contained within reaction chamber **1972** until reactor **1900** is cleaned and recharged (fresh precursor and activator is added).

[00240] Pressurization device **1962** may be removable. Alternatively, pressurization device **1962** may be entirely separate from housing **1950** and may be applied to housing **1950** by

a user only when the user desires to activate reactor **1900**. Pressurization duct **1974** may likewise include a valve **1980**, which may be a check valve, backflow valve, seal, or the like.

[00241] **FIGS. 20A-20D** illustrate a reactor **2000** for generating an antimicrobial gas (e.g., ClO_2 gas). Reactor **2000** may be a prepackaged device loaded with a liquid precursor **902**, and a solid activator **1330** within containers inside reactor **2000**. Liquid precursor **902** may be sealed within its container and may require pressurized air to flow into reaction chamber **906**. Solid activator **1330** may be sealed within the reaction chamber **906**.

[00242] Reactor **2000** may include a housing **2040** containing liquid precursor **902**, activator **1330**, a reaction chamber **906**, and a waste liquid container **916**, wherein device elements are machined or otherwise formed out of a housing material, as in common in the production of microfluidic devices. Reactor **2000** may be a microfluidic device.

[00243] Reactor **2000** may include a pressure input **2041** capable of applying an air pressure to liquid precursor **902** to break a seal within its container and/or cause liquid precursor **902** to travel to reaction chamber **906**. Pressure input **2041** may receive pressure from a pump, a syringe, or the like.

[00244] Reaction chamber **906** may include a capillary element **2042** that permits waste liquid to travel into waste liquid container **916** via capillary action. Waste liquid container **916** may include an inactivator, neutralizing agent, or the like capable of rendering waste liquid from reaction chamber **906** into a safe state.

[00245] Reaction chamber **906** may include a gas permeable membrane **2044**, which allows antimicrobial gas (e.g., ClO_2 gas) created in reaction chamber **906** to pass through membrane **2044** at a controlled rate but prevents a waste liquid from reaction chamber **906** from passing through membrane **2044**. Antimicrobial gas (e.g., ClO_2 gas) may exit reactor **2000** via a gas outlet **2043**. Gas outlet **2043** may permit antimicrobial gas (e.g., ClO_2 gas) to exit reactor **2000** and enter the surrounding area, including for example an enclosed space (e.g., a room within a building).

[00246] As illustrated in **FIG. 20D**, reactor **2000** may include a cover **2046** that seals the above-referenced contents (e.g., liquid precursor **902**, reaction chamber **906**, and waste liquid container **916**) within housing **2040**.

[00247] **FIG. 21A-21E** illustrate a reactor **2100** for generating an antimicrobial gas (e.g., ClO_2 gas). Reactor **2100** may be a prepackaged device loaded with a liquid precursor **902** and a liquid activator **904** within containers inside reactor **2100**. Reactor **2100** may include a housing **2140** containing liquid precursor **902**, activator **904**, a reaction chamber **906**, and a waste liquid container **916**, wherein device elements are machined or otherwise formed out of a housing

material, as in common in the production of microfluidic devices. Reactor **2100** may be a microfluidic device.

[00248] Liquid precursor **902** may be sealed within its container and may require pressurized air to flow into reaction chamber **906**. Liquid activator **904** may be sealed within its container and may require pressurized air to flow into reaction chamber **906**. Reactor **2100** may include seals **2184** within channels connecting liquid precursor **902**'s container and liquid activator **904**'s container with reaction chamber **906**. Seals **2184** may include a foil, membrane, check valve, backflow valve, or the like, which may be breached with the application of an adequate pressure to permit the passage of liquid precursor **902** and/or liquid activator **904** past seals **2184**.

[00249] Reactor **2100** may include a pressure input **2141** capable of receiving a fluid pressure and directing the pressure to liquid precursor **902** and activator **904** to break seals **2184** within, before, or after their respective containers and/or cause them to travel to reaction chamber **906**. Pressure input **2141** may receive pressure from a fluid surrounding reactor **2100**, including for example, a pressurized gas. Reactor **2100** may include seals **2184** between pressure input **2141** and liquid precursor **902**'s container and liquid activator **904**'s container.

[00250] Reaction chamber **906** may include a capillary filter (not shown) that permits waste liquid to travel into waste liquid container **916** via capillary action. Waste liquid container **916** may include an inactivator, neutralizing agent, or the like capable of rendering waste liquid from reaction chamber **906** into a safe state.

[00251] Reaction chamber **906** may include a gas permeable membrane (not shown), which allows antimicrobial gas (e.g., ClO_2 gas) created in reaction chamber **906** to pass through the membrane at a controlled rate but prevents a waste liquid from reaction chamber **906** from passing through the membrane. Antimicrobial gas (e.g., ClO_2 gas) may exit reactor **2100** via an outlet **2143**. Outlet **2143** may permit antimicrobial gas (e.g., ClO_2 gas) to exit reactor **2100** and enter a dip tube tee **2182**. Dip tube tee **2182** may be configured to receive the ends of an interrupted (discontinuous) dip tub as described more fully herein. Tee **2182** includes a hollow bore **2183** through which the desired contents of reaction chamber **906** (a gas, a liquid, or both) may pass and enter a dip tube. While tee **2182** is illustrated having a straight portion extending along the end of reactor **2100** with a perpendicular extending into outlet **2143**, it is understood that tee **2182** could take on other shapes and configurations capable of fluidically connecting reactor **2100** to the interior of a dip tube.

[00252] As illustrated in **FIGS. 21A**, **21D**, and **21E** reactor **2100** may include a cover **2146** that seals the above-referenced contents (e.g., liquid precursor **902**, activator **904**, reaction chamber **906**, and waste liquid container **916**) within housing **2140**.

[00253] **FIG. 22A-22E** illustrate a reactor **2200** for generating an antimicrobial gas (e.g., ClO_2 gas). Reactor **2200** may be a prepackaged device loaded with a liquid precursor **902** and a solid activator **1330** within containers inside reactor **2200**. Reactor **2200** may include a housing **2240** containing liquid precursor **902**, a reaction chamber **906**, and a waste liquid container **916**, wherein device elements are machined or otherwise formed out of a housing material, as in common in the production of microfluidic devices. Solid activator **1330** may be sealed within reaction chamber **906**. Reactor **2200** may be a microfluidic device.

[00254] Liquid precursor **902** may be sealed within its container and may require pressurized air to flow into reaction chamber **906**. Reactor **2200** may include seals **2284** within channels connecting liquid precursor **902**'s container with reaction chamber **906**. Seals **2284** may include a foil, membrane, check valve, backflow valve, or the like, which may be breached with the application of an adequate pressure to permit the passage of liquid precursor **902** past seals **2284**.

[00255] Reactor **2200** may include a pressure input **2241** capable of receiving a fluid pressure and directing the pressure to liquid precursor **902** to break seals **2284** within, before, or after their respective containers and/or cause them to travel to reaction chamber **906**. Pressure input **2241** may receive pressure from a fluid surrounding reactor **2200**, including for example, a pressurized gas. Reactor **2200** may include seals **2284** between pressure input **2241** and liquid precursor **902**'s container.

[00256] Reaction chamber **906** may include a capillary filter (not shown) that permits waste liquid to travel into waste liquid container **916** via capillary action. Waste liquid container **916** may include an inactivator, neutralizing agent, or the like capable of rendering waste liquid from reaction chamber **906** into a safe state.

[00257] Reaction chamber **906** may include a gas permeable membrane (not shown), which allows antimicrobial gas (e.g., ClO_2 gas) created in reaction chamber **906** to pass through the membrane at a controlled rate but prevents a waste liquid and/or solid activator **1330** from reaction chamber **906** from passing through the membrane. Antimicrobial gas (e.g., ClO_2 gas) may exit reactor **2200** via an outlet **2243**. Outlet **2243** may permit antimicrobial gas (e.g., ClO_2 gas) to exit reactor **2200** and enter a dip tube tee **2282**. Dip tube tee **2282** may be configured to receive the ends of an interrupted (discontinuous) dip tub as described more fully herein. Tee **2282** includes a hollow bore **2283** through which the desired contents of reaction chamber **906** (a gas, a liquid,

or both) may pass and enter a dip tube. While tee **2282** is illustrated having a straight portion extending along the end of reactor **2200** with a perpendicular extending into outlet **2243**, it is understood that tee **2282** could take on other shapes and configurations capable of fluidically connecting reactor **2200** to the interior of a dip tube.

[00258] As illustrated in **FIGS. 22A**, **22D**, and **22E** reactor **2200** may include a cover **2246** that seals the above-referenced contents (e.g., liquid precursor **902**, reaction chamber **906**, and waste liquid container **916**) within housing **2240**.

[00259] Reactors **2100**, **2200** may be substantially similar in function and layout to reactors **1800**, **2000**, with the addition of dip tube tee **2182**, **2282**.

[00260] **FIGS. 23A-23G**, and **FIG. 24** illustrate an example antimicrobial gas (e.g., ClO_2 gas) generator **2300**, **2400**, respectively. Generator **2400** is substantially similar to generator **2300**, but includes a second reagent container **2356**, a second pressure generator **2366**, and all associated ducts and passages to permit the second reagent to flow to a generation chamber **2374**.

[00261] Antimicrobial gas (e.g., ClO_2 gas) generator **2300**, **2400** may include a base **2354**, at least one reagent container **2356** holding a liquid reagent **2358**, and a reagent container lid **2360** with air permeable seal configured to prevent escape of liquid reagent **2358**.

[00262] Within base **2354**, at least one pressure chamber **2362** is oriented below at least one reagent container **2356**, with at least one chamber passage **2364** in communication with pressure chamber **2362** and reagent container **2356**. At least one pressure generator **2366** is oriented in communication with both pressure chamber **2362** and passage **2364**, such that pressure generator **2366** can selectively block or unblock the entrance of chamber passage **2364** into pressure chamber **2362**. Pressure generator **2366** is biased into a position by at least one biasing device **2368**. Biasing device **2368** may be a common biasing device such as a spring. Biasing device **2368** may bias pressure generator **2366** into an open position. Biasing device **2368** may bias pressure generator **2366** into a closed position.

[00263] At least one fluid duct **2370** extends through base **2354** from pressure chamber **2362** to a microfluidic chip **2372**. Microfluidic chip **2372** may include a generation chamber **2374**. A generation duct **2376** may extend partly through base **2354** and partly through the wall of an off-gas and waste chamber **2378**. Chamber **2378** may include an absorber material, an evaporator, or the like. Chamber **2378** may include an absorber material for absorbing spent reagent waste. Chamber **2378** may include an inactivator for waste. Chamber **2378** may include a gas permeable lid **2380** configured to allow the passage of antimicrobial gas (e.g., ClO_2 gas) out of chamber **2378**. Lid **2380** may be a gas permeable membrane.

[00264] Each of the reagent container **2356**, microfluidic chip **2372**, and off-gas and waste chamber **2378** may be attached to and supported upon base **2354**.

[00265] In operation, pressure generator **2366** begins in its closed position, as illustrated in **FIGS. 23A** and **23B**. In this position, pressure generator **2366** seals chamber passage **2364**, such that no liquid reagent **2358** may enter chamber **2362**. Upon an instruction to generate antimicrobial gas (such as ClO_2 gas) (e.g., from a microcontroller such as microcontroller **306**), pressure generator **2366** moves to its open position, as illustrated in **FIGS. 23C** and **23D**. Liquid reagent **2358** passes out of reagent container **2356** and into pressure chamber **2362**. Pressure chamber **2362** may be sized and shaped to permit a specific desired volume of liquid reagent **2358** to fill pressure chamber **2362** for transfer to microfluidic chip **2372**. Finally, pressure generator **2366** moves back to its closed position, as illustrated in **FIGS. 23E-23G**, at once sealing chamber passage **2364** to prevent further introduction of liquid reagent **2358** from reagent container **2356**, and pressurizing the liquid reagent within chamber **2362**, so as to force the liquid reagent through the remainder of the system. Specifically, the liquid reagent is forced through fluid duct **2370**, through generation chamber **2374**, through generation duct **2376**, and into off-gas and waste chamber **2378**. Here, liquid waste **2382** is captured within chamber **2378**, while antimicrobial gas (e.g., ClO_2 gas) **2384** passes through gas permeable lid **2380** and into the ambient environment.

[00266] It is understood that more than one cycle of pressure generator **2366** from its closed position, to its open position, and back to its closed position, may be required to push reagent **2358** completely through the system. Particularly, when antimicrobial gas (e.g., ClO_2 gas) generator **2300** is new, a few cycles of pressure generator **2366** may be required to begin generating antimicrobial gas (e.g., ClO_2 gas).

[00267] As illustrated in **FIGS. 23A-23G**, generator **2300** may include a single liquid reagent **2358** that enters generation chamber **2374** to generate an antimicrobial gas (e.g., ClO_2 gas). Thus, microfluidic chip **2372** may utilize a microfluidic electrochemical generator as described above.

[00268] Alternatively, as illustrated in **FIGS. 23A-23G**, generator **2300** may include a single liquid reagent **2358** comprising $NaClO_2$ that enters generation chamber **2374** where a solid activator is contained, thus generating an antimicrobial gas, such as ClO_2 gas.

[00269] Alternatively, as illustrated in **FIG. 24**, generator **2400** may include two separate reagent containers **2356**, with two separate pressure chambers **2362**, two separate pressure generators **2366**, and two separate fluid ducts **2370**, such that the two separate liquid reagents enter generation chamber **2374** separately where they combine and mix to generate antimicrobial gas (e.g., ClO_2 gas).

[00270] Pressure generator **2366** may be actuated via a connection to an actuator (not shown), including for example an electric motor, including an electric step motor, or the like. Pressure generator **2366** may be a plunger and may generate pressure via translation fore and aft (longitudinally).

[00271] Pressure generator **2366** may be, and translate in a direction, coaxial with chamber **2362** and fluid duct **2370**. Pressure generator **2366** may be oriented at, and translate in a direction at, an angle to chamber passage **2364**. In one aspect, pressure generator **2366** translates along an axis that is at a right angle (90 degrees) from the axis of chamber passage **2364**.

[00272] Generator **2300**, **2400** may include one or more control valves (not shown) in communication with pressure generator(s) **2366** and/or reagent container(s) **2356**. Likewise, one or more control valve (not shown) may be in communication with chamber passage(s) **2364** and microfluidic chip **2372**. These valves may selectively permit, prevent, or otherwise control the flow of reagents into generation chamber **2374**. Generator **2300**, **2400** may include a sensor system for determining the quantity, mass, volume, or the like of reagents transiting chamber passage(s) **2364**.

[00273] As such, while these alternative embodiments are not illustrated, they are contemplated and as such, the figures are not intended to be limiting.

Antimicrobial Distribution Systems and Devices

[00274] **FIGS. 25A-25C** illustrate an example antimicrobial gas (e.g., ClO_2 gas) generator and sensor device **2500**. Device **2500** may include a device housing **2504**, a reservoir **2542**, a nozzle **2544**, a cartridge **2546**, an indicator light **2548**, an air sampler intake **2550**, and a base **2552**.

[00275] Housing **2504** may generally contain the remainder of device **2500**. Reservoir **2542** may contain one or more liquid reagent for use in the generation of antimicrobial gas (e.g., ClO_2 gas). One or more reagent from reservoir **2542** may be directed into cartridge **2546**, which includes the consumable elements of system **300**, **400** described above. Antimicrobial gas (e.g., ClO_2 gas) is generated in cartridge **2546** and directed out of device **2500** via nozzle **2544**.

[00276] Base **2552** may contain the electrical elements of device **2500**, including for example, a microcontroller, one or more air pumps, sensors, and the like as described in system **300**, **400**. Indicator light **2548** may act to communicate information to a user regarding the state of device **2500**, such as generating, low battery, connecting to a wireless network, cartridge replacement or reservoir replacement is necessary, and the like.

[00277] Base **2552** may include the air sampler intake **2550**, which pulls ambient air into device **2500** for sampling to determine the antimicrobial gas (e.g., ClO_2 gas) concentration in the ambient air, as described in system **300**, **400**.

[00278] **FIGS. 26A** and **26B** illustrate an example antimicrobial gas (e.g., ClO_2 gas) generator and sensor device **2600**. Device **2600** may include a device housing **2604**, a reservoir **2642**, a nozzle **2644**, a cartridge **2646**, an indicator light **2648**, an air sampler intake **2650**, and a base **2652**.

[00279] Housing **2604** may generally contain the remainder of device **2600**. Reservoir **2642** may contain one or more liquid reagent for use in the generation of antimicrobial gas (e.g., ClO_2 gas). One or more reagent from reservoir **2642** may be directed into cartridge **2646**, which includes the consumable elements of system **300**, **400** described above. Antimicrobial gas (e.g., ClO_2 gas) is generated in cartridge **2646** and directed out of device **2600** via nozzle **2644**.

[00280] Base **2652** may contain the electrical elements of device **2600**, including for example, a microcontroller, one or more air pumps, sensors, and the like as described in system **300**, 400. Indicator light **2648** may act to communicate information to a user regarding the state of device **2600**, such as generating, low battery, connecting to a wireless network, cartridge replacement or reservoir replacement is necessary, and the like.

[00281] Base **2652** may include the air sampler intake **2650**, which pulls ambient air into device **2600** for sampling to determine the antimicrobial gas (e.g., ClO_2 gas) concentration in the ambient air, as described in system **300**, **400**.

[00282] **FIGS. 27A** and **27B** illustrate an example antimicrobial gas (e.g., ClO_2 gas) generator and sensor device **2700**. Device **2700** may include a device housing **2704**, a reservoir **2742**, a nozzle **2744**, a cartridge **2746**, an indicator light **2748**, an air sampler intake **2750**, and a base **2752**.

[00283] Housing **2704** may generally contain the remainder of device **2700**. Reservoir **2742** may contain one or more liquid reagent for use in the generation of antimicrobial gas (e.g., ClO_2 gas). One or more reagent from reservoir **2742** may be directed into cartridge **2746**, which includes the consumable elements of system **300**, **400** described above. Antimicrobial gas (e.g., ClO_2 gas) is generated in cartridge **2746** and directed out of device **2700** via nozzle **2744**.

[00284] Base **2752** may contain the electrical elements of device **2700**, including for example, a microcontroller, one or more air pumps, sensors, and the like as described in system **300**, **400**. Indicator light **2748** may act to communicate information to a user regarding the state of device **2700**, such as generating, low battery, connecting to a wireless network, cartridge replacement or reservoir replacement is necessary, and the like.

[00285] Base **2752** may include the air sampler intake **2750**, which pulls ambient air into device **2700** for sampling to determine the antimicrobial gas (e.g., ClO_2 gas) concentration in the ambient air, as described in system **300**, **400**.

[00286] Any of devices **2500**, **2600**, **2700** may use system **300** or **400** described above for the generation and sensing of antimicrobial gas (e.g., ClO_2 gas).

[00287] **FIGS. 28A** and **28B** illustrate an example portable antimicrobial gas reactor **2800**.

[00288] Portable reactor **2800** includes: a reactor body **2802**; a base **2803**; a lid **2804** removably connected to one or both of reactor body **2802** or a snap on fan and pierce assembly **2806**; a sidewall **2805**; a fan **2808**; impeller blades **2809**; a power switch **2810**; an optional power cord **2812**; a package holder **2814**; a funnel tip **2816**; piercers **2818**; an antimicrobial reactant package **2820**; an activator package **2830**; an antimicrobial liquid **2840**; and antimicrobial gas **2842**.

[00289] Portable reactor **2800** mixes an antimicrobial gas generating solution (via antimicrobial reactant package **2820**) with an activator solution (via activator package **2830**) to generate a safe level of concentration of antimicrobial gas **2842** such as chlorine dioxide (ClO_2) or hydrogen peroxide (H_2O_2) gas to disinfect localized ambient air in an indoor environment or in a limited enclosed space.

[00290] Portable reactor **2800** may be a cup formed from reactor body **2802** having a base **2803** and one or more sidewall **2805**, with a funnel-shaped package holder **2814** and a pair of piercers **2818** to pierce the packages **2820**, **2830** and mix the solutions to generate antimicrobial gas **2842**.

[00291] The generated antimicrobial gas **2842** in reactor **2800** may be ventilated to ambient air through forced convection by an electric powered fan **2808** disposed at a cup opening, opposite base **2803**. Electric powered fan **2808** may be powered through an external power source (e.g., power cord **2812**), or through a built-in battery (not shown), where the battery may be rechargeable.

[00292] Reactor **2800** may have a built-in stirrer (not shown) and a wall baffle (not shown) to facilitate agitation of the mixture in the cup to facilitate completeness of chemical reactions. These elements may be included at or near base **2803** where antimicrobial liquid **2840** pools following piercing of packages **2820** and **2830**.

[00293] In one aspect, previously unpierced packages **2820** and **2830** are placed inside funnel-shaped package holder **2814**. Snap-on fan and pierce assembly **2806** is placed onto the top of body **2802**, engaging with a lip **2807**, and causing piercers **2818** to pierce packages **2820** and **2830**. This piercing allows an antimicrobial reactant stream **2822** and an activator solution stream

2832 to flow downwardly (via funnel tip **2816**) and form the antimicrobial liquid **2840** pool. The reactant and activator mix to form both antimicrobial liquid **2840** and antimicrobial gas **2842**, which flows out of body **2802** via a pathway defined by one or more sidewall **2805**, and into the ambient air. Optionally, fan **2808** via impeller blades **2809** may draw antimicrobial gas **2842** upwardly and out of reactor **2800**.

[00294] The packaged antimicrobial reactant **2820** and the packaged activator solution **2830** may be individually packaged or come as a dual packages pair ready for mixing.

[00295] Portable reactor **2800** may alternatively use an anhydrous solid powder form of the antimicrobial gas generator compound, instead of an antimicrobial gas generating solution (vina antimicrobial reactant package **2820**). The antimicrobial generating compound may comprise of an anhydrous powder form a chlorite containing compound and an anhydrous powder of a chemical activator which, when exposed to water, serves as an acid or a proton donor to chemically react with the chlorite containing compound to generate chlorine dioxide (ClO_2) as the antimicrobial gas. The antimicrobial generating compound may also be an anhydrous powder of a urea hydrogen peroxide, borax, perborate, or a percarbonate compound to generate hydrogen peroxide H_2O_2 as the antimicrobial gas in the presence of water.

[00296] In another example, an anhydrous solid mixture includes an antimicrobial generating powder and an activator powder which may chemically react by addition of water, alcohol, or a solvent.

[00297] **FIGS. 29A** and **29B** illustrate an example packaged antimicrobial gas generator solution and packaged activator solution. **FIG. 29A** illustrates packaged antimicrobial reactant **2820** and packaged activator solution **2830**. **FIG. 29B** illustrates a sectional view of package **2820** taken about section **A-A**.

[00298] **FIGS. 30A** and **30B** illustrate an antimicrobial gas generator **3000** in the form of a card shape or a sheet containing an antimicrobial generating compound. Antimicrobial card generator **3000** may include a cavity **3001**; a second surface **3002**; a lid **3004** opposite second surface **3002**; a surrounding sealed wall or circumferential seam **3006**; an opening **3008**; a semi-permeable membrane **3010**; a seal **3012**; an adhesive layer **3014**; and an anhydrous solid mixture **3030**. Card generator **3000** may be carried in a card carrier **3020** having a strap **3016**; a clip **3018**; and an opening **3022**.

[00299] The antimicrobial generator **3000** in various structures, may be fabricated into items comprising: a card, a badge, a face mask, a respirator, a blanket, a note pad, a deodorant card, a fragrant releasing card, a pouch, a packaging box, grocery bags, wipes, air filters, decorative items, greeting cards, bookmarks, and paper products. In another application, an

antimicrobial solution may be applied directly onto the antimicrobial gas generator or to refill the solid form of antimicrobial compound mixture for a recharge or to extend a slow release of low concentration antimicrobial gas. Antimicrobial gas generator **3000** may be used in tandem with a device to deliver antimicrobial gas into a three-dimensional space. Antimicrobial gas from antimicrobial generator **3000** or the antimicrobial generator materials may be added to water to produce an antimicrobial solution.

[00300] The antimicrobial may be a chlorine dioxide (ClO_2) or hydrogen peroxide (H_2O_2) anhydrous solid mixture, which includes: an antimicrobial generating compound and an activator that chemically reacts in presence of moisture, liquid, or solvent. The generated antimicrobial gas released from the item may be sufficient to disinfect within a close proximity of surrounding ambient air, by destroying airborne viruses, germs and when coming into contacts with bacteria or certain insects or pests.

[00301] Some configurations of antimicrobial generating compounds which may be impregnated into the absorbent materials of the multi-ply sheets structure are disclosed below

[00302] Preparation of reactant plies: starting with liquid precursors, reactant plies may be formed by absorbing antimicrobial (e.g., ClO_2) generating liquids (sodium chlorite and any form of activator) into a medium; drying medium to leave ClO_2 generating salts in medium; exposing medium to water or humidity; causing interaction with H_2O mobilizing salts/reagents; and reagents chemically interacting to form ClO_2.

[00303] Preparation of reactant plies: starting with solid precursors, reactant materials may be formed by blending solid reactants (sodium chlorite and any form of activator) into a water permeable medium; solidifying medium and reactants into a heterogeneous phase; exposing medium to water or humidity; interaction with H_2O mobilizing salts/reagents; and reagents chemically interacting to form ClO_2. A solution bath may be water, solvent, alcohol, or blends of these.

[00304] The solidification process may be physical, thermal, or chemical.

[00305] The medium can be anything that is permeable to water or water vapor (e.g., natural or synthetic fibers/papers or polymers). Alternatively, the medium may be a material that is soluble in water.

[00306] In constructing antimicrobial generator **3000**, one or more plies of each component must be in contact for reaction to occur when activated. Plies may be physically, thermally, or chemically bonded. A binder may be applied separately as a tie layer, including for example, an adhesive applied via spraying, dipping, and the like. A binder may be included in one or both of

the solutions used to soak plies. A binder may be an emulsion adhesive, naturally derived like a starch, a polymer, a water absorbent polymer, and the like.

[00307] The plies should be in close proximity for reaction to occur; one on top or another or side by side. Additional plies may be added to as follows: polymer films may be incorporated into the construction to limit the rate of reaction and/or release of ClO_2; films may be between reactant plies to regulate reagent transport; films may be applied on the outside of the reagent plies to regulate ClO_2 release and/or water absorption; and other plies may be used to enhance water absorption.

[00308] Salt solutions may be used to make plies that absorb water to drive the reaction. Hydrophilic polymers may be used in a film or coated form or blends of the two. Hydrophilic fibers (natural or synthetic) may be sued to absorb or wick water. Masking plies may be incorporated to effectively reduce the surface area of reaction or release of the antimicrobial gas.

[00309] Adhesive (e.g., peel and stick) layers may be added to support application, including to permit a user to attach antimicrobial generator **3000** to a surface, a garment, or the like.

[00310] Removable non-permeable layers may be added to prevent premature generation via the sealing of reactants away from moisture or the like. Acid scavenging materials may be integrated into/between plies to inhibit premature reaction process, including for example AHTC (activated hydrotalcite).

[00311] Antioxidants, retardants, or polymers may be added to reduce flammability of antimicrobial generator **3000**.

[00312] Controlling generation: the amount of antimicrobial gas (e.g., ClO_2) generated, rate, and duration of generation may be controlled by: the number of reactant plies; concentration of solutions or materials used to make reactant plies; absorption rate of materials used to make reactant plies; residence time or reactant ply materials in solution; thickness of plies; number of plies; and surface area of plies. To control water absorption: control water absorption rate of materials used to make reactant plies; adjust the number, type, and placement of plies used to enhance water absorption; and adjust the number, type, and placement of plies used to control (retard) water absorption or transport between plies. To control ClO_2 release: adjust type and thickness of materials used to regulate ClO_2 release and/or water absorption; address packaging of antimicrobial generator **3000** by ensuring plies stored in non-permeable packaging materials prior to use, desiccating materials may be used to eliminate moisture. Ply papers may change color to indicate stages of use, including for example not activated, activated, and spent.

[00313] The aforementioned concept may be used to generate other chemical solutions or reactions., including for example generating sodium chlorite as a disinfecting agent by itself.

[00314] **FIG. 31** illustrates an example of an antimicrobial generator **3100** in the form of a pouch with optional addition of water internal to the pouch. Pouch generator **3100** may include: a cavity **3101**; a bottom surface **3102**; a top surface **3104**; a surrounding sealed wall or circumferential seam **3106**; an opening **3108**; a semi-permeable membrane **3110**; a seal **3112**; an adhesive layer **3114**; a spout **3124**; and an anhydrous solid mixture **3130**.

[00315] Pouch generator **3100** may be designed, optimized, and used in the same manner as card generator **3000**. Semi-permeable membrane **3110** may be ClO_2 permeable (where the antimicrobial gas is ClO_2), or air permeable only. Seal **3112** may be a vapor barrier film that contacts adhesive layer **3114** and is removable prior to activation and use of pouch generator **3100**. Spout **3124** may be closable to add water for higher ClO_2 generation, and/or may be humidity activated for lower concentration of ClO_2. Anhydrous solid mixture **3130** may be ClO_2 generating powder that is contained in a smaller pouch, a loose powder, or formed in a solid block.

[00316] **FIGS. 32A** illustrates an example of an antimicrobial generator **3200** in the form of a solution treated single or multi-ply porous material.

[00317] **FIG. 32B** illustrates an example of antimicrobial generator **3200** with liquid reactants absorbed or adsorbed on substrates and blended with a porous matrix material with optional addition of an exterior film to control release.

[00318] **FIG. 32C** illustrates an example of antimicrobial generator **3200** with solid reactants blended in a porous material and optional addition of an exterior film to control release.

[00319] **FIG. 32D** illustrates an example of antimicrobial generator **3200** in the form of a perforated pouch.

[00320] **FIG. 32E** illustrates an example of antimicrobial generator **3200** where reactant materials of **FIGS. 32A-32C** are configured side by side with optional materials to support activation and control release.

[00321] Antimicrobial generator **3200** may be designed, optimized, and used in the same manner as card generator **3000**.

[00322] Antimicrobial generator **3200** may include an antimicrobial sheet **3210**. Antimicrobial sheet **3210** may include a top sheet **3212**, an intermediate sheet **3214**, and a bottom sheet **3216**. Top sheet **3212** may be paper or another absorbent material dip-coated in a sodium chlorite solution and dried. Bottom sheet **3216** may be paper or other absorbent materials dip-coated in an activator solution and dried. Intermediate sheet **3214** may act as a tie layer.

[00323] Antimicrobial generator **3200** may include an antimicrobial sheet **3220**. Antimicrobial sheet **3220** may include a seal or package **3222** and an anhydrous solid mixture **3224**. Anhydrous solid mixture **3224** may be formed by absorbing liquid sodium chlorite and an activator into dry powders or fibers, redry the powders or fibers, and press form the powder or fibers into a solid with an optional binder. Seal or package **3222** may be made of, or may include, optional films to control release characteristics of antimicrobial generator **3200**.

[00324] Antimicrobial generator **3200** may include an anhydrous solid mixture **3230**. Anhydrous solid mixture **3230** may include a seal or package **3223** and an antimicrobial compound and activator mixture **3234**. Anhydrous solid mixture **3230** may be formed by pressing sodium chlorite and citric acid into a matrix of synthetic or natural fibers (LLDPE, paper, or the like).

[00325] Antimicrobial generator **3200** may include a pouch **3240**. Pouch **3240** may include a seal **3242**, an anhydrous solid mixture **3244**, an adhesive layer **3246**, and an opening **3248**. Anhydrous solid mixture **3244** may include LLDPE film to hold a powder in a desired shape or configuration.

[00326] Antimicrobial generator **3200** may include an antimicrobial sheet **3250**. Antimicrobial sheet **3250** may include a top sheet **3252**, a control release film or coating **3254**, a first anhydrous solid mixture **3256**, and a second anhydrous solid mixture **3258**. Top sheet **3252** may include a wicking or water absorbent material configured to activate first and second anhydrous solid mixtures **3256**, **3258** when top sheet **3252** is exposed to moisture/water. Control release film or coating **3254** may be optional and added to one or more sides to control release characteristics of generator **3200**. First anhydrous solid mixture **3256** may include sodium chlorite made pursuant to the method and configuration described with respect to **FIGS. 32A-32C**. Second anhydrous solid mixture **3258** may include an activator made pursuant to the method and configuration described with respect to **FIGS. 32A-32C**.

[00327] **FIGS. 33A-33D** illustrate an aerosol container **3386**. It is understood that while container **3386** is illustrated in a cutaway manner in **FIGS. 33A-33D**, container **3386** is an enclosed container, and may be similar to a common aerosol can, such as a spray paint can, with an interior defined by a wall and an optional liner for chemical isolation. Container **3386** may include a nozzle **3388** and a hollow dip tube **3390**. Dip tube **3390** may be oriented within the interior of container **3386**. Dip tube **3390** may include a distal end **3391** open to the interior of container **3386**. Dip tube **3390** as illustrated in **FIG. 33A** is interrupted (discontinuous) with a cutout portion permitting attachment to a dip tube tee **2182**, **2282** of a reactor **2100**, **2200**. Dip tube **3390** may include a proximal end fluidically connected to nozzle **3388**, such that contents of

container **3386** may be directed through the interior of dip tube **3390** and out nozzle **3388** and into the surrounding environment.

[00328] As dip tube **3390** is discontinuous, dip tube **3390** includes a proximal (upper, as illustrated) portion and a distal (lower, as illustrated) portion, with two ends abutting the interrupted portion of dip tube **3390**. These ends of dip tube **3390** are inserted into opposing ends of dip tube tee **2182**, **2282**, such that the interior of reactor **2100**, **2200** is fluidically connected to the interior of dip tube **3390**.

[00329] **FIG. 33C** illustrates an arrangement wherein reactor **2100** may be fluidically connected to the interior of dip tube **3390**, while **FIG. 3D** illustrates an arrangement wherein reactor **2200** may be fluidically connected to the interior of dip tube **3390**.

[00330] Reactor **2100**, **2200** may generate an antimicrobial gas (e.g., ClO_2 gas), which exits outlet **2143**, **2243** and enters dip tube tee **2182**, **2282**. The antimicrobial gas may be drawn into dip tube **3390** and exit container **3386** via nozzle **3388**. Container **3386** may include a pressurized propellant gas contained within the interior of container **3386** outside of reactor **2100**, **2200**. The antimicrobial gas may be mixed with a carrier fluid or carrier gas that is contained within the interior of container **3386** outside of reactor **2100**, **2200**. The carrier fluid/gas may enter dip tube **3390** via distal end **3391**. The carrier fluid/gas may carry antimicrobial gas out of nozzle **3388** and into the surrounding environment. The carrier fluid/gas may carry antimicrobial gas out of nozzle **3388** using pressure provided by the pressurized propellant gas. In one aspect, container **3386** may contain a pressurized propellant gas and a carrier liquid. In another aspect, container **3386** may contain a pressurized carrier gas and no pressurized propellant gas.

[00331] The propellant gas and/or carrier fluid/gas may be pre-pressurized at a pressure above atmospheric pressure outside of container **3386**, and thus may flow (or the propellant gas may cause the carrier fluid/gas to flow) into dip tube **3390** via distal end **3391** upon opening of nozzle **3388**. The carrier fluid/gas may draw antimicrobial gas into dip tube **3390** via outlet **2143**, **2243** by way of a venturi effect due to reactor **2100**, **2200** being open to the interior pressure of container **3386** at pressure input **2141**, **2241**. With reference to reactor **2100**, this venturi effect may create a negative pressure at outlet **2143** drawing liquid precursor **902** and liquid activator **904** in reactor **2100** into reaction chamber **906**, where liquid precursor **902** and liquid activator **904** react to create antimicrobial gas, which is then drawn into outlet **2143**. With reference to reactor **2200**, the venturi effect may create a negative pressure at outlet **2243**, drawing liquid precursor **902** into reaction chamber **906** where it reacts with solid activator **1330** to create ClO_2 gas, which is then drawn into outlet **2243**.

[00332] Nozzle **3388** may include any of a variety of valves, including a spring-loaded valve that may be manually opened by a user (e.g., by pressing down on the nozzle, pulling a trigger, and the like), and which returns to a closed position upon release by a user. Nozzle **3388** may also be automated to open and/or close by an actuator. In this manner, only a desired amount of the contents of container **3386** are discharged into the environment as the valve is selectively opened and closed. Nozzle **3388** may be manipulated by a user, actuator, or the like, and locked into place, such that when opened the contents of container **3386** are discharged into the surrounding environment until the internal pressure of container **3386** is equal to the pressure of the surrounding environment (e.g., atmospheric pressure).

[00333] Any waste liquids created in the generation of antimicrobial gas (e.g., ClO_2 gas) may be maintained within reactor **2100**, **2200**. Seals **2184**, **2284** may be designed so as to prevent liquid precursor **902**, liquid activator **904**, and/or waste liquids created in reaction chamber **906** from flowing backward (that is, away from outlet **2143**, **2243**) and thus maintains these liquids within reactor **2100**, **2200**.

[00334] While reactors **2100**, **2200** are described as generating antimicrobial gas (e.g., ClO_2 gas), it is understood that reactors **2100**, **2200** may be used to generate any multi-component liquid or gas by simply altering the precursor and/or activator contained within reactors **2100**, **2200**. Reactors **2100**, **2200** may be used to produce any multi-component liquid or gas from materials that may react or otherwise be incompatible (immediately or over time) when mixed, and thus cannot be mixed during the initial packaging of container **3386**. For example, container **3386** may be used with two-component paints or adhesives, activated hydrogen peroxide products, activated peracetic acid products, and the like.

[00335] In one alternative aspect, reactor **2100**, **2200** does not contain any activator, and alternatively, a solid activator is contained within dip tube **3390** in a proximal (upper) portion of drip tube **3390**, between reactor **2100**, **2200** and nozzle **3388**.

[00336] Any of reactors **1800**, **1900**, and **2000** may be adapted for use in place of reactors **2100**, **2200** in aerosol can **3386**.

[0001] **FIG. 34** illustrates an aerosol container **3486** including a flexible bladder **3492** connected to a dip tube **3490**. It is understood that while container **3486** is illustrated in a cutaway manner in **FIG. 34**, container **3486** is an enclosed container, and may be similar to a common aerosol can, such as a spray paint can, with an interior defined by a wall and an optional liner. Container **3486** may include a nozzle **3488** and a hollow dip tube **3490**. Dip tube **3490** may be oriented within the interior of container **3486**. Dip tube **3490** may include a distal end **3491** open to the interior of container **3486**. Dip tube **3490** may include a proximal end fluidically connected

to nozzle **3488**, such that contents of container **3486** may be directed through the interior of dip tube **3490** and out nozzle **3488** and into the surrounding environment.

[0002] A flexible bladder **3492** is contained within container **3486**, and fluidically connected to dip tube **3490** by a fitting **3493**. That is, the interior of flexible bladder **3492** is fluidically connected to the interior of dip tube **3490**, such that the contents of flexible bladder **3492** may be conveyed into the interior of dip tube **3490**.

[0003] Flexible bladder **3492** may be made of any of a variety of materials, including for example a rubber. Flexible bladder **3492** may contain within its interior a secondary liquid reactant, including for example a precursor, an activator, or the like. Additionally, a primary liquid reactant that is different from the liquid reactant within flexible bladder **3492** may be contained within the interior of container **3486**, but outside of flexible bladder **3492**. Additionally, a pressurized propellant gas may be contained within container **3486**.

[0004] In practice, the pressure of the secondary liquid reactant within flexible bladder **3492** may be maintained at the same pressure as the primary liquid reactant and/or pressurized propellant gas (if present). In this state, an equilibrium exists within container **3486** that keeps the secondary reactant within flexible bladder **3492**. However, a check valve, backflow valve, seal, or the like (not shown) may be fluidically connected to the interior of flexible bladder **3492** (e.g., within fitting **3493**) that helps keep secondary liquid within flexible bladder **3492** until a user operates nozzle **3488**.

[0005] Nozzle **3488** may include any of a variety of nozzles, including a spring-loaded valve that may be manually opened by a user (e.g., by pressing down on the nozzle, pulling a trigger, and the like), and which returns to a closed position upon release by a user. Nozzle **3488** may also be automated to open and/or close by an actuator. In this manner, only a desired amount of the contents of container **3486** are discharged into the environment. Nozzle **3488** may be manipulated by a user, actuator, or the like, and locked into place, such that when opened the contents of container **3486** are discharged into the surrounding environment until the internal pressure of container **3486** is equal to the pressure of the surrounding environment (e.g., atmospheric pressure).

[0006] When nozzle **3488** is opened, primary liquid reactant travels into distal end **3491** of dip tube **3490**, and out nozzle **3488**. This in turn causes the pressure of primary liquid reactant within container **3486** to drop, which in turn causes secondary liquid reactant within flexible bladder **3492** to overcome a seal, backflow valve, or the like (referenced above) and flow from flexible bladder **3492**, through fitting **3493**, into dip tube **3490**, and out nozzle **3488**. A backflow valve fluidically connected to bladder **3492** may prevent the primary liquid reactant from entering

flexible bladder **3492** and keep the secondary liquid reactant traveling in the direction of nozzle **3488**. The primary liquid precursor and the secondary liquid precursor may mix and react within dip tube **3490**, thus directing the product of the reaction out of nozzle **3488**.

[0007] In one aspect, the product is antimicrobial gas, such as ClO_2 gas. However, it is understood that this arrangement may be used to generate any multi-component liquid or gas by simply altering the primary and second liquid reactants. The product may be any multi-component liquid or gas formed from materials that may react or otherwise be incompatible (immediately or over time) when mixed, and thus cannot be mixed during the initial packaging of container **3486**. For example, container **3486** may be used with two-component paints or adhesives, activated hydrogen peroxide products, activated peracetic acid products, and the like.

[0008] While only one flexible bladder **3492** is illustrated, it is contemplated that more than one flexible bladder **3492** may be used where additional reactants are required for the desired product.

[0009] It is contemplated that where a solid activator is desired, the solid activator may be oriented within dip tube **3490** so as to react with one or both of the primary and secondary liquid reactants on the way out of dip tube **3490** and nozzle **3488**.

[0010] The volume and pressure of the flexible bladder **3492** and container **3486**, diameter of fitting **3493** and dip tube **3490**, liquid reactant viscosities, and/or the use of restrictor valves may be adjusted and optimized to create the desired product from the reactants, at the desired rate of discharge from nozzle **3488**.

[0011] **FIGS. 35A** and **35B** illustrate an aerosol container **3586** including a plurality of flexible bladders **3596**. It is understood that while container **3586** is illustrated in a cutaway manner in **FIGS. 35A** and **35B**, container **3586** is an enclosed container, and may be similar to a common aerosol can, such as a spray paint can, with an interior defined by a wall. Container **3586** may include a nozzle **3588** and a hollow mixing tube **3595**. Mixing tube **3595** may be oriented within the interior of container **3586**. Mixing tube **3595** may include a tee with distal ends fluidically connected to the interior of flexible bladders **3594**. Mixing tube **3595** may include a proximal end fluidically connected to nozzle **3588**, such that contents of flexible bladders **3594** may be directed through the interior **3596** of mixing tube **3595** and out nozzle **3588** and into the surrounding environment.

[0012] In practice, the flexible bladders **3594** contain liquid reactants necessary for the generation of a desired product. For example, a first flexible bladder **3594** may contain a primary liquid reactant while a second flexible bladder **3594** may contain a secondary liquid reactant. Each flexible bladder **3594** is pressurized to a pressure greater than the atmospheric pressure outside of

container **3586**. When nozzle **3588** is opened, the pressure within flexible bladders **3594** forces the contents of flexible bladders **3594** into the interior **3596** of mixing tube **3595** where the primary and secondary liquid reactants mix and react to create a product, which is directed out nozzle **3588**.

[0013] Nozzle **3588** may include any of a variety of nozzles, including a spring-loaded valve that may be manually opened by a user (e.g., by pressing down on the nozzle, pulling a trigger, and the like), and which returns to a closed position upon release by a user. Nozzle **3588** may also be automated to open and/or close by an actuator. In this manner, only a desired amount of the contents of container **3586** are discharged into the environment. Nozzle **3588** may be manipulated by a user, actuator, or the like, and locked into place, such that when opened the contents of container **3586** are discharged into the surrounding environment until the internal pressure of container **3586** is equal to the pressure of the surrounding environment (e.g., atmospheric pressure).

[0014] In one aspect, the product is an antimicrobial gas, such as ClO_2 gas. However, it is understood that this arrangement may be used to generate any multi-component liquid or gas by simply altering the primary and second liquid reactants. The product may be any multi-component liquid or gas formed from materials that may react or otherwise be incompatible (immediately or over time) when mixed, and thus cannot be mixed during the initial packaging of container **3586**. For example, container **3586** may be used with two-component paints or adhesives, activated hydrogen peroxide products, activated peracetic acid products, and the like.

[0015] While only two flexible bladders **3594** are illustrated, it is contemplated that more than one flexible bladder **3594** may be used where additional reactants are required for the desired product.

[0016] It is contemplated that where a solid activator is desired, the solid activator may be oriented within mixing tube **3595** so as to react with one or both of the primary and secondary liquid reactants on the way through mixing tube **3595** and nozzle **3588**.

[0017] The volume and pressure of flexible bladders **3594** and container **3586**, diameter of mixing tub **3595**, liquid reactant viscosities, and/or the use of restrictor valves may be adjusted and optimized to create the desired product from the reactants, at the desired rate of discharge from nozzle **3588**.

[0018] In one aspect, nozzle **3588** may include a shroud or baffle (not shown) upon which the liquid product exiting nozzle **3588** impinges, causing liquid to fall into a containment reservoir (not shown), while pure gas product is permitted to continue out of nozzle **3588** and into the surrounding environment. In this manner, liquid product can be captured and retained while gas

product is permitted to be dispensed. The containment reservoir may be within container **3586**, outside container **3586**, or in one possible arrangement, between an inner container **3586** and an outer container (not shown) within which container **3586** is contained.

[00337] Reactors **1800**, **1900**, **2000**, **2100**, **2200** described herein may be small and portable and may create an antimicrobial gas (e.g., ClO_2 gas) rapidly for convenient use to disinfect three-dimensional spaces. For example, reactors **1800**, **1900**, **2000**, **2100**, and/or **2200** may be approximately 1.0 in. (2.54 cm) wide and 3.0 in. (7.62 cm) long. Reactor **1800**, **1900**, **2000**, **2100**, and/or **2200** may be reusable/rechargeable. Reactor **1800**, **1900**, **2000**, **2100**, and/or **2200** may be sized to create an amount of antimicrobial gas (e.g., ClO_2 gas) optimal for disinfecting a three-dimensional space (e.g., a room) of a particular size or range of sizes, such that reactor **1800**, **1900**, **2000**, **2100**, and/or **2200** may be larger or smaller for larger or smaller spaces. Alternatively, use of reactor **1800**, **1900**, **2000**, **2100**, and/or **2200** in spaces larger than intended may require the use of more than one reactor **1800**, **1900**, **2000**, **2100**, and/or **2200**. Additionally, aerosol containers **3386**, **3486**, and/or **3586** may be sized, shaped, and designed for treatment of three-dimensional spaces of a particular size or range of sizes. Aerosol containers **3386**, **3486**, and/or **3586** may be designed to be recharged by accessing the interior of aerosol containers **3386**, **3486**, and/or **3586** and replacing, reusing, or recharging the reactor. Alternatively, aerosol containers **3386**, **3486**, and/or **3586** may be designed for a one-time use.

[00338] **FIG. 36** illustrates an apparatus **3600** for generating antimicrobial gas or vapor external to a sealed environment for disinfecting items therein. **FIG. 37** illustrates a system **3700** generating antimicrobial gas or vapor external to a sealed environment for disinfecting items therein. **FIGS. 38A** and **38B** illustrate a system **3800** generating antimicrobial gas or vapor within a sealed environment for disinfecting items in the sealed environment. **FIGS. 39A-39C** illustrate an apparatus **3900** generating antimicrobial vapor within a sealed environment for disinfecting items therein. **FIG. 40** illustrates methods of generating antimicrobial gas or vapor within a sealed environment or external to the sealed environment to disinfect items within the sealed environment. **FIGS. 41A** and **41B** illustrate ClO_2 efficacy test data on controlled samples.

[00339] As used herein, the term "items" may include both personal protective equipment ("PPE") and non-PPE items, such as personal items, garments, medical equipment, apparel, garments, shoes, personal electronic devices, furniture, office supplies, built-in structures, drapes, fabrics, utensils, fixtures, decorative items, food, and plants. In addition, the term "sealed environment" may include any of: a sealable bag, a tent, a storage container, a drum, a tumbler drum, a chamber, a room, an office, a store, a warehouse, a home, a hospital, a floor of a multi-

level building, a cabin, an aircraft cabin, a vehicle cabin, a shipping container, a surface vessel cabin, an underwater vessel cabin, public transportation vehicles.

[00340] Apparatuses/systems **3600**, **3700**, **3800**, and **3900** utilize an antimicrobial gas, such as chlorine dioxide (ClO_2) gas, for disinfecting PPE including, without limitation, N95 respirators, surgical masks, protective suits, goggles, and helmets, making them safe for reuse by healthcare professionals and patients, as well as personal items and facilities in office and home settings. In addition, the disclosed methods and apparatuses may be applicable to general decontamination of contained spaces and items.

[00341] The technology has been shown effective against an Ebola surrogate on common hard surface and porous household materials and as a broad-spectrum chemical and biological decontaminant for sensitive equipment. The feasibility of disinfecting and reusing N95 masks has previously been demonstrated using hydrogen peroxide gas or vapor, but the need for specialized (and expensive) equipment requires moving used/contaminated N95 masks to a single location for treatment.

[00342] With the proposed approach, used N95s may be placed in a sealable chamber (**FIGS. 8** and **39A-39C**) and exposed to the headspace of an antimicrobial gas (e.g., ClO_2 solution, generated on-site and at the time of use). After a short antimicrobial gas generation period, dissolved antimicrobial gas is off-gassed within the chamber, allowing the antimicrobial gas to penetrate and disinfect the respirators. After a sufficient disinfection period, the liquid and gas disinfection solution (e.g., ClO_2) are neutralized before opening the chamber to retrieve the disinfected N95s. Neutralization may be performed by adding a small quantity of neutralizing agent, such as a non-hazardous dry chemical packaged with the kit. The spent disinfection solution and any packaging materials are then disposed as non-hazardous waste. The system design is very scalable, from a single item construct for small batches (approx. 1 - 20 respirators) to a room-size chambers or dedicated rooms for large batches (hundreds or thousands of N95s) for use at treatment facilities, forward operating bases, or hospitals to treat large numbers of N95 masks and other equipment. The method requires no electricity, and the decontamination kit (including the reactive ingredients and a container, such as a plastic bag) can be easily transported with other field equipment. Optionally, gas dispersion units ("GDU") within large room-size chambers for dedicated rooms for large batches may include fans or blowers to accelerate the liberation of ClO_2 while forcing ClO_2 out into the enclosure for faster and more uniform distribution. The GDU may require very little power (e.g., may be operated with a battery).

[00343] Preliminary efficacy testing (**FIGS. 41A** and **41B**) had been conducted by contaminating nine coupons cut from an N95 with 7.7-logs of Phi6 bacteriophage (surrogate for Coronavirus and Ebola) prepared in an organic test soil. Coupons were exposed to ClO_2 gas generated from 6 liters of a 180 ppm ClO_2 solution in an 82-L container. A small fan was directed across the surface of the ClO_2 solution to aid in off-gassing and mixing. Coupons were removed after 1.50, 2.25, and 3.00 hours; the exposure times correspond to three treatment levels: 1500, 2200, and 2800 ppm-hours, respectively. Control coupons were held under ambient conditions for the duration of the experiment (3 hours). After treatment, the coupons were assayed; for all three treatment levels, no virions were recovered from the coupons treated with ClO_2 gas. For all three treatment levels, a 6-log reduction of virons was observed. **FIGS. 41A** and **41B** show the recovered virions and log reduction observed for each treatment level. The limit of detection (LOD) for this assay was 1.7-logs. Based on this initial test, ClO_2 gas was effective against the Phi6 surrogate and 6-log reduction was achieved in less than 90 minutes.

[00344] **FIG. 36** is a schematic diagram of an apparatus **3600** generating antimicrobial gas or vapor **3636** external to a sealed environment **3601** for disinfecting items **3608** (e.g., PPE, clothing, and the like) therein. Apparatus **3600** may include a gas or vapor generator **3630** coupled to a blower or pump **3603** which provides antimicrobial gas or vapor **3636** to disinfect items **3608** contained within sealed environment **3601**. Gas or vapor generator **3630** may be a tank in which a chemical reaction may take place by reacting a chlorite containing compound (sodium chlorite $NaClO_2$) with a proton donor **3632** (e.g., a mild acid solution such as oxalic acid or citric acid) to generate antimicrobial gas or vapor **3636**, such as chlorine dioxide ClO_2. The chlorite containing compound may be a permeable membrane or a sachet **3634** containing sodium chlorite $NaClO_2$ powder.

[00345] Antimicrobial vapor **3636** may be externally pumped into sealed environment **3601** containing items **3608** which are to be disinfected. As shown in **FIG. 36**, sealed environment **3601** may be a tumbling drum that turns by a motor **3604** through belts or pulleys **3607**, to rotate the tumbling drum about a central axis to ensure uniformity in mixing and tumbling items **3608** inside. The tumbling drum may be similar to a dryer having inlet **3611** (first passage) and an exhaust outlet **3610** (second passage), such that antimicrobial vapor **3636** may be recirculated back to the vapor generator **3630**. Items **3608** for decontamination may include one or more of: healthcare PPE, respirators, surgical masks, helmets, medical gloves, medical gowns, protective suits, goggles, shoe, and the like. Disinfecting of items **3608** contained in sealed environment

3601 may achieve destruction of one or more of: microbial organisms, bacteria, viruses, fungi, pests, toxins, germs, mites, bed bugs, and the like.

[00346] **FIG. 37** is another schematic diagram of a system **3700** including an apparatus **3710** generating antimicrobial gas or vapor external to a sealed environment **3750** for disinfecting items therein. System **3700** may include a gas or vapor generator apparatus **3710** coupled to a heating ventilation and air conditioning ("HVAC") system or a humidifier system to pass humidified disinfecting gas or vapor (e.g., ClO_2 gas or vapor) from a concentrated chlorine dioxide solution **3702**, and the humidified disinfecting gas or vapor **3730** (e.g., ClO_2 gas or vapor) may be further evaporated through a heater **3720** that may be recirculated within the sealed environment for disinfecting items therein.

[00347] System **3700** may additionally include a pump **3704** for pumping ClO_2 solution **3702** to generator apparatus **3710**. A water line **3706** may provide water to generator apparatus **3710**. A generator controller **3708** may act to control, permit user input into, or both, generator apparatus **3710**. A ClO_2 sensor **3734** may be oriented within sealed environment **3750** and may be in communication with (wired or wireless) a process controller **3736**. Process controller **3736** may ultimately control all antimicrobial gas or vapor generation of system **3700**, including receiving data from sensor **3734** regarding the concentration of disinfecting gas or vapor within sealed environment **3750**. Process controller **3736** may cause the generation of more or less disinfecting gas or vapor **3730** to achieve a desired antimicrobial gas or vapor concentration, based upon data received from sensor **3734**.

[00348] The items for disinfection may include one or more of: healthcare personal protective equipment ("PPE"), medical equipment, apparel, garments, shoes, personal electronic devices, furniture, office supplies, built-in structures, drapes, fabrics, utensils, fixtures, decorative items, plants, and packaged or unpackaged food.

[00349] Sealed environment **3750** may be any of: a sealable bag, a tent, a container, a drum, a tumbler drum, a chamber, a room, an office, a store, a warehouse, a home, a floor of a multi-level building, a cabin, an aircraft cabin, a vehicle cabin, a surface vessel cabin, an underwater vessel cabin. Disinfecting the items contained in sealed environment **3750** may achieve destruction of one or more of: microbial organisms, bacteria, viruses, fungi, pests, toxins, germs, mites, bed bugs, and the like.

[00350] **FIGS. 38A** and **38B** illustrate a system **3800** for generating antimicrobial gas or vapor within a sealed environment for disinfecting items in the sealed environment. System **3800** may include apparatuses **3810** and **3860** for generating antimicrobial vapor within a sealed environment for disinfecting items in the sealed environment (**3820**, **3830**, **3840**, **3850**).

[00351] In **FIG. 38A**, system **3800** includes an apparatus **3810** (e.g., shop vacuum) used to evacuate **3812** (via a suction side **3813**) a sealed environment **3820** (e.g., large bag) through a single passage **3822**. After the evacuation, sealed environment **3820** may be back filled **3814** (via an exhaust side **3815**) with antimicrobial gas or vapor through single passage **3822** for disinfecting items **3824** therein.

[00352] In **FIG. 38B**, apparatus **3860** may be used to evacuate (via a suction side **3813**) and a plurality of sealed environments **3830**, **3840**, **3850**, and backfill (via an exhaust side **3815**) the plurality of sealed environments **3830**, **3840**, **3850** with antimicrobial gas or vapor through respective passages **3832**, **3842**, **3852** for disinfecting items therein. Alternatively, as illustrated in **FIG. 38B**, apparatus **3860** may be used as a gas or vapor generator within a sealed environment **3870**. Sealed environment **3870** may be anyone of: a sealable bag, a tent, a container, a drum, a tumbler drum, a chamber, a room, an office, a store, a warehouse, a home, a floor of a multi-level building, a cabin, an aircraft cabin, a vehicle cabin, a surface vessel cabin, an underwater vessel cabin.

[00353] **FIGS. 39A-39C** illustrate a system **3900** apparatus **3930** for generating antimicrobial gas or vapor within a sealed environment **3910** for disinfecting items **3920** therein. **FIG. 39A** shows that items **3920** to be disinfected may first be put into a sealed environment **3910** (e.g., a bag). Items **3920** may include PPE, medical equipment, apparel, garments, shoes, personal electronic devices, goggles, helmets, drapes, fabrics, utensils, decorative items, and the like. **FIG. 39B** shows that antimicrobial gas or vapor (e.g., ClO_2) may be generated using a gas or vapor generator **3930**. Gas or vapor generator **3930** may be a cup, holder, or a container having a lid to keep the content from spilling out, where antimicrobial gas or vapor (e.g., ClO_2) may be generated by mixing reactants (e.g., a sodium chlorite package **3932** mixed with a mild acid **3934**) and placing gas or vapor generator **3930** inside sealed environment **3910**. **FIG. 39C** shows that the items **3920** inside the sealed environment **3910** may be disinfected by the antimicrobial gas or vapor (e.g., ClO_2) **3934** after a defined time period.

[00354] **FIGS. 8** and **39A-39C** illustrate example systems **800** and **3900** for applying an antimicrobial to a sealed environment **810** and **3910**, respectively. Gas or vapor generator **830** and **3930** may be placed within sealed environment **810** and **3910**, respectively, to treat items **3920** (not shown in **FIG. 8**). Neutralization may be performed by adding a small quantity of neutralizing agent, such as a non-hazardous dry chemical packaged with the kit. The spent disinfection solution and any packaging materials are then disposed as non-hazardous waste. The system design is very scalable, from a single item construct for small batches (approx. 1 - 20

respirators) to a room-size chambers or dedicated rooms for large batches (hundreds or thousands of N95s) for use at treatment facilities, forward operating bases, or hospitals to treat large numbers of N95 masks and other equipment. The method requires no electricity, and the decontamination kit (including the reactive ingredients and a container, such as a plastic bag) can be easily transported with other field equipment.

[00355] **FIG. 40** illustrates a method **4000** for generating antimicrobial gas or vapor within a sealed environment or external to the sealed environment to disinfect items within the sealed environment. Method **4000** includes: providing an antimicrobial vapor to an enclosed environment (step **4002**); generating the antimicrobial vapor within the enclosed environment through one of: (step **4004**) (a) pumping a controlled concentration level of liquid chlorine dioxide solution into a humidifier system to produce a stream of chlorine dioxide antimicrobial vapor, (b) directly pumping a controlled concentration level of chlorine dioxide antimicrobial vapor to an ambient of the enclosed environment, (c) generating ambient chlorine dioxide antimicrobial vapor by dissolving solid chlorine dioxide reactant reagent into a container filled with water; and placing the container that releases the ambient chlorine dioxide antimicrobial vapor into the enclosed environment, (step **4006**); generating the antimicrobial vapor external to the enclosed environment through one of: (step **4008**) (a) pumping a controlled concentration level of liquid chlorine dioxide solution into a humidifier system to produce a stream of chlorine dioxide antimicrobial vapor, (b) directly pumping a controlled concentration level of liquid chlorine dioxide antimicrobial vapor to ingress the enclosed environment through a single passage of the enclosed environment, and (c) directly pumping a controlled concentration level of chlorine dioxide antimicrobial vapor to ingress the enclosed environment through a first passage of the enclosed environment (step **4010**).

[00356] As illustrated, method **4000** optionally performs step **4002** followed by steps **4004** and **4006**, or performs step **4002** followed by steps **4008** and **4010**.

[00357] **FIG. 42** illustrates an apparatus **4200** that generates antimicrobial gas or vapor for disinfecting items in three-dimensional space. **FIG. 43** illustrates an apparatus **4300** that generates antimicrobial gas or vapor for disinfecting items in three-dimensional space. **FIG. 44** illustrates a procedure **4400** for the use of apparatus **4300** in **FIG. 43** to generate antimicrobial gas. **FIG. 45** illustrates a table showing temperature effects to solubility of ClO_2 gas in water and in air and required amount of ClO_2 gas for a defined room size. **FIG. 46** illustrates a uniformity of ClO_2 gas concentration distributed within a room. **FIG. 47** illustrates gas concentration profiles in room setting with furniture. **FIG. 48** illustrates relative humidity and generated ClO_2 gas concentration from a ClO_2 solution. **FIG. 49** illustrates a correlation of increase in disinfection efficacy with

elevated humidity. **FIG. 50** illustrates a method **5000** for generating an antimicrobial gas and dispersing the gas via an apparatus.

[00358] **FIGS. 42** and **50** illustrate an example of a mobile apparatus **4200** performing a computer implemented method **5000** to generate and disperse an antimicrobial gas **4220** to a defined volume of space. Method **5000** includes performing the following steps: measuring a volume of space to be disinfected (step **5002**); setting by a controller **4231**, disinfection parameters based on the measured volume of space **4250** to be disinfected (step **5004**), wherein the disinfection parameters comprising at least the following: (a) determining an optimal location of the apparatus **4200** in the volume of space for uniform dispersion of the antimicrobial gas **4220**, (b) a time duration of disinfection cycle, (c) a minimum amount of antimicrobial gas required to be generated, (d) a flow rate of antimicrobial gas generation, a volume of antimicrobial solution, and a concentration of antimicrobial solution **4205** to meet the required flow rate of antimicrobial gas **4220**, (e) a range of antimicrobial gas relative humidity to be used during a disinfection cycle (step **5006**). Afterwards, activating the apparatus **4200** to run the disinfection cycle until completion; discharging through a plurality of nozzles **4210** which are mounted on an oscillating head **4212**, the antimicrobial gas **4220** to volume of space **4250**.

[00359] Method **5000** may further include: monitoring periodically, a reading of antimicrobial gas concentration at a plurality of remote locations (by a plurality of remote sensors **4242-4248**) within volume of space **4250** during the disinfection cycle and adjusting one or more of: the antimicrobial gas flow rate and the antimicrobial gas concentration for uniform antimicrobial gas dispersion in volume of space **4250** (step **5010**).

[00360] Measuring of the volume of space may be performed by an integrated on-board laser beam scanner **4214**. The method may include oscillating along an axis, the plurality of nozzles **4210** mounted on the oscillating head **4212** in a full circle or less than a half circle. The method may include: in response to the monitored reading of the antimicrobial gas concentration at each of the plurality of locations **4242-4248**, configuring one or more respective nozzles **4210** mounted on the oscillating head **4212** to perform one or a combination of the following to offset concentration differences of the antimicrobial gas at the plurality of locations: adjusting a vertical angle of the nozzle, adjusting a discharge flow rate of the antimicrobial gas, and adjusting a discharge pressure of the antimicrobial.

[00361] In response to the monitored reading of the antimicrobial gas concentration at each of the plurality of locations **4242-4248**, the method may include varying a fan speed of a first blower **4206** which sucks the antimicrobial gas **4208** released from an antimicrobial solution contained in a reactor **4204**. The antimicrobial gas may be released from the antimicrobial

solution in vapor phase at the range of relative humidity (RH) according the setting of the controller **4231**, wherein the range of relative humidity of the vapor phase is correlated to a temperature of the antimicrobial solution **4205**.

[00362] The antimicrobial gas or vapor **4220** may be one of: chlorine dioxide (ClO_2) gas or vapor and hydrogen peroxide (H_2O_2) gas or vapor. The ClO_2 gas or vapor may be generated by chemically reacting a chlorite containing compound with an activator and the H_2O_2 gas or vapor is generated by chemically reacting a urea hydrogen peroxide, borax, perborate, or percarbonate compound with the activator, wherein the activator includes an acid or a proton donating solvent. The chlorite or peroxide containing compound and the activator are separately packaged as anhydrous powder or separately packaged as concentrated solution packages which are to be mixed together in the reactor **4206** to form the antimicrobial solution **4205**.

[00363] Upon completion of the disinfection cycle, an aeration cycle may be started for a defined duration of time to adsorb ambient antimicrobial gas in the volume of space. Alternately, the aeration may also take place during the antimicrobial dispersing cycle to facilitate homogeneity of the antimicrobial gas **4220** in ambient. More specifically, the aeration cycle may be performed by drawing and recirculating by a second blower **4207**, ambient air through a carbon/HEPA filter **4224** disposed at an inlet **4209** of the apparatus, and venting filtered air at an outlet **4211** of the apparatus, wherein the second blower **4207** is physically disposed below and away from the first blower, such that the antimicrobial gas or vapor in the ambient is adsorbed by the carbon/HEPA filter **4224**.

[00364] The mobile apparatus **4200** may be mounted on wheels **4228** to provide mobility. The method may include sending a warning signal from the mobile apparatus in a situation including one or a combination of: (1) when the antimicrobial gas or vapor **4250** in the ambient air exceeds a defined unsafe level, (2) malfunctioning of either the first blower **4206** or the second blower **4207**, or (3) depletion of antimicrobial solution **4205** in the reactor **4206**. The warning signal may be visual, audible, transmitted wirelessly to a remote device (e.g., phone), or any combination thereof.

[00365] **FIGS. 43** and **44** illustrate an example of a mobile apparatus **4300** performing a computer implemented method **4400** to generate and disperse an antimicrobial gas or vapor **4310** for disinfecting items in three-dimensional space. Apparatus **4300** may include a humidifier unit **4302**, a main unit **4304**, a support element **4306**, a filtered air outlet **4308**, a carbon filter intake **4312**, main unit fans **4314**, a gas sensor **4316**, a removable remote and data readout tablet **4318**, an oscillating tower fan **4322** with fan outlet **4320**, under cart storage and portable battery

placement area **4324**, and a cycle indicator light **4326**. Apparatus **4300** may be mobile and placed upon wheels for easy transport into and from a three-dimensional space to be disinfected.

[00366] Method **4400** may include turning a cap **4436** of a concentrated solution bottle **4432, 4434** to "prime" and let sit for at 2 hours; place bottles **4432, 4434** into container unit **4402** (of humidifier unit **4302**); turn caps **4436** of bottles **4432, 4434** to "in use" and close lid down to lock bottles **4432, 4434** into the system's pump; place container unit **4402** into mobile apparatus **4300** adjacent to main unit **4404**; remove remote **4318** from apparatus **4300** and leave the room to be treated, and when yellow light **4441** illuminates, apparatus **4300** will begin pumping fluid into main unit **4404**; when green light **4442** illuminates, apparatus **4300** is ready to begin disinfection; when blue light **4443** illuminates, apparatus **4300** has begun its cycle and humidifier **4302** and fans **4314**, **4322** are activated; when the disinfection cycle is complete, a deactivation command will appear, and UV lights **4446** and chemical release will cause the system to deactivate; when red light **4444** illuminates, apparatus **4300**'s cycle is complete, it is safe for the user to return to the disinfected room, and the fluid has been pumped out of main unit **4304, 4404** and into the original bottles **4432, 4434**; container unit **4402** will unlock upon replacement of remote **4318** back upon apparatus **4300**, bottles **4432, 4434** may be inspected and caps **4436** may be set to "dispose" and discarded.

[00367] In another aspect, the process of generating antimicrobial gas may include the following steps:

[00368] 1. <u>Steps in Process</u>

[00369] a. User inputs room identifying information (or automated via RFID tag) and selects disinfection routine via touch screen, Bluetooth or WIFI communication.

[00370] i. Disinfection cycle may vary based on need, e.g., short-cycle sanitization, between patient turnover, known contagion in room, deodorizing, and the like.

[00371] ii. Laser scanner to calculate room dimensions/volume.

[00372] iii. Disinfection cycle parameters (e.g., RH, ramp up, concentration, time, aeration) based on data models for targeted level of disinfection and room size.

[00373] 1. Actual data will be recorded for each cycle for each room and used to refine models, in general and for specific rooms/spaces.

[00374] iv. User provided feedback giving estimated time to run disinfection cycle.

[00375] v. Warning light activated indicating cycle about to start (occupants should leave the room).

[00376] b. Device executes user selected disinfection routine based on data model.

[00377] i. Warning light changes color indicating cycle has started; user is notified via remote monitoring app.

[00378] ii. Conditions the room to target RH value (based on remote sensor feedback).

[00379] iii. Calculates rate of antimicrobial gas generation needed to reach target concentration (ppm) during pre-determined time window for initial ramp up.

[00380] iv. Generates and dispenses antimicrobial gas at calculated rate.

[00381] v. Uses forced air flow and directional and/or rotating nozzles to dispense gas into room volume.

[00382] vi. CFM is in excess of gas generation uptake rate and enough to uniformly mix gas in room volume.

[00383] vii. Intake air for gas antimicrobial mixing is HEPA filtered.

[00384] viii. Adjusts rate of antimicrobial gas generation to hit targeted rate during ramp up based on feedback from remote chemical sensors to adjust gas generation.

[00385] 1. Required rate of antimicrobial gas generation is impacted by amount of equipment, furniture, etc. in the room (taking up calculated volume space), the uptake of antimicrobial gas by porous items in the room, and the natural decay of antimicrobial gas concentration.

[00386] ix. Automatically adjusts rate of antimicrobial gas generation based on feedback from remote chemical sensors to maintain target concentration for duration of disinfection cycle.

[00387] x. Updates user on time to end of cycle once steady-state conditions are met.

[00388] xi Continuously monitors and records sensor data, creating a record that disinfection process parameters were maintain throughout cycle.

[00389] xii. Terminates gas generation at end of program cycle.

[00390] xiii. Aeration cycle is initiated.

[00391] 1. Lower blower system turns over room in air until chemical antimicrobial is no longer detectable (plus factor of safety).

[00392] 2. Intake air is filtered through carbon filter and HEPA filter to remove antimicrobial and contaminants from air.

[00393] xiv. Warning light changes color indicating cycle has ended; user is notified via remote monitoring app that it is safe to enter the room.

[00394] c. Reporting and data analytics.

[00395] i. Report file generated and uploaded to central data collection system for documentation purposes.

[00396] ii. Process data added to model training data set to continuously refine disinfection models, both generally and for that specific room.

[00397] 2. Chlorine Dioxide Gas

[00398] a. Pure chlorine dioxide gas can be generated from any number of source materials; preferably, generation materials produce a high level of chlorine dioxide.

[00399] b. Method of generating ClO_2 needs to be capable of enough ClO_2 for at least one antimicrobial cycle.

[00400] c. Method of generating ClO_2 needs to be capable of producing ClO_2 fast enough to reach target room concentration levels within about 15 minutes.

[00401] d. Method of ClO_2 generation may be batch process generation or just-in-time production.

[00402] e. Generation materials are preferably provided in a form that does not require human contact, here introduction/integration process with equipment support chemical feed, and feed rate can be controlled to control the rate of ClO_2 production.

[00403] f. Pure ClO_2 gas can be separated from liquid using any method, e.g., stirring/mixing; aeration; surface fans/blower; water tower with countercurrent air; airflow over/through water flow or spray; thin film evaporation; vacuum; piezoelectric; heating; and the like.

[00404] g. Liquid byproducts from ClO_2 generation process may be neutralized by any number of chemical reaction processes to destroy residual ClO_2. Alternatively, generation liquids can be recirculated through the system during the aeration cycle to remove residual ClO_2.

[00405] 3. Configuration

[00406] a. The ClO_2 gas disinfection system can be configured as a fully automated unit, with full process control and documentation features, as described.

[00407] b. Manual configurations without process automation and control may be configured for use by properly trained personnel.

Example 1:

[00408] As illustrated in **FIG. 8**, gas or vapor generator **830** may be oriented within sealed environment **810**. The use of micro devices (e.g., gas or vapor generator **830**) to generate ClO_2 can generate low target concentrations in large volumes (e.g., 1,300 cubic feet/36.8 cubic meters) while requiring low raw materials. In Example 1, a dose of 22 µL of 0.75 g/mL $NaClO_2$ and 36 µL of 12 M HCl were dispensed using two syringe pumps into a PVC tube applicator with 1.5 L/min flow rate of air blowing across the liquid drop as it was dispensed. The syringe pumps and PVC tube applicator were located in the center of an ISO shipping container (e.g., sealed

environment **810**). The blower blew the air within the enclosed, and sealed, ISO shipping container, which had an internal volume of 1,300 cubic feet/36.8 cubic meters. **FIG. 51A** illustrates the time (minutes) to equilibrium for a target concentration of 0.1 ppm of ClO_2 to air. As illustrated, equilibrium was reached in a matter of minutes using this very small setup.

[00409] After the ambient air inside the ISO shipping container reached an equilibrium of 0.08 ppm, the syringe pumps were turned on to a rate of 1 μL/min. and the ClO_2 concentration was measured at five different ports in the ISO shipping container walls, the ports being spread at different locations around the ISO shipping container. **FIG. 51B** illustrates the concentration (ppm of ClO_2 to air) measured at each of the five ports over time (minutes). The concentration measured at each port was substantially similar over the test time, as illustrated in **FIG. 51B**.

Example 2:

[00410] The use of micro devices (e.g., gas or vapor generator **830**) to generate ClO_2 can generate low target concentrations in large volumes (e.g., 1,300 cubic feet/36.8 cubic meters) while requiring low raw materials. In Example 2, a dose of 125 mL of 0.75 g/mL $NaClO_2$ and 632 mL of 0.50 g/mL $Na_2S_2O_8$ were dispensed into a unit with fans blowing down onto the ClO_2 solution. The unit was located in the center of an ISO shipping container (e.g., sealed environment **810**). The fans blew the air within the enclosed, and sealed, ISO shipping container, which had an internal volume of 1,300 cubic feet/36.8 cubic meters. **FIG. 52A** illustrates the time (minutes) to equilibrium for a target concentration of 350 ppm of ClO_2 to air. As illustrated, equilibrium was reached in about 60 minutes.

[00411] After the ambient air inside the ISO shipping container reached a concentration of about 350 ppm, ClO_2 production was ceased, and a PortaSens device was used to read the concentration at 12 different ports in the ISO shipping container walls, the ports being spread at different locations around the ISO shipping container. **FIG. 52B** illustrates the concentration (ppm of ClO_2 to air) measured at each of the 12 ports over time (minutes). The concentration measured at each port was substantially similar over the test time, as illustrated in **FIG. 52B**.

Example 3:

[00412] **FIGS. 53A** and **53B** illustrate diagrams of an example system **5300** for generating ClO_2 vapor from small volumes of high concentration liquid precursors. System **5300** includes a sodium chlorite concentrate **5302** and an activator concentrate **5304**. Sodium chlorite concentrate **5302** is fluidically connected to a pump **5306**, while activator concentrate **5304** is fluidically connected to a pump **5308**. A controller **5310** is operatively connected to both of pumps **5306** and **5308**. Controller **5310** controls the operation of pumps **5306** and **5308**, including at least volume of fluid pumped, flow rate, timing of pump activation, and the like.

[00413] As illustrated in **FIG. 53A**, each of pumps **5306** and **5308** are fluidically connected to a t-mixing chamber **5312**, where sodium chlorite concentrate **5302** and activator concentrate **5304** are combined to generate ClO_2 vapor. As illustrated in **FIG. 53B**, each of pumps **5306** and **5308** are fluidically connected to a microfluidic mixing chip **5318**, where sodium chlorite concentrate **5302** and activator concentrate **5304** are combined to generate ClO_2 vapor.

[00414] ClO_2 vapor is diffused into the ambient air at diffuser **5314**. A ClO_2 sensor **5316** senses the concentration of ClO_2 in the ambient air and is operatively connected to controller **5310**. If the concentration of ClO_2 in the ambient air is lower than desired, controller **5310** causes pumps **5306** and **5308** to generate more ClO_2, or to generate ClO_2 at a greater rate, as necessary to achieve the desired concentration of ClO_2. If the concentration of ClO_2 in the ambient air is greater than desired, controller **5310** causes pumps **5306** and **5308** to generate less ClO_2, or to generate ClO_2 at a lesser rate, or to cease the generation of ClO_2 for a desired time to allow the concentration of ClO_2 to fall to a desired level, as necessary to achieve the desired concentration of ClO_2.

[00415] Pumps, such as pumps **5306**, **5308**, **308A**, **308B**, and **308C**, may be positive displacement pumps. Positive displacement pumps may provide a benefit in that for each rotation/reciprocation of the pump, the volume of fluid pumped is known. In this arrangement, a mass flow controller or flow sensor (such as flow sensors **318A** and **318B**) may be eliminated from the system. Positive displacement pumps may allow a closed loop independent sensor (e.g., an encoder) on the pump's rotation/reciprocation means, which further allows the system to yield an independent measure of the pump's movement and/or the volume of fluid pumped. When not reciprocating or rotating, the pumping action may maintain a normally-closed configuration to eliminate leakage flow, which is critical to the control of microvolumes (e.g., microliters), and may eliminate one or more secondary valves, including for example one or more of a leak control valve and a check valve.

[00416] In one aspect, the matter transport system of antimicrobial generators must be designed to minimize post-pump to generator-release "dead volume," which pertains to how much material is left between a pump and downstream active/passive fluidic and/or generator elements. In one aspect, a target may be less than 1X, or less than 0.5X of minimum generator cycle volume of precursors consumed as same dead space.

[00417] **FIGS. 54A-C** illustrate results of ClO_2 generation using system **5300** or similar systems. The results illustrated in **FIGS. 54A-C** correspond to generation of 0.1 ppm of ClO_2 vapor from small volumes of high concentration precursors. **FIG. 54A** illustrates results obtained from a two-component concentrated liquid generation of ClO_2. **FIG. 54B** illustrates results obtained from an electrochemical generation of ClO_2 from concentrated liquid $NaClO_2$. **FIG.**

54C illustrates projections for chemical use necessary for a 1,000 cubic foot (28.3 cubic meter) room including various activators, both for initial treatment and after 30 days of continuous operation.

Example 4:

[00418] The efficacy of ClO_2 at ranges of approximately 0.1 ppmv and 5 ppmv was assessed against clinically-relevant infectious bacteria including Klebsiella pneumonia (Kp), Pseudomonas aeruginosa (PA), Staphylococcus aureus (Sa), and Salmonella enterica (Se), as well as bacteriophage Phi6 and MS2 (representing enveloped and non-enveloped virus, respectively). The microorganisms were prepared in phosphate buffered saline (PBS), dispensed onto replicate glass coupons (five 10 µL droplets; equivalent to 5-6 log cells or virions per coupon), placed into a room-scale test chamber conditioned with ClO_2 and 50-60% relative humidity (RH) and operated at ambient temperatures ranging from 18 to 21 °C.

[00419] To assess efficacy, the concentration viable bacteria or infective virions recovered from ClO_2 treated coupons versus untreated control coupons versus time were measured. Per test, replicate coupons (duplicates or triplicates) were removed from the test chamber at various time intervals and assayed (extracted and enumerated) to determine the total quantity of organisms recovered. The results were plotted as kill curves (expressed as log organisms recovered versus time). The kill curves were then used to calculate the D-values of gas treatment, representing the time required to achieve a 90% reduction (or 1 log reduction) of viable/infective organisms at a given test condition. The area of the kill curve in which linear decay was observed was used to determine the D-value (calculated as the negative inverse of the linear decay slope).

[00420] **FIGS. 55A** and **55B** illustrate the mean D-values (hours) from replicate tests per organism performed at the range of 0.11 ± 0.04 ppmv (**FIG. 55A**) and 5.3 ± 2.4 ppmv (**FIG. 55B**).

[00421] The results demonstrate that at 0.1 ppmv (**FIG. 55A**) a reduction of 90% of all organisms was rapid and comparable ranging from 0.5 to 1.2 hours (or 31 to 70 minutes).

[00422] As would be expected, the efficacy increased with treatment at 5 ppmv (**FIG. 55B**) with D-values ranging from 0.2 to 0.3 hours (or 13 to 19 minutes).

[00423] Based on this data, the time to achieve a 99.9 % or 3-log reduction at 0.1 ppmv and 5 ppmv correlates to 1.5 to 3.6 hours and 0.6 to 0.9 hours, respectively.

[00424] A system for generating and monitoring an antimicrobial, is provided, the system comprising: a computational system; an antimicrobial sensor; and an antimicrobial generator, wherein the computational system, the antimicrobial generator, and the antimicrobial sensor are operatively connected. The computational system may be at least one of a microprocessor and a microcontroller. The system may further include an external communication device. The system

may include a separate sensor sub-system comprising: at least one of a sensor sub-system microprocessor and a sensor sub-system microcontroller; a sensor sub-system external communications device; at least one of a sensor sub-system antimicrobial sensor and a sensor sub-system environmental sensor; and a sensor sub-system computational system. The system may include a separate generation sub-system comprising: at least one of a generation sub-system microprocessor and a generation sub-system microcontroller; a generation sub-system external communications device; and a generation sub-system antimicrobial generator. The external communications device, the computational system, the antimicrobial generator, and the at least one of an antimicrobial sensor and an environmental sensor may be oriented within an enclosed volume under treatment. At least one sensor sub-system and/or generation sub-system may be oriented within an enclosed volume under treatment.

[00425] A system for generating and monitoring an antimicrobial is provided, the system comprising: a sensor sub-system comprising: at least one of a sensor sub-system microprocessor and a sensor sub-system microcontroller, a sensor sub-system external communications device, at least one of a sensor sub-system antimicrobial sensor and a sensor sub-system environmental sensor, and a sensor sub-system computational system; a generation sub-system comprising: at least one of a generation sub-system microprocessor and a generation sub-system microcontroller, a generation sub-system external communications device, and a generation sub-system antimicrobial generator; and an enclosed space forming a volume under treatment. The sensor sub-system and the generation sub-system may be oriented within the enclosed volume under treatment. The sensor sub-system may be oriented within the enclosed volume under treatment and the generation sub-system may be oriented outside of the enclosed volume under treatment. The generation sub-system may be oriented within the enclosed volume under treatment and the sensor sub-system may be oriented outside of the enclosed volume under treatment. The system may include an HVAC air supply fluidically connected to the interior of the enclosed volume under treatment, the sensor sub-system may be oriented within the enclosed volume under treatment, the generation sub-system may be oriented outside of the enclosed volume under treatment, and the generation sub-system may be fluidically connected to the HVAC air supply. The system may include an HVAC air return fluidically connected to the interior of the enclosed volume under treatment, the generation sub-system may be oriented within the enclosed volume under treatment, the sensor sub-system may be oriented outside of the enclosed volume under treatment, and the sensor sub-system may be fluidically connected to the HVAC air return.

[00426] A system for generating and monitoring ClO_2 is provided, the system comprising: a device housing including an inlet; a microcontroller or microprocessor; a reagent container

containing a reagent; a device for generating a ClO_2 from the reagent; and a sensing system. The system may include two reagent containers, and each reagent container may contain a different reagent. The device for generating the ClO_2 may be a microfluidic mixer, and the two reagents may mix in the microfluidic mixer to generate the ClO_2. The device for generating the ClO_2 may be an electrochemical generator. The sensing system may measure a concentration of ClO_2 in ambient air introduced via the inlet. The measurement of concentration of ClO_2 in the ambient air may be communicated to the microcontroller or microprocessor, and the microcontroller or microprocessor may cause the system to generate the ClO_2 if the ClO_2 concentration is below a target value. The system may include one reagent container and one reagent, the device for generating the ClO_2 may be an electrochemical generator, and the electrochemical generator may use an electrical potential to cause a reaction with the reagent that generates the ClO_2. The electrochemical generator may be a microfluidic device. The system may include a barometric sensor to sense a pressure of ambient air introduced via the inlet, the pressure may be communicated to the microcontroller or microprocessor, and a negative pressure may cause the microcontroller or microprocessor to pause ClO_2 generation until a neutral and/or positive pressure is sensed by the barometric sensor. The system may include an off-gas and waste chamber having a membrane, waste from the generation of the ClO_2 may be absorbed in an absorber material, and ClO_2 may exit the off-gas and waste chamber through the membrane and into an ambient atmosphere. The system may include an air pump electrically connected to the microcontroller or microprocessor and fluidically connected to the inlet via an air duct. The microcontroller or microprocessor is controlled by machine learning algorithms to alter system performance. The microcontroller or microprocessor may be controlled by artificial intelligence algorithms to alter system performance. The microcontroller or microprocessor may alter system performance automatically. The microcontroller or microprocessor may alter system performance by control by a user. The microcontroller or microprocessor may alter the system performance based upon at least one of: a detection of a virus in ambient air containing the system; a detection of bacteria in ambient air containing the system; an altitude of the system; a temperature of the system; changes in ambient air measured by changes in a concentration of ClO_2 in ambient air; changes in occupancy by living beings of an area containing the system; alterations for a user's preferences; prediction of cycles of occupancy and vacancy by living beings of the area containing the system; and a diagnosis of normal or abnormal performance of the system.

[00427] A network of systems for generating and monitoring ClO_2 is provided, the network of systems comprising: a plurality of systems for generating and monitoring ClO_2, including: a device housing including an inlet; a microcontroller; a reagent container containing a reagent; a

microfluidic device for generating a ClO_2 from the reagent; and a sensing system; wherein the microcontroller includes a communication device capable of communication between the plurality of systems, wherein the communication device establishes distributed control of each system's microcontroller, and wherein the microcontroller is controlled by machine learning algorithms to alter system performance. The distributed control may include at least one of: adjusting individual systems to achieve a uniform or deliberately non-uniform distribution of ClO_2 in each individual sensor's location within a specified space; consumption of ClO_2; control of day and/or night generation cycles; using the sensing system to sense patterns across time, three-dimensional volumes, seasonal variations; sending patterns that are inferred or traced to a signal measured; and sensing patterns that are directly traceable to variations observed in ClO_2 concentrations across the network of systems installed across distinct spaces.

[00428] A network of systems for generating and monitoring ClO_2 concentration is provided, the network of systems comprising: a plurality of systems for generating and monitoring ClO_2, including: a device housing including an inlet; a microcontroller; a reagent container containing a reagent; a microfluidic device for generating a ClO_2 from the reagent; and a sensing system; wherein the microcontroller includes a communication device capable of communication between the plurality of systems, wherein the communication device establishes distributed control of each system's microcontroller, and wherein the microcontroller is controlled by artificial intelligence algorithms to alter system performance. The distributed control may include at least one of: adjusting individual systems to achieve a uniform or deliberately non-uniform distribution of ClO_2 in each individual sensor's location within a specified space; consumption of ClO_2; control of day and/or night generation cycles; using the sensing system to sense patterns across time, three-dimensional volumes, seasonal variations; sending patterns that are inferred or traced to a signal measured; and sensing patterns that are directly traceable to variations observed in ClO_2 concentrations across the network of systems installed across distinct spaces.

[00429] To the extent that the term "includes" or "including" is used in the specification or the claims, it is intended to be inclusive in a manner similar to the term "comprising" as that term is interpreted when employed as a transitional word in a claim. Furthermore, to the extent that the term "or" is employed (e.g., A or B) it is intended to mean "A or B or both." When the applicants intend to indicate "only A or B but not both" then the term "only A or B but not both" will be employed. Thus, use of the term "or" herein is the inclusive, and not the exclusive use. See Bryan A. Garner, A Dictionary of Modern Legal Usage 624 (2d. Ed. 1995). Also, to the extent that the terms "in" or "into" are used in the specification or the claims, it is intended to additionally mean

"on" or "onto." To the extent that the term "substantially" is used in the specification or the claims, it is intended to take into consideration the degree of precision available in manufacturing. To the extent that the term "selectively" is used in the specification or the claims, it is intended to refer to a condition of a component wherein a user of the apparatus may activate or deactivate the feature or function of the component as is necessary or desired in use of the apparatus. To the extent that the term "operatively connected" is used in the specification or the claims, it is intended to mean that the identified components are connected in a way to perform a designated function. As used in the specification and the claims, the singular forms "a," "an," and "the" include the plural. Finally, where the term "about" is used in conjunction with a number, it is intended to include ± 10 % of the number. In other words, "about 10" may mean from 9 to 11.

[00430] As stated above, while the present application has been illustrated by the description of aspects thereof, and while the aspects have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art, having the benefit of the present application. Therefore, the application, in its broader aspects, is not limited to the specific details, illustrative examples shown, or any apparatus referred to. Departures may be made from such details, examples, and apparatuses without departing from the spirit or scope of the general inventive concept.

CLAIMS

What is claimed is:

1. A system for generating and monitoring an antimicrobial, comprising:

a computational system;

an antimicrobial sensor; and

an antimicrobial generator,

wherein the computational system, the antimicrobial generator, and the antimicrobial sensor are operatively connected.

2. The system of claim 1, wherein the computational system is at least one of a microprocessor and a microcontroller.

3. The system of claim 1, further comprising an external communication device.

4. The system of claim 1, further comprising a separate sensor sub-system comprising:

at least one of a sensor sub-system microprocessor and a sensor sub-system microcontroller;

a sensor sub-system external communications device;

at least one of a sensor sub-system antimicrobial sensor and a sensor sub-system environmental sensor; and

a sensor sub-system computational system.

5. The system of claim 1, further comprising a separate generation sub-system comprising:

at least one of a generation sub-system microprocessor and a generation sub-system microcontroller;

a generation sub-system external communications device; and

a generation sub-system antimicrobial generator.

6. The system of claim 3, wherein the external communications device, the computational system, the antimicrobial generator, and the at least one of an antimicrobial sensor and an environmental sensor is oriented within an enclosed volume under treatment.

7. The system of claim 4, wherein at least one sensor sub-system is oriented within an enclosed volume under treatment.

8. The system of claim 5, wherein at least one generation sub-system is oriented within an enclosed volume under treatment.

9. A system for generating and monitoring an antimicrobial, comprising:

a sensor sub-system comprising:

at least one of a sensor sub-system microprocessor and a sensor sub-system microcontroller,

a sensor sub-system external communications device,

at least one of a sensor sub-system antimicrobial sensor and a sensor sub-system environmental sensor, and

a sensor sub-system computational system;

a generation sub-system comprising:

at least one of a generation sub-system microprocessor and a generation sub-system microcontroller,

a generation sub-system external communications device, and

a generation sub-system antimicrobial generator; and

an enclosed space forming a volume under treatment.

10. The system of claim 9, wherein the sensor sub-system and the generation sub-system are oriented within the enclosed volume under treatment.

11. The system of claim 9, wherein the sensor sub-system is oriented within the enclosed volume under treatment and wherein the generation sub-system is oriented outside of the enclosed volume under treatment.

12. The system of claim 9, wherein the generation sub-system is oriented within the enclosed volume under treatment and wherein the sensor sub-system is oriented outside of the enclosed volume under treatment.

13. The system of claim 9, further comprising an HVAC air supply fluidically connected to the interior of the enclosed volume under treatment, wherein the sensor sub-system is oriented within the enclosed volume under treatment, wherein the generation sub-system is oriented outside of the enclosed volume under treatment, and wherein the generation sub-system is fluidically connected to the HVAC air supply.

14. The system of claim 9, further comprising an HVAC air return fluidically connected to the interior of the enclosed volume under treatment, wherein the generation sub-system is oriented within the enclosed volume under treatment, wherein the sensor sub-system is oriented outside of the enclosed volume under treatment, and wherein the sensor sub-system is fluidically connected to the HVAC air return.

15. A system for generating and monitoring ClO_2, comprising:

a device housing including an inlet;

a microcontroller or microprocessor;

a reagent container containing a reagent;

a device for generating a ClO_2 from the reagent; and

a sensing system.

16. The system of claim 15, wherein the system comprises two reagent containers, and wherein each reagent container contains a different reagent.

17. The system of claim 16, wherein the device for generating the ClO_2 is a microfluidic mixer, and wherein the two reagents mix in the microfluidic mixer to generate the ClO_2.

18. The system of claim 15, wherein the device for generating the ClO_2 is an electrochemical generator.

19. The system of claim 15, wherein the sensing system measures a concentration of ClO_2 in ambient air introduced via the inlet.

20. The system of claim 19, wherein the measurement of concentration of ClO_2 in the ambient air is communicated to the microcontroller or microprocessor, and wherein the microcontroller or microprocessor causes the system to generate the ClO_2 if the ClO_2 concentration is below a target value.

21. The system of claim 15, wherein the system comprises one reagent container and one reagent, wherein the device for generating the ClO_2 is a electrochemical generator, and wherein the electrochemical generator uses an electrical potential to cause a reaction with the reagent that generates the ClO_2.

22. The system of claim 21, wherein the electrochemical generator is a microfluidic device.

23. The system of claim 15, further comprising a barometric sensor to sense a pressure of ambient air introduced via the inlet, wherein the pressure is communicated to the microcontroller or microprocessor, and wherein a negative pressure causes the microcontroller or microprocessor to pause ClO_2 generation until a neutral and/or positive pressure is sensed by the barometric sensor.

24. The system of claim 15, further comprising an off-gas and waste chamber having a membrane, wherein waste from the generation of the ClO_2 is absorbed in an absorber material, and wherein ClO_2 exits the off-gas and waste chamber through the membrane and into an ambient atmosphere.

25. The system of claim 15, further comprising an air pump electrically connected to the microcontroller or microprocessor and fluidically connected to the inlet via an air duct.

26. The system of claim 15, wherein the microcontroller or microprocessor is controlled by machine learning algorithms to alter system performance.

27. The system of claim 15, wherein the microcontroller or microprocessor is controlled by artificial intelligence algorithms to alter system performance.

28. The system of claim 26 or 27, wherein the microcontroller or microprocessor alters system performance automatically.

29. The system of claim 26 or 27, wherein the microcontroller or microprocessor alters system performance by control by a user.

30. The system of claim 26 or 27, wherein the microcontroller or microprocessor alters the system performance based upon at least one of:

a detection of a virus in ambient air containing the system;

a detection of bacteria in ambient air containing the system;

an altitude of the system;

a temperature of the system;

changes in ambient air measured by changes in a concentration of ClO_2 in ambient air;

changes in occupancy by living beings of an area containing the system;

alterations for a user's preferences;

prediction of cycles of occupancy and vacancy by living beings of the area containing the system; and

a diagnosis of normal or abnormal performance of the system.

31. A network of systems for generating and monitoring ClO_2, comprising:

a plurality of systems for generating and monitoring ClO_2, including:

a device housing including an inlet;

a microcontroller;

a reagent container containing a reagent;

a microfluidic device for generating a ClO_2 from the reagent; and

a sensing system;

wherein the microcontroller includes a communication device capable of communication between the plurality of systems,

wherein the communication device establishes distributed control of each system's microcontroller, and

wherein the microcontroller is controlled by machine learning algorithms to alter system performance.

32. The network of systems of claim 31, wherein the distributed control includes at least one of:

adjusting individual systems to achieve a uniform or deliberately non-uniform distribution of ClO_2 in each individual sensor's location within a specified space;

consumption of ClO_2;

control of day and/or night generation cycles;

using the sensing system to sense patterns across time, three-dimensional volumes, seasonal variations;

sending patterns that are inferred or traced to a signal measured; and

sensing patterns that are directly traceable to variations observed in ClO_2 concentrations across the network of systems installed across distinct spaces.

33. A network of systems for generating and monitoring ClO_2 concentration, comprising:

a plurality of systems for generating and monitoring ClO_2, including:

a device housing including an inlet;

a microcontroller;

a reagent container containing a reagent;

a microfluidic device for generating a ClO_2 from the reagent; and

a sensing system;

wherein the microcontroller includes a communication device capable of communication between the plurality of systems,

wherein the communication device establishes distributed control of each system's microcontroller, and

wherein the microcontroller is controlled by artificial intelligence algorithms to alter system performance.

34. The network of systems of claim 33, wherein the distributed control includes at least one of:

adjusting individual systems to achieve a uniform or deliberately non-uniform distribution of ClO_2 in each individual sensor's location within a specified space;

consumption of ClO_2;

control of day and/or night generation cycles;

using the sensing system to sense patterns across time, three-dimensional volumes, seasonal variations;

sending patterns that are inferred or traced to a signal measured; and

sensing patterns that are directly traceable to variations observed in ClO_2 concentrations across the network of systems installed across distinct spaces.

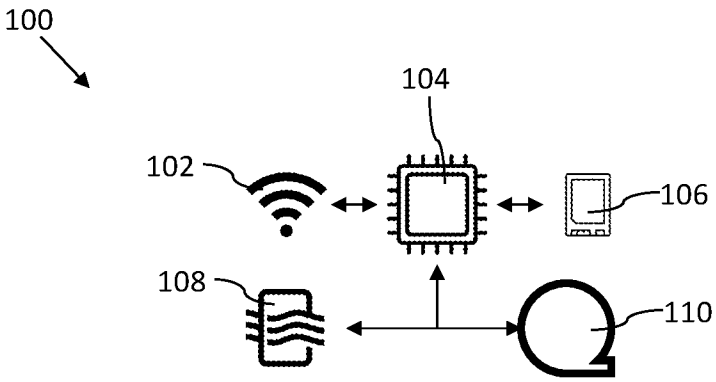
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FIG. 1A

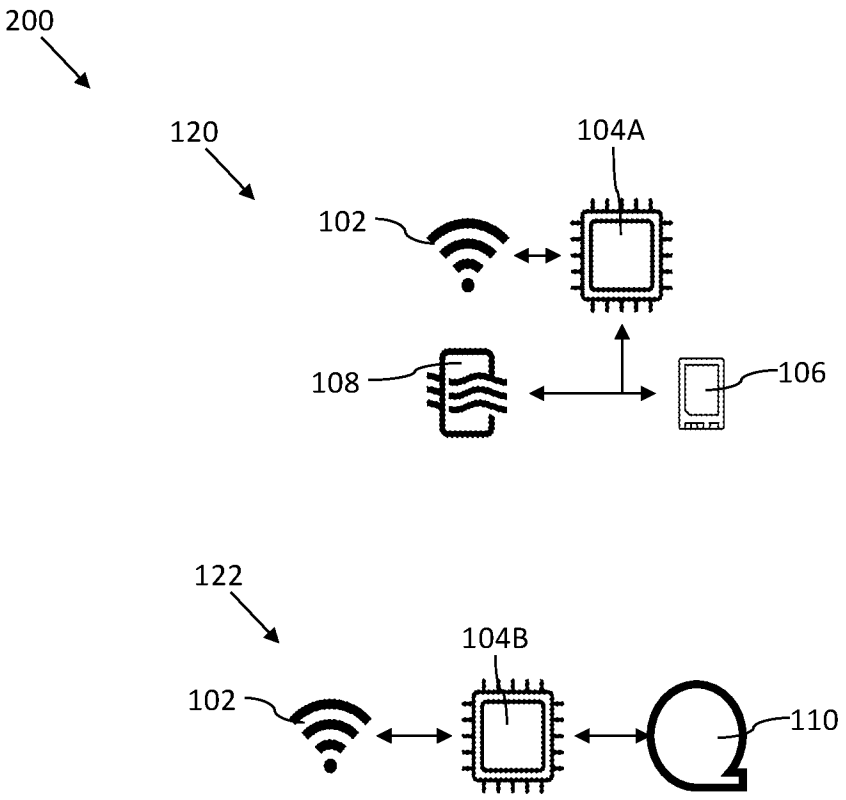
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FIG. 2A

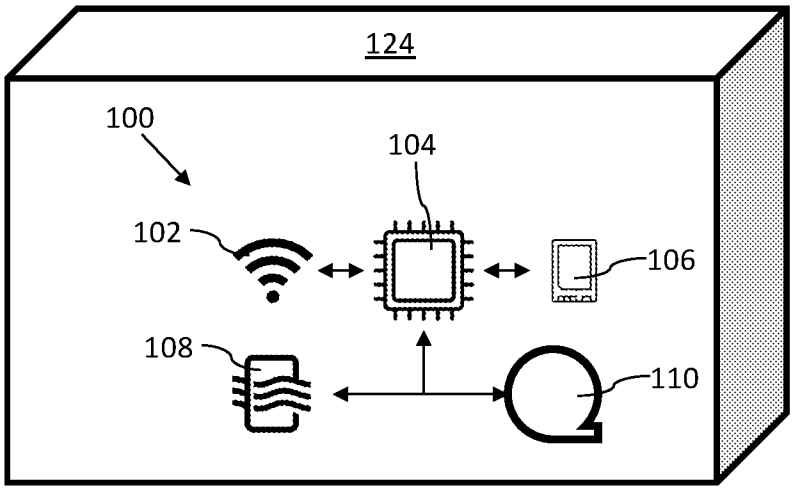
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FIG. 1B

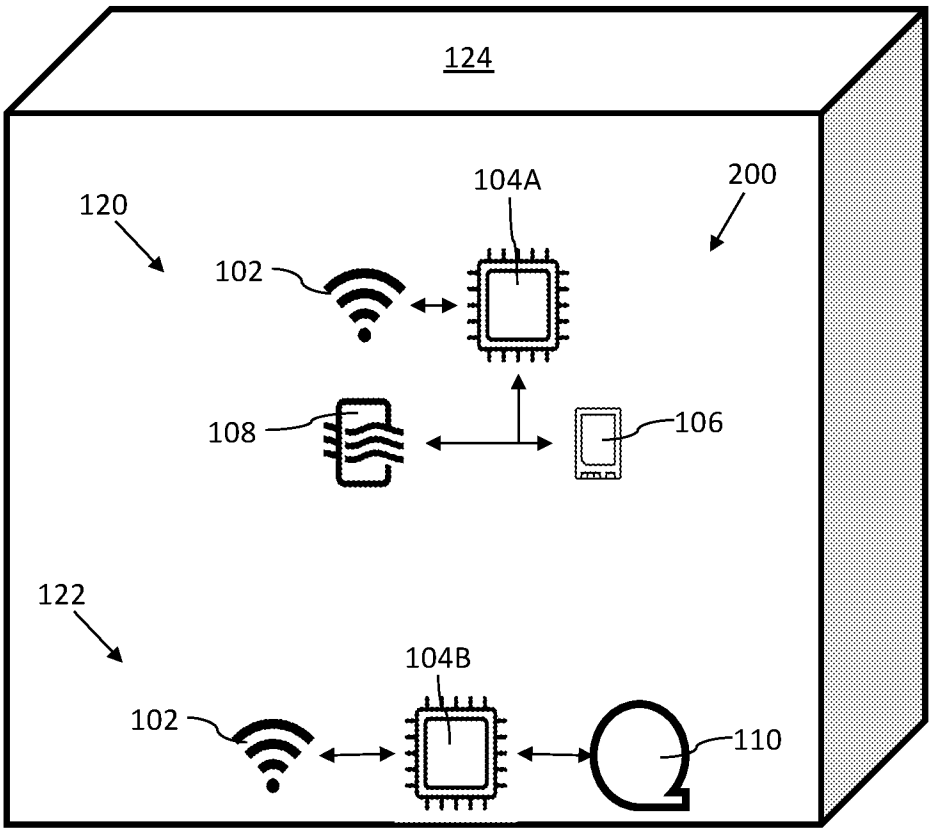
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FIG. 2B

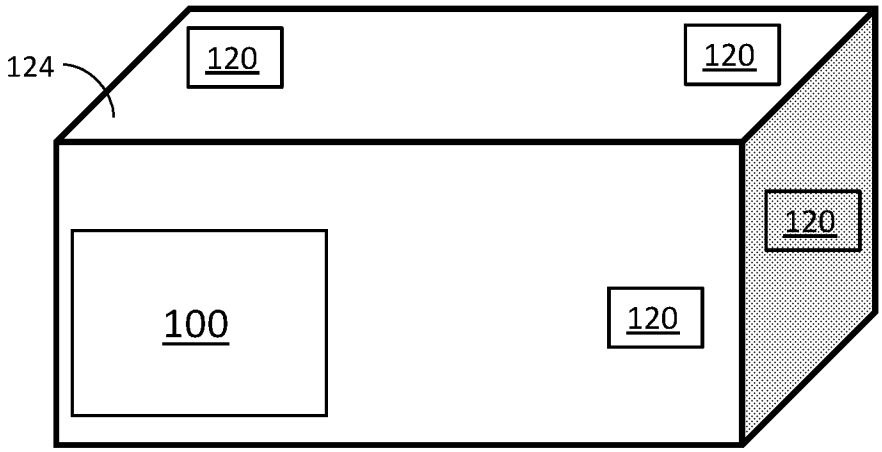
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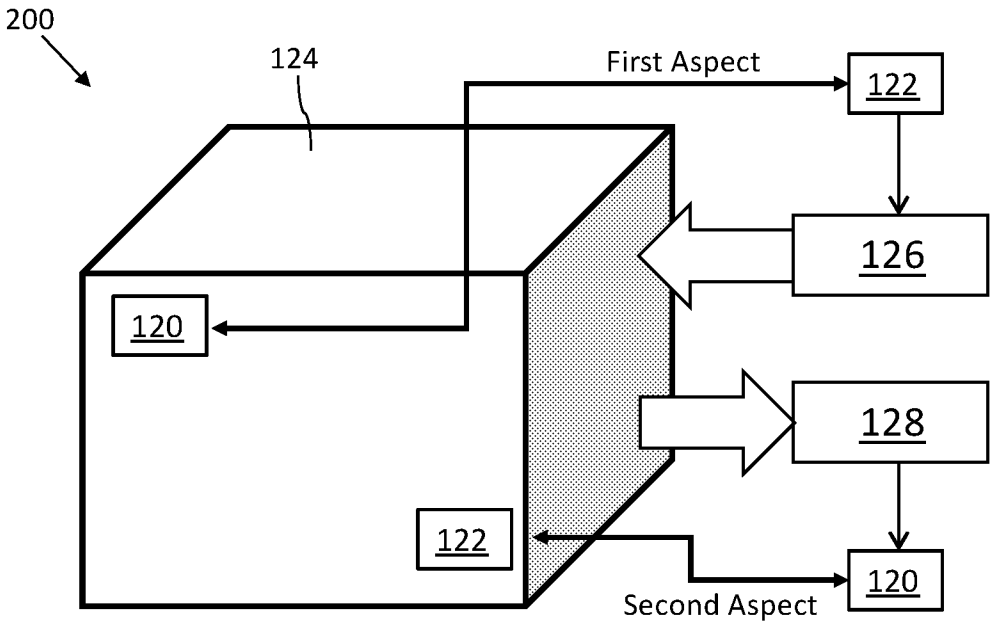
FIG. 1C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120
Second Aspect

FIG. 2C

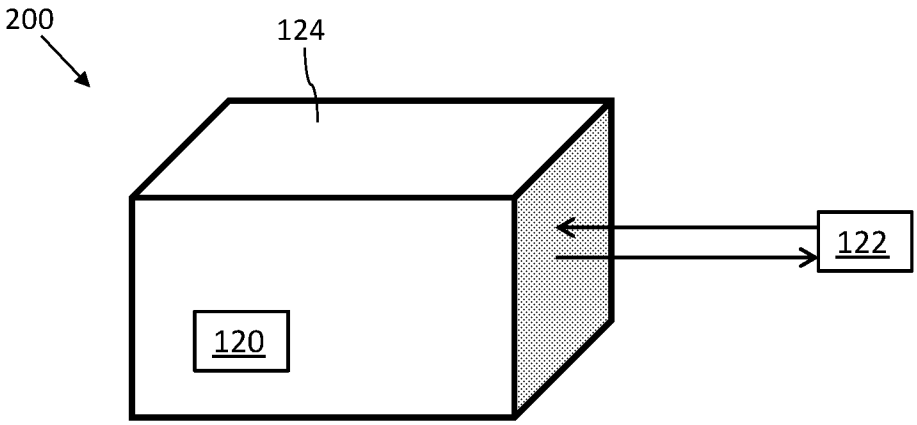

FIG. 2D

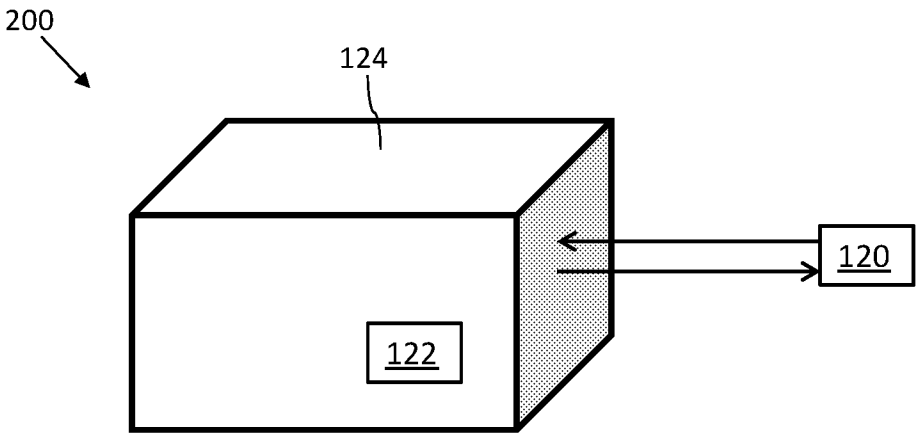

FIG. 2E

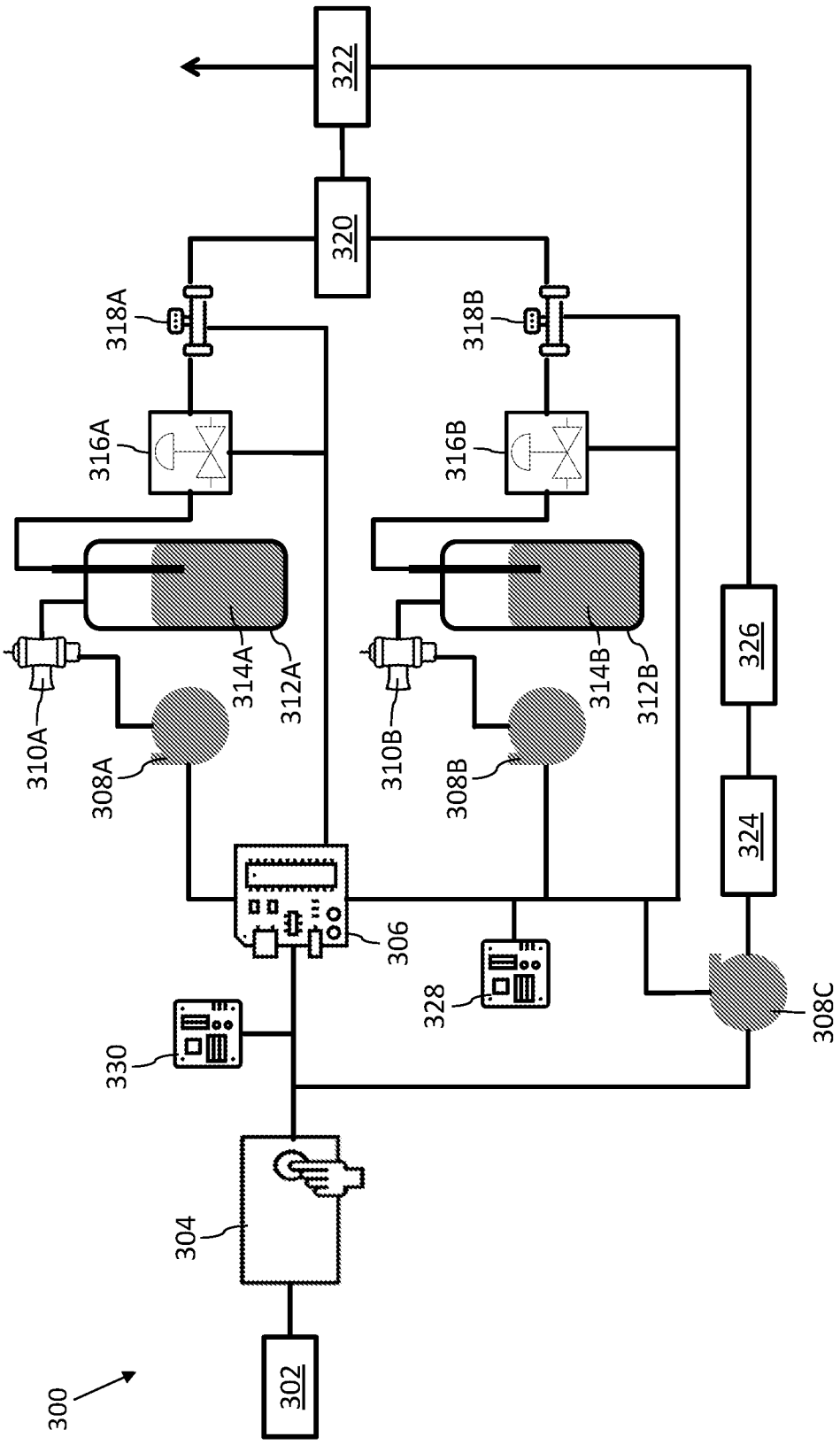
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FIG. 3

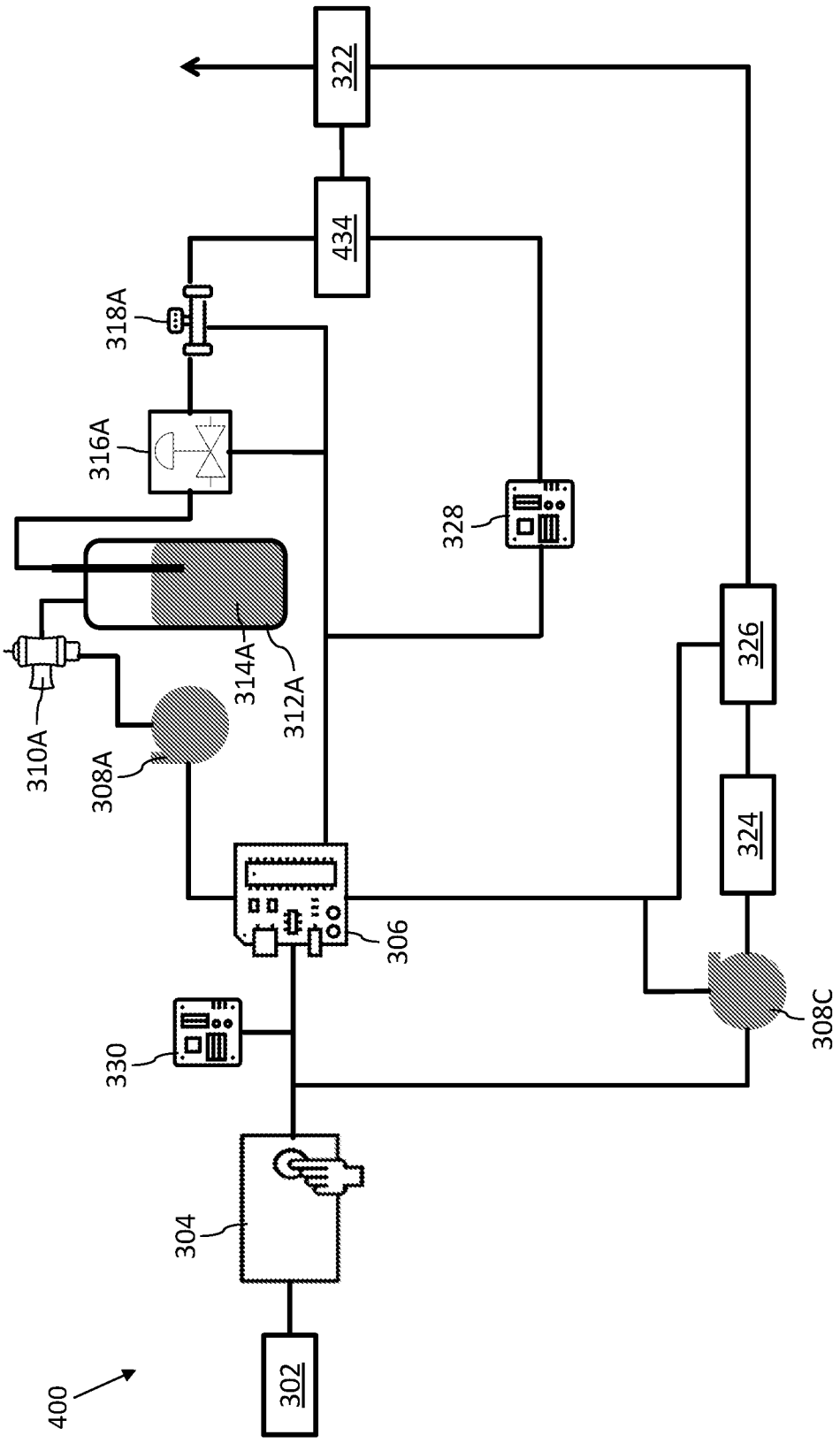
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FIG. 4

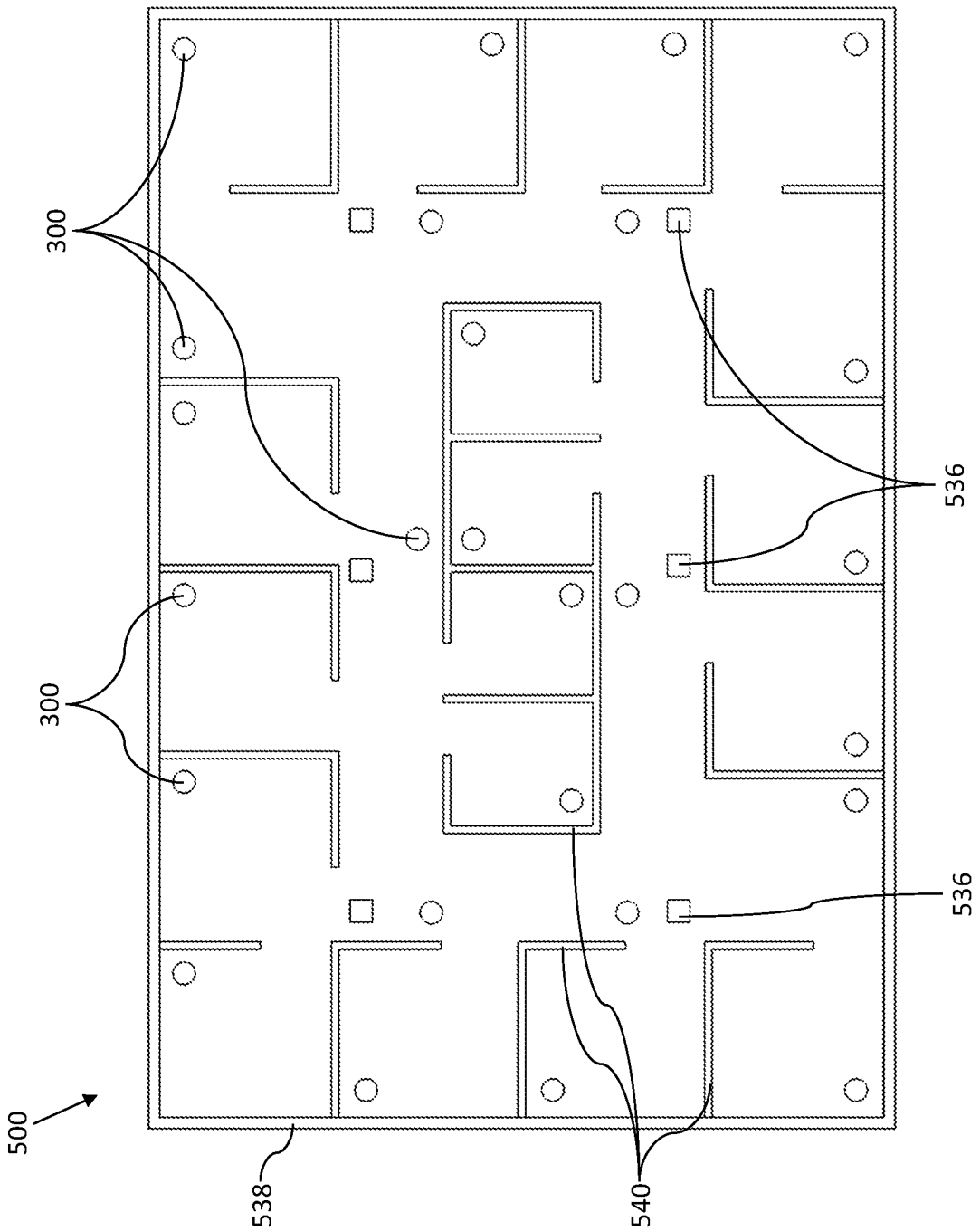

FIG. 5

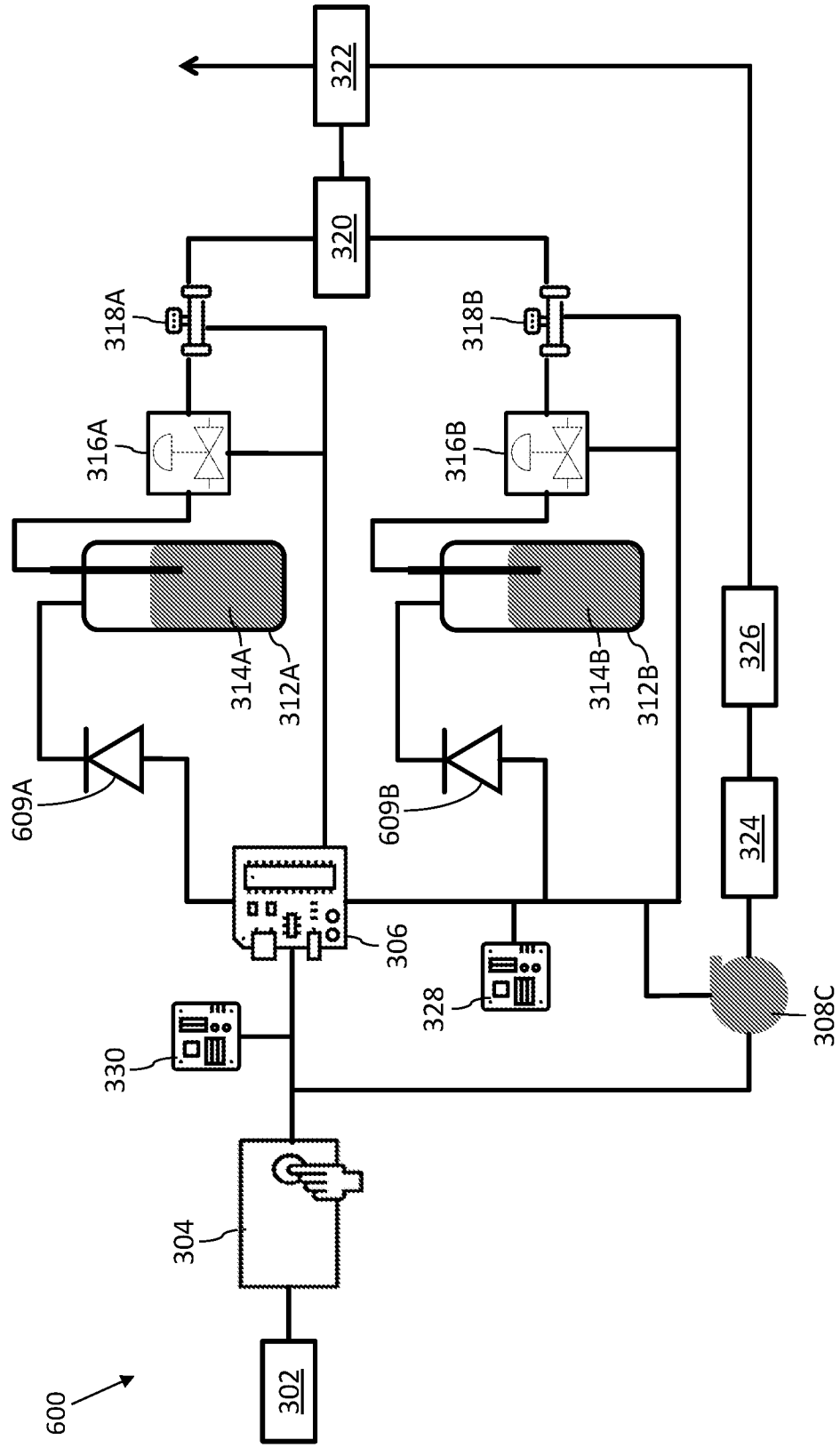
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FIG. 6

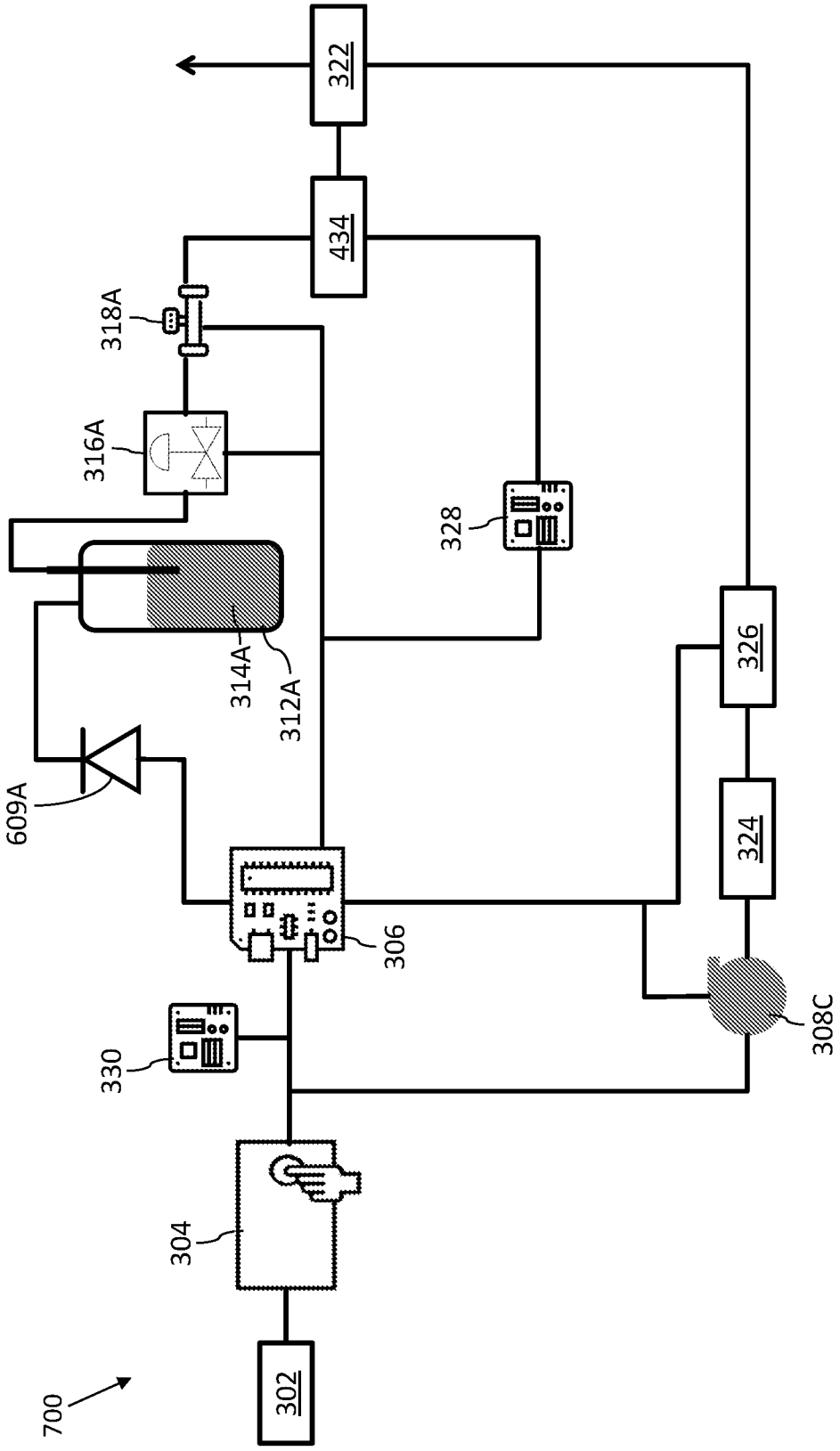
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FIG. 7

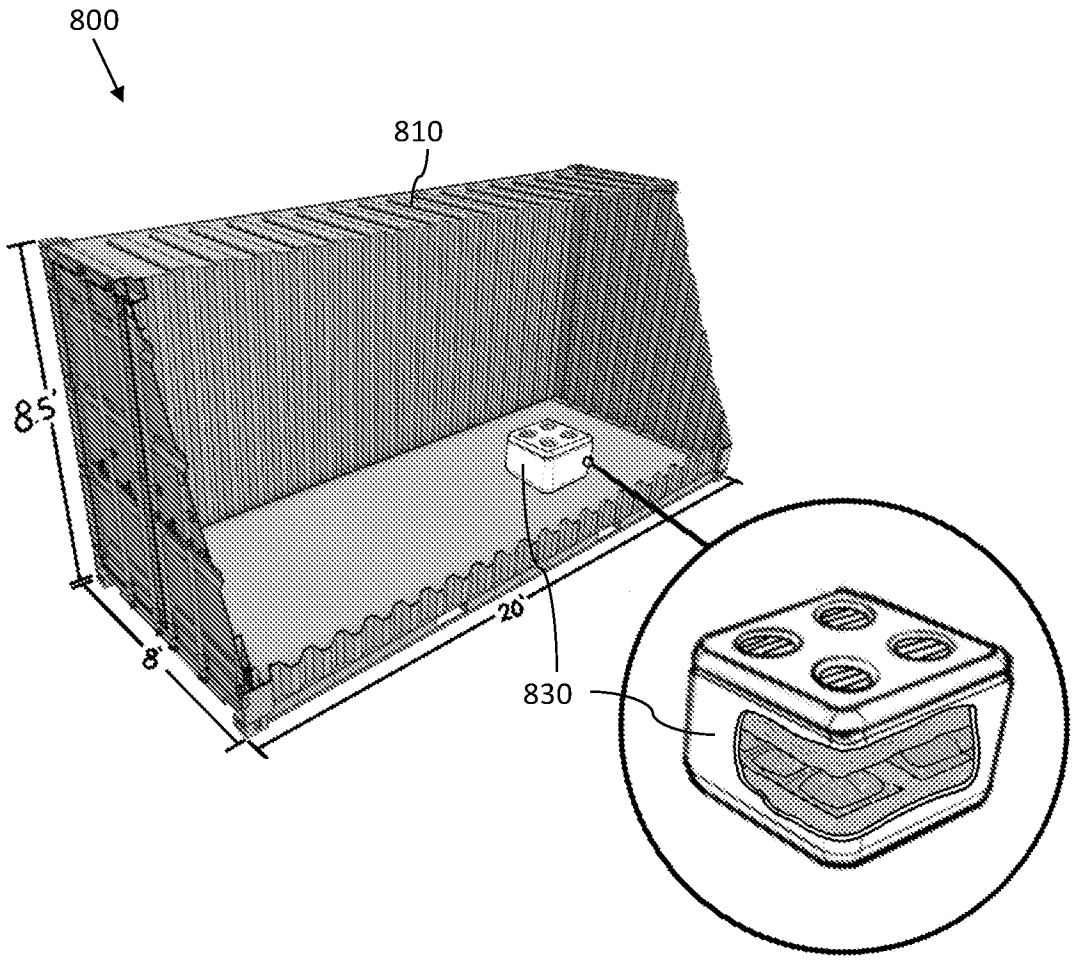

FIG. 8

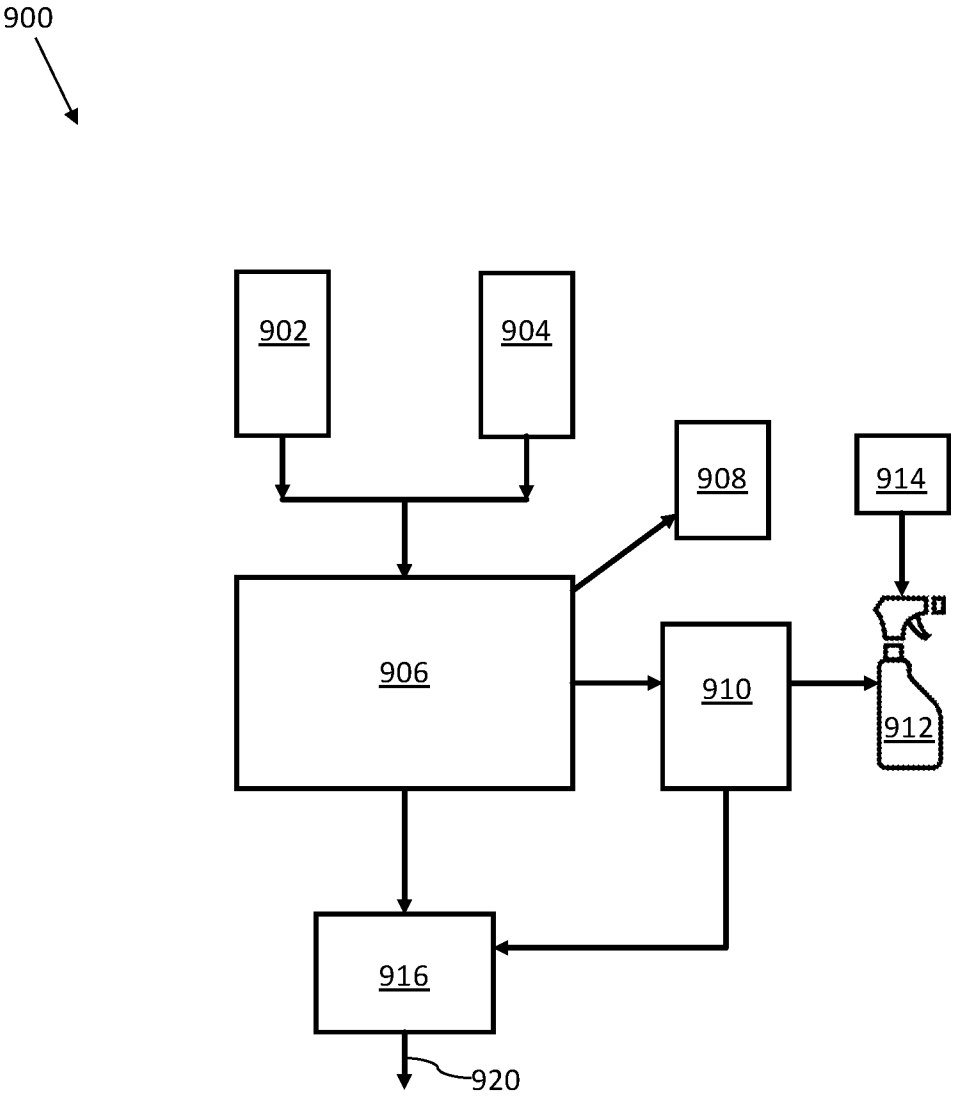

FIG. 9

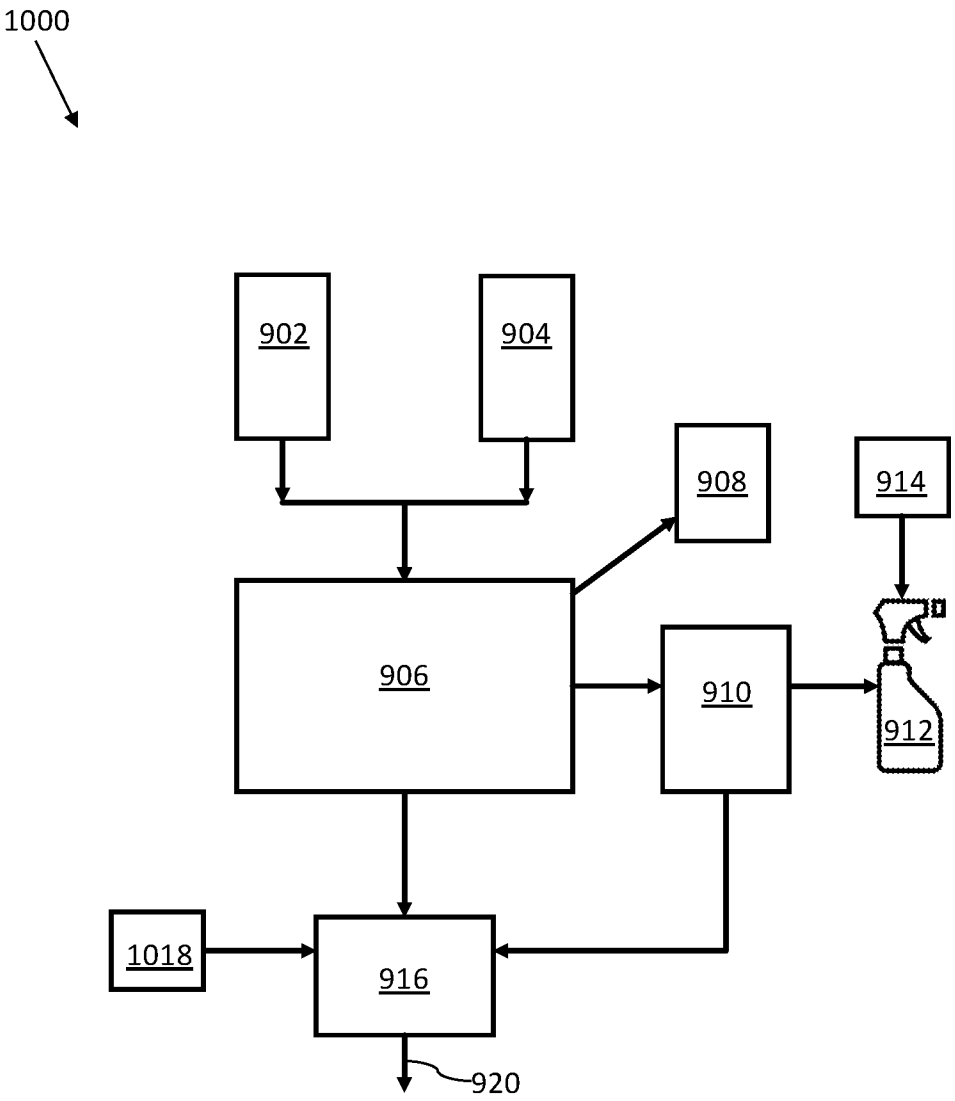

FIG. 10

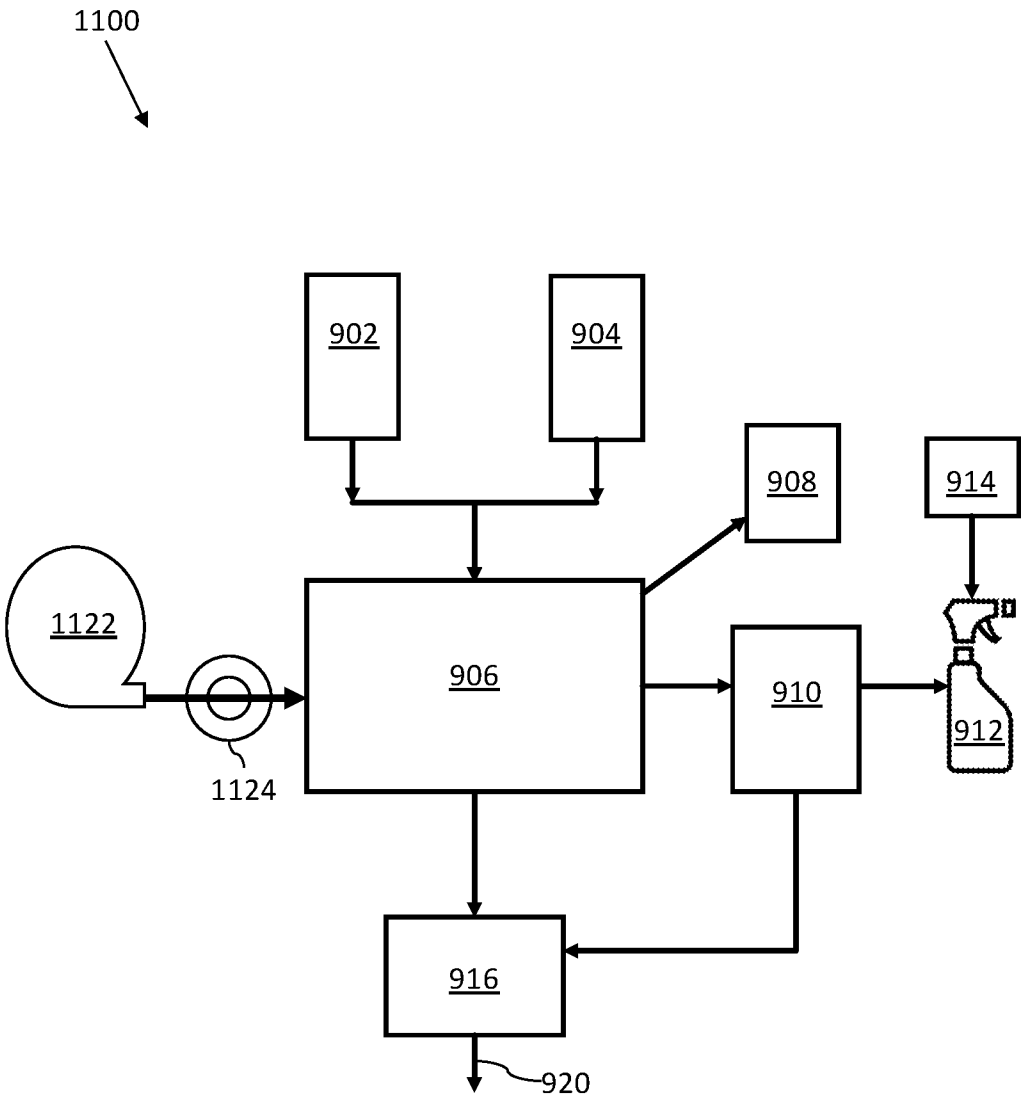

FIG. 11

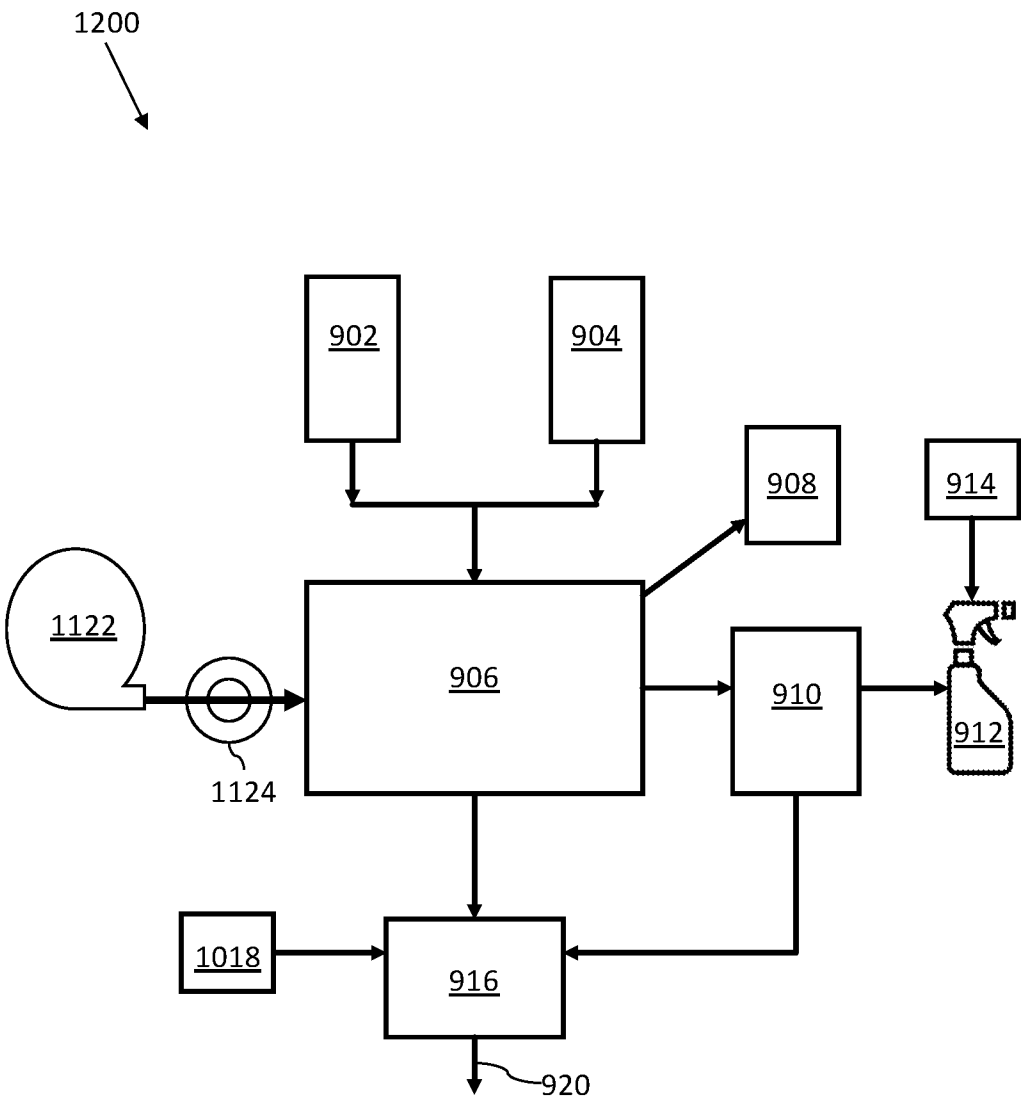

FIG. 12

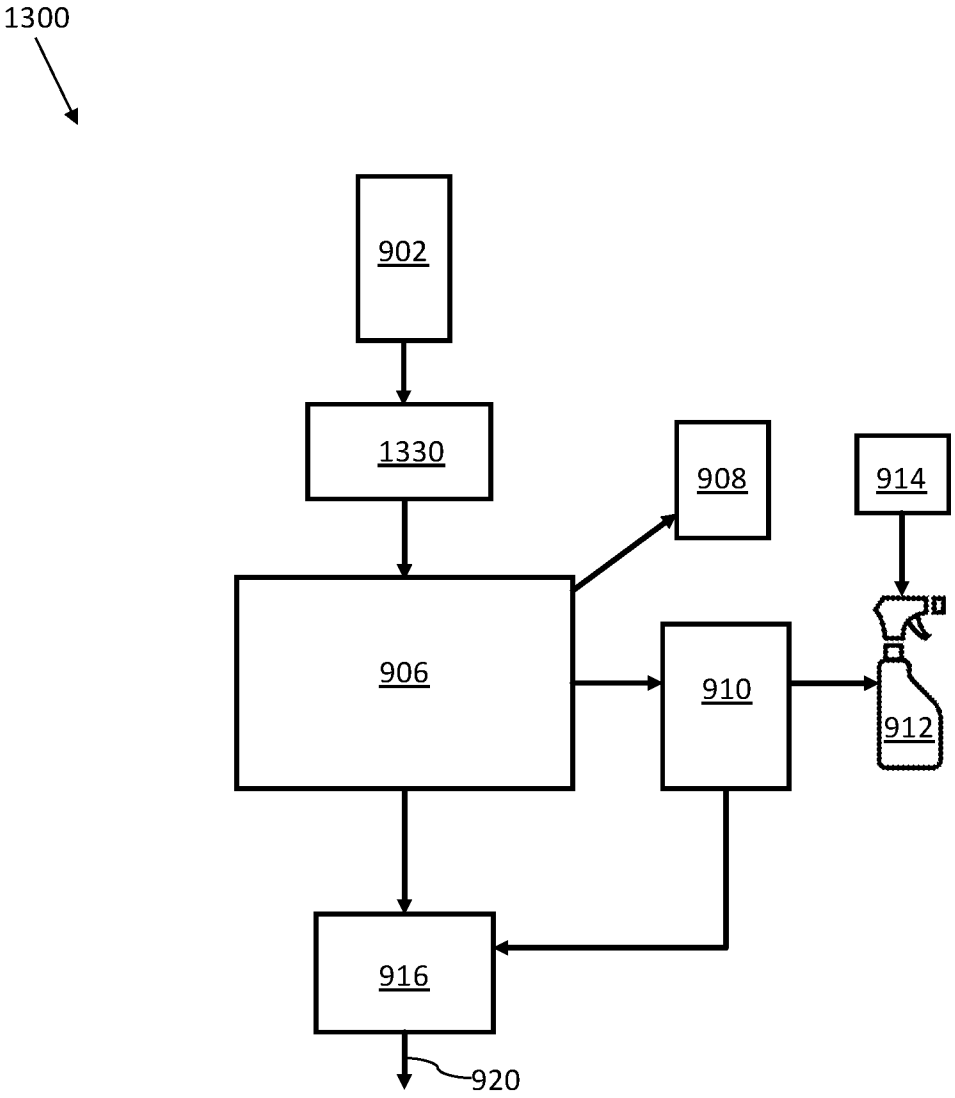

FIG. 13

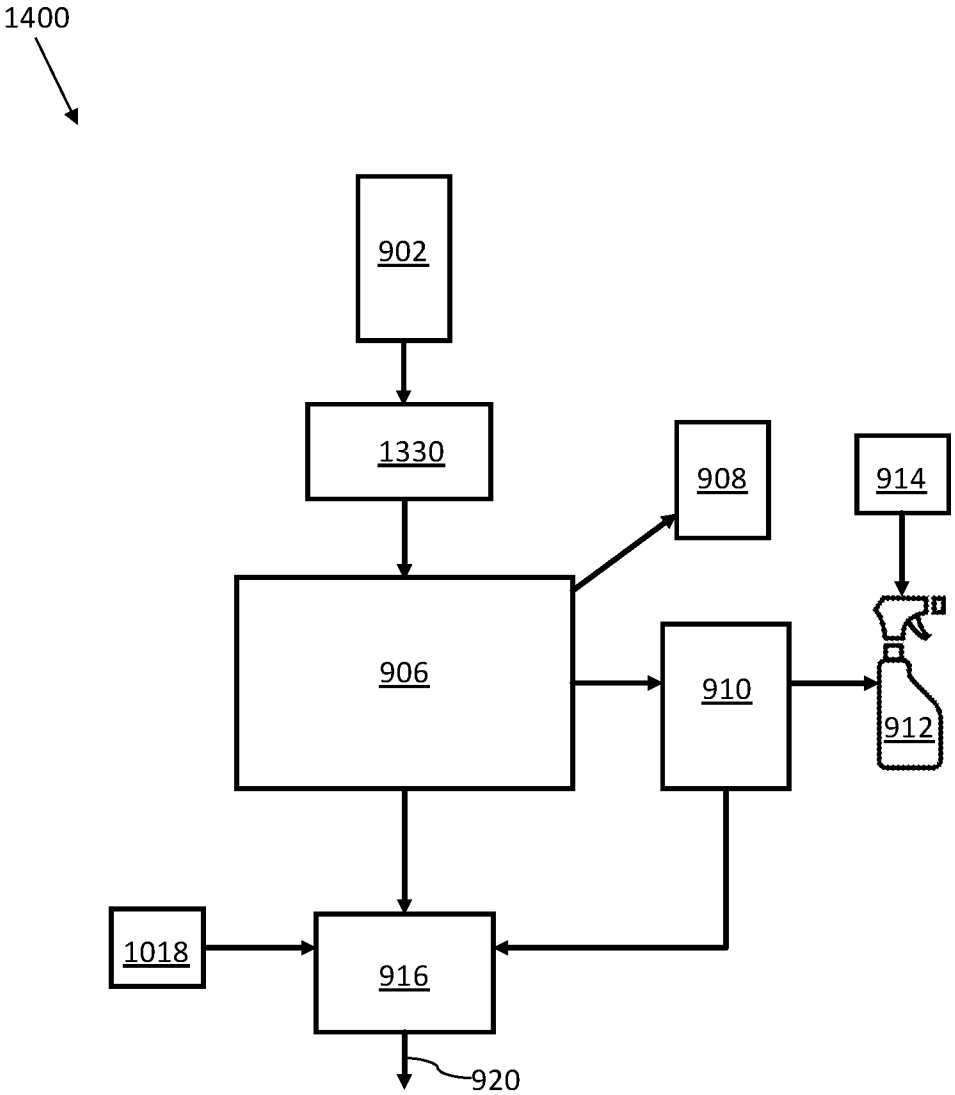

FIG. 14

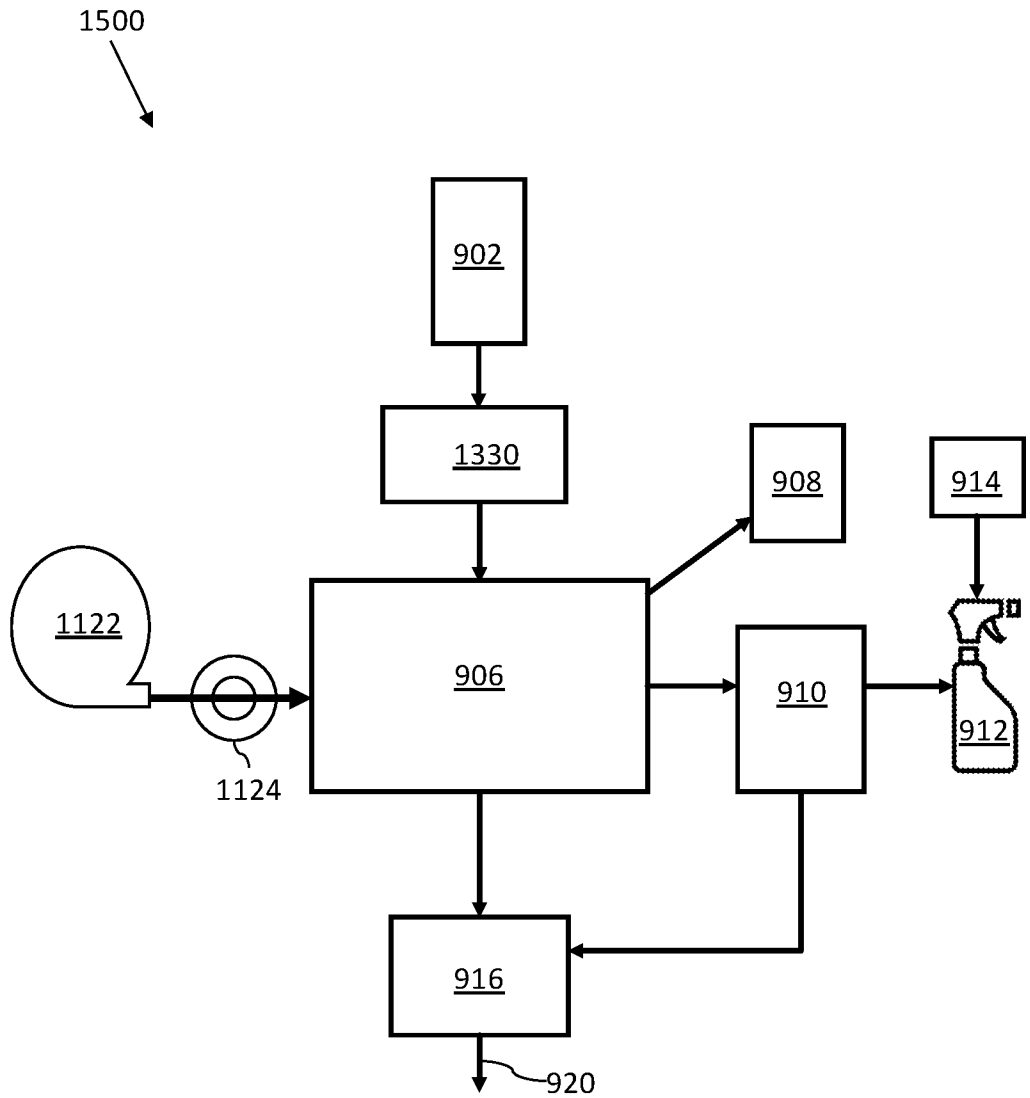

FIG. 15

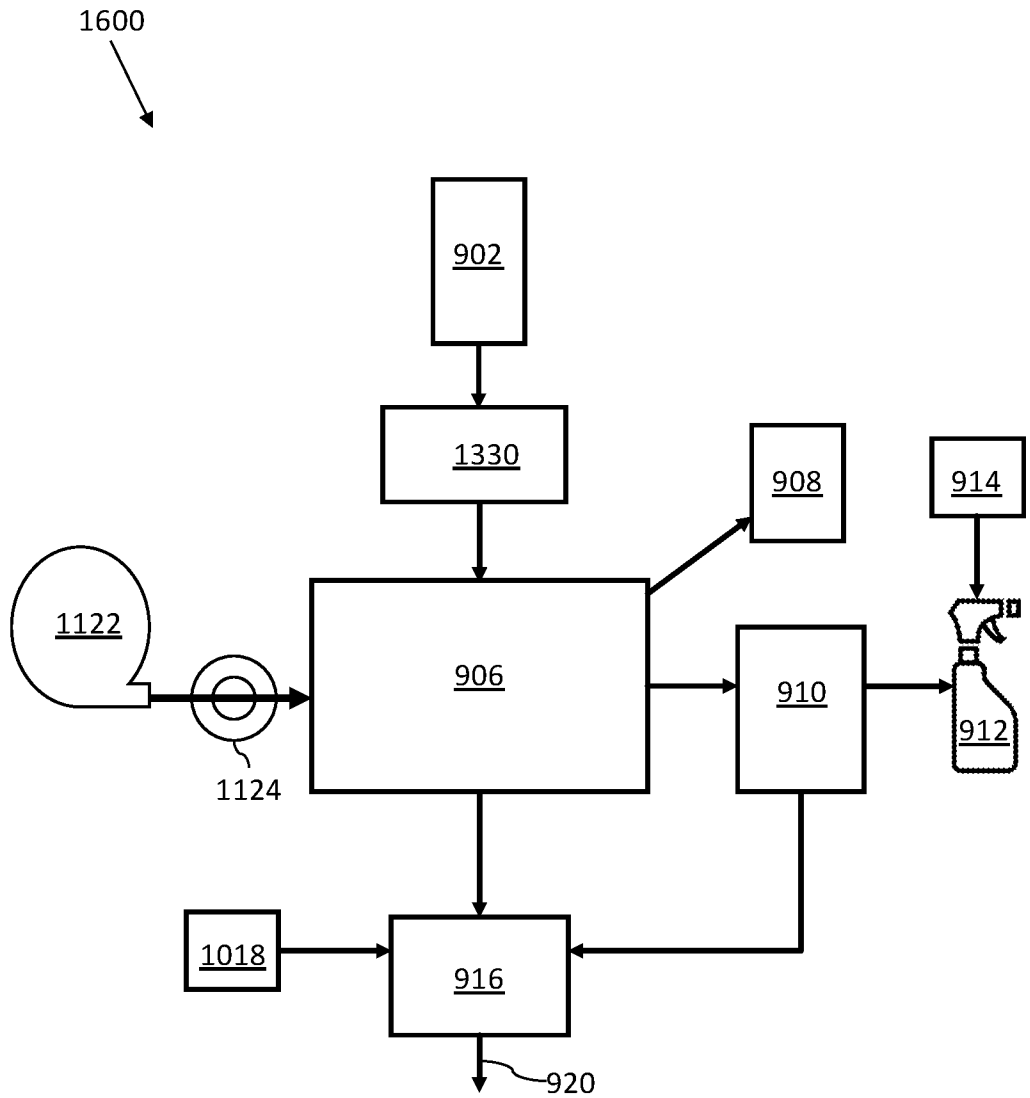

FIG. 16

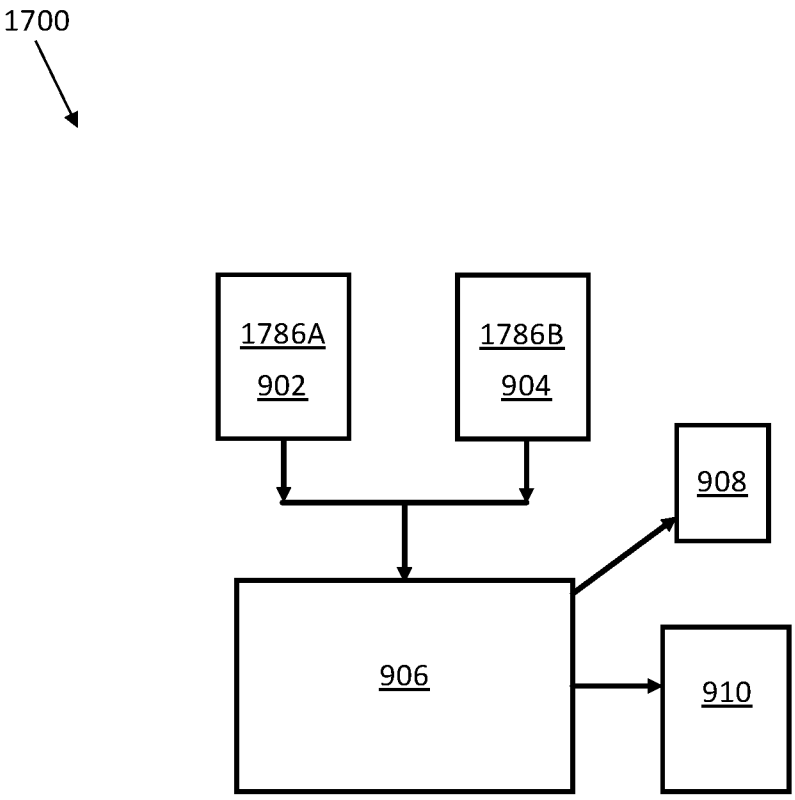

FIG. 17

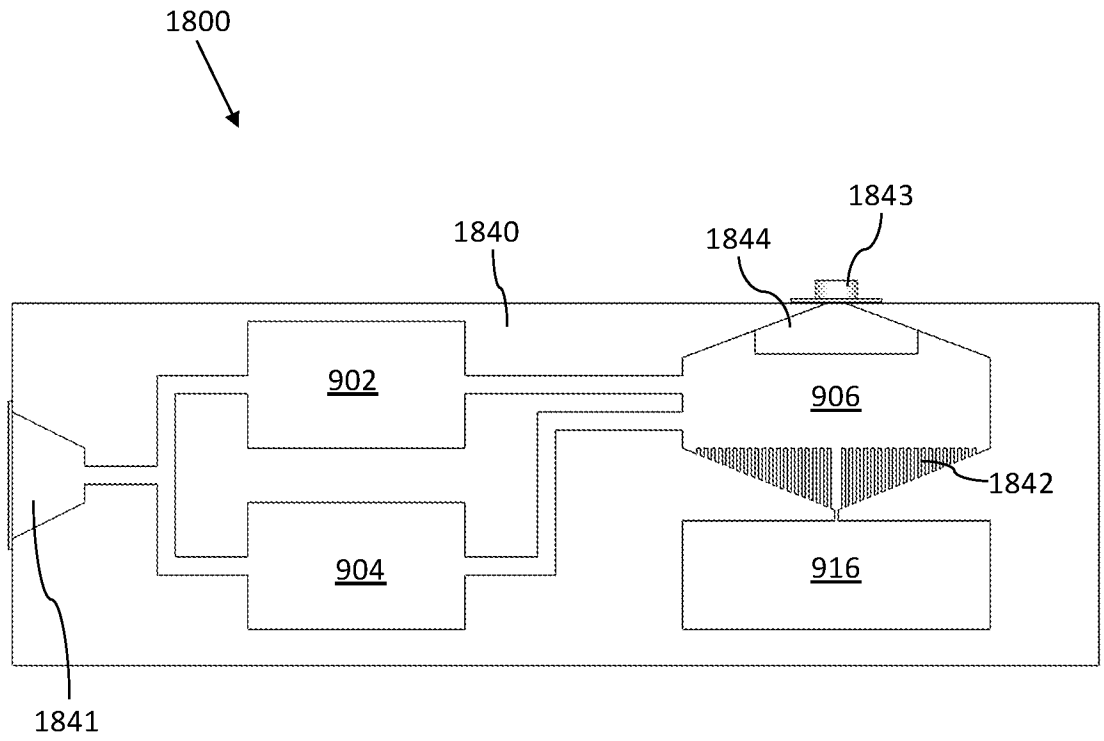

FIG. 18A

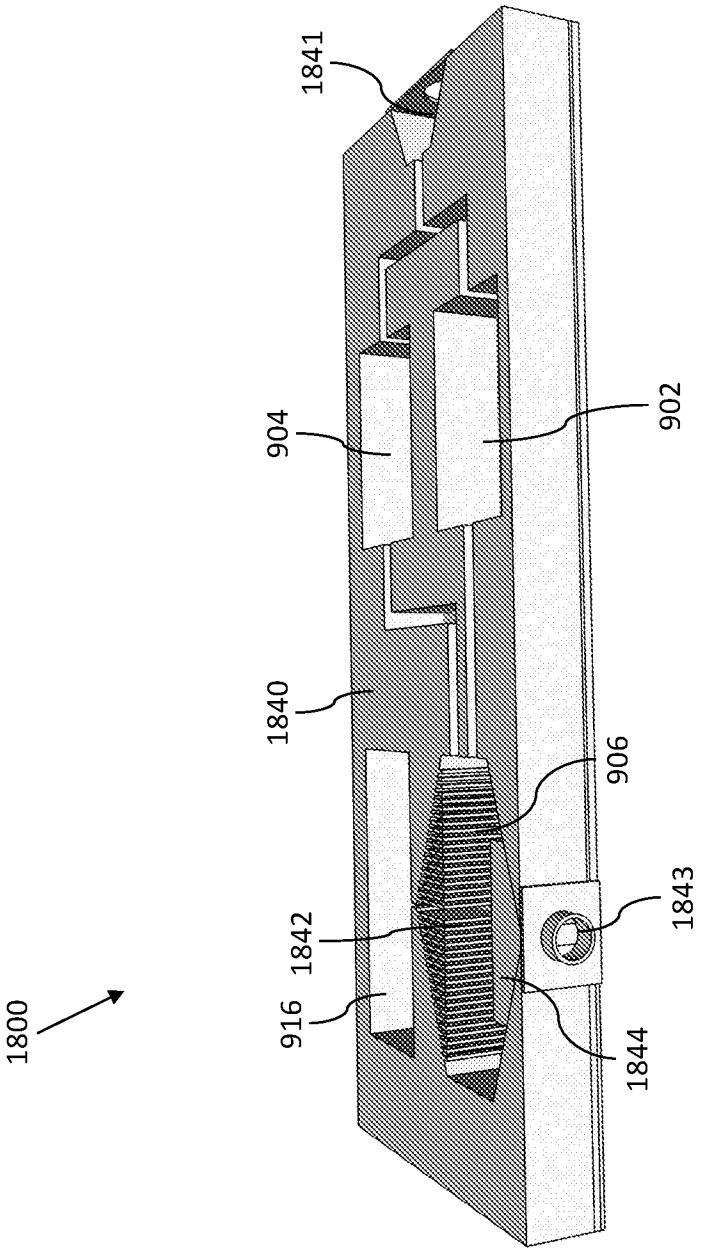

FIG. 18B

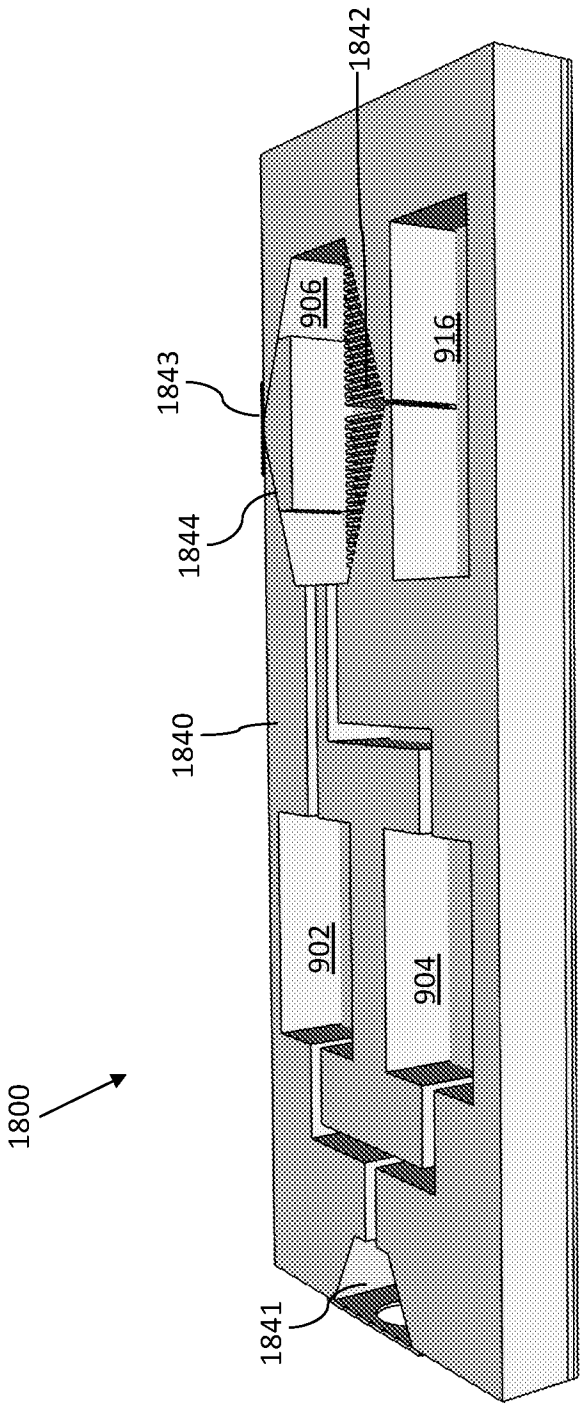

FIG. 18C

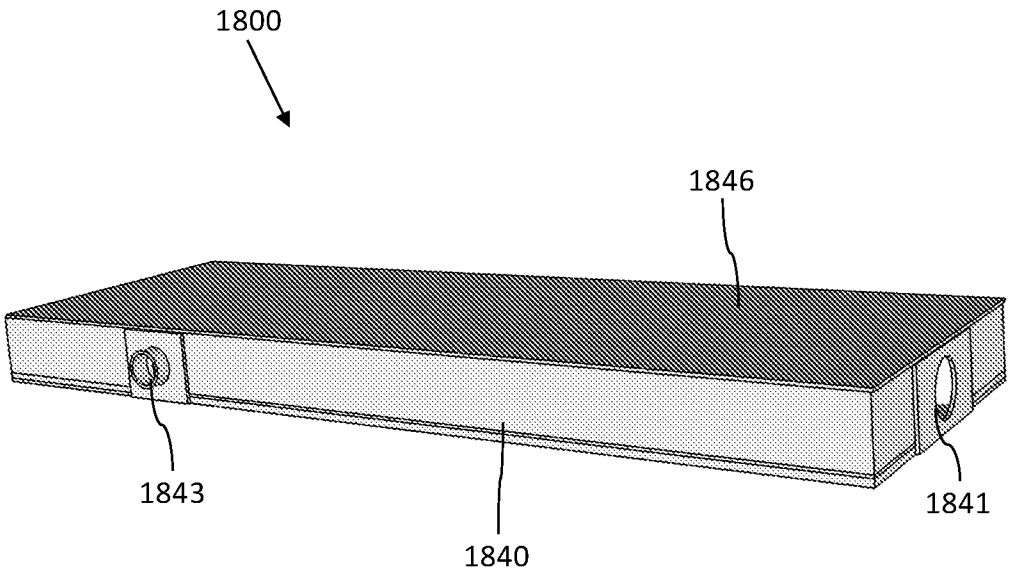

FIG. 18D

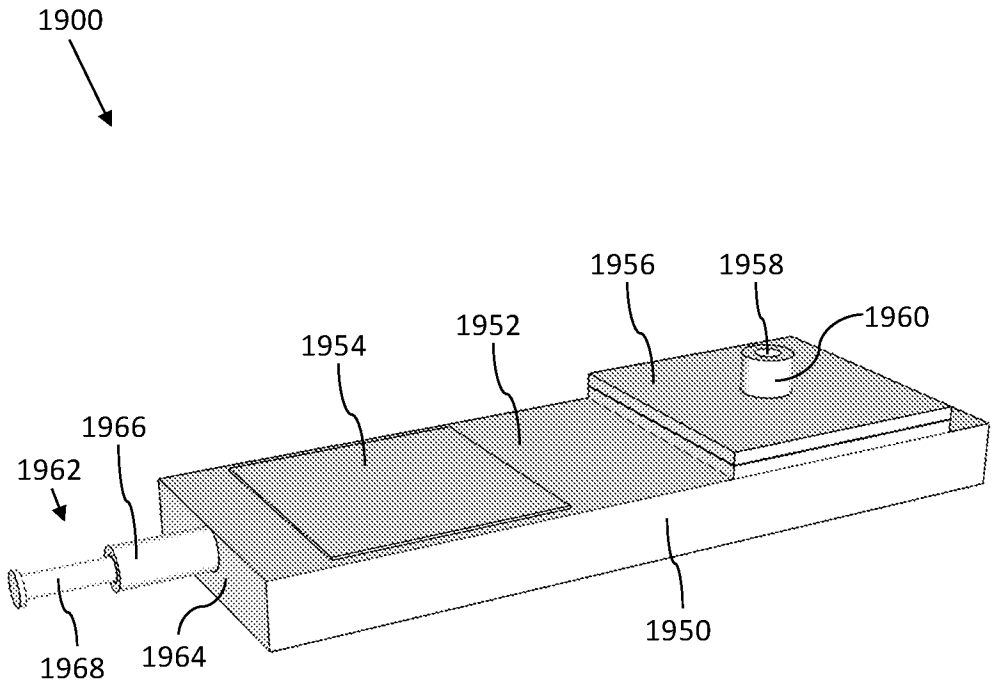

FIG. 19A

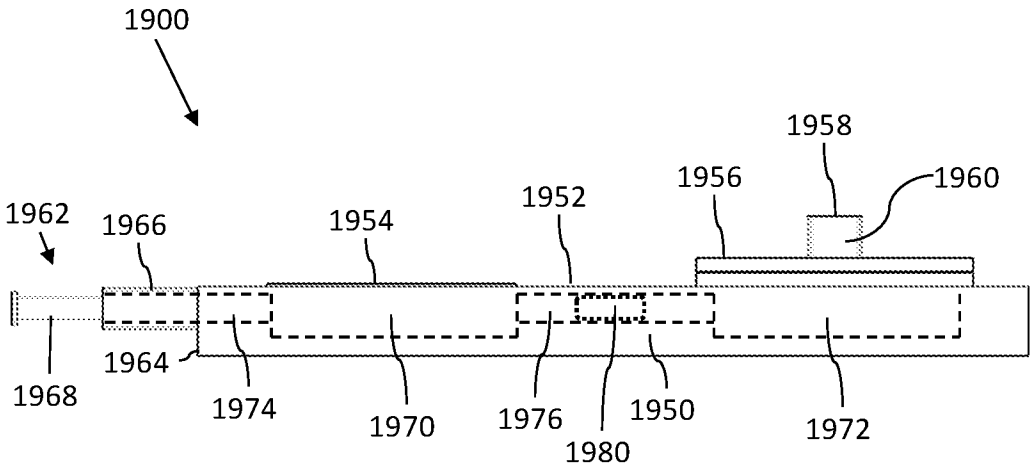

FIG. 19B

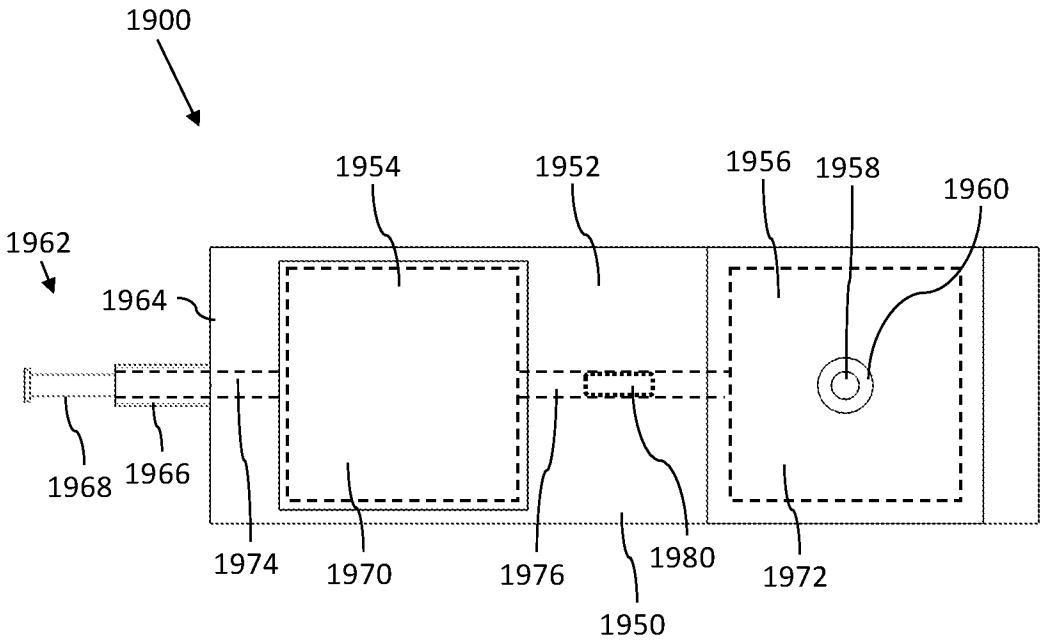

FIG. 19C

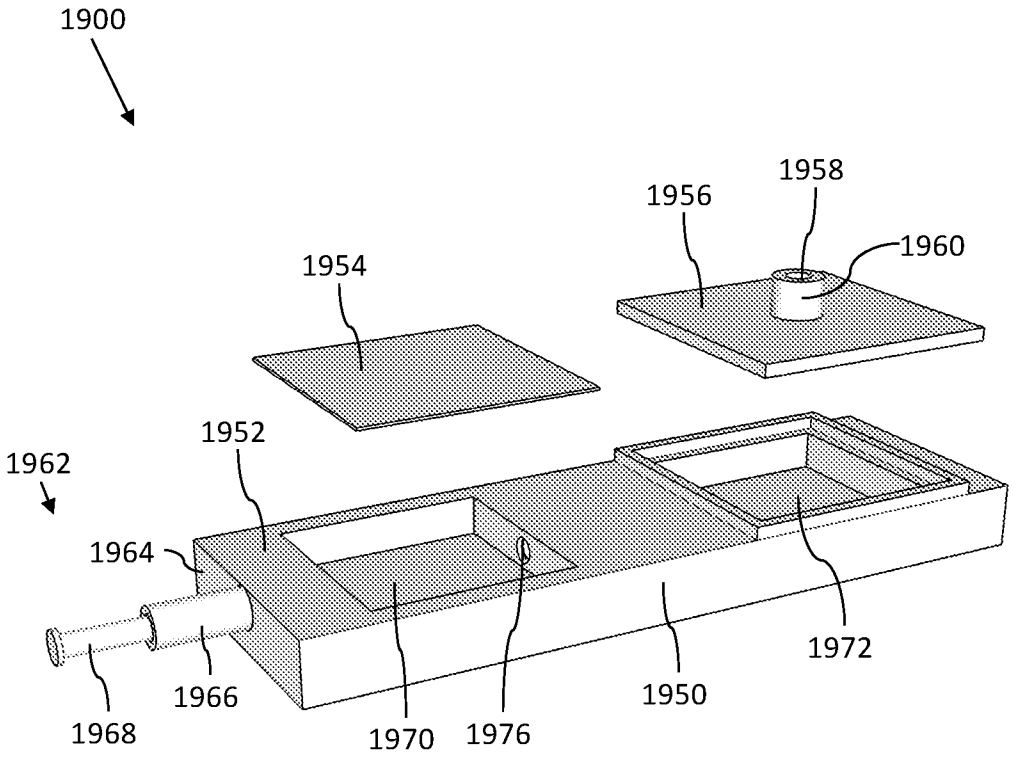
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FIG. 19D

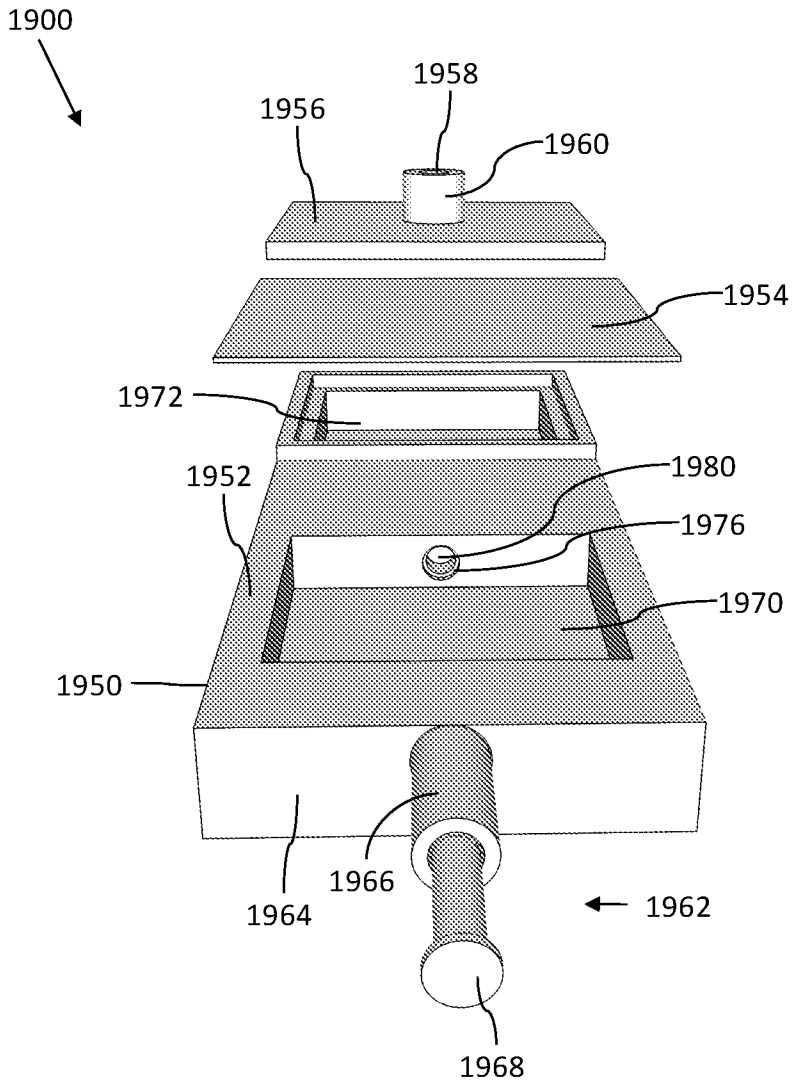
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FIG. 19E

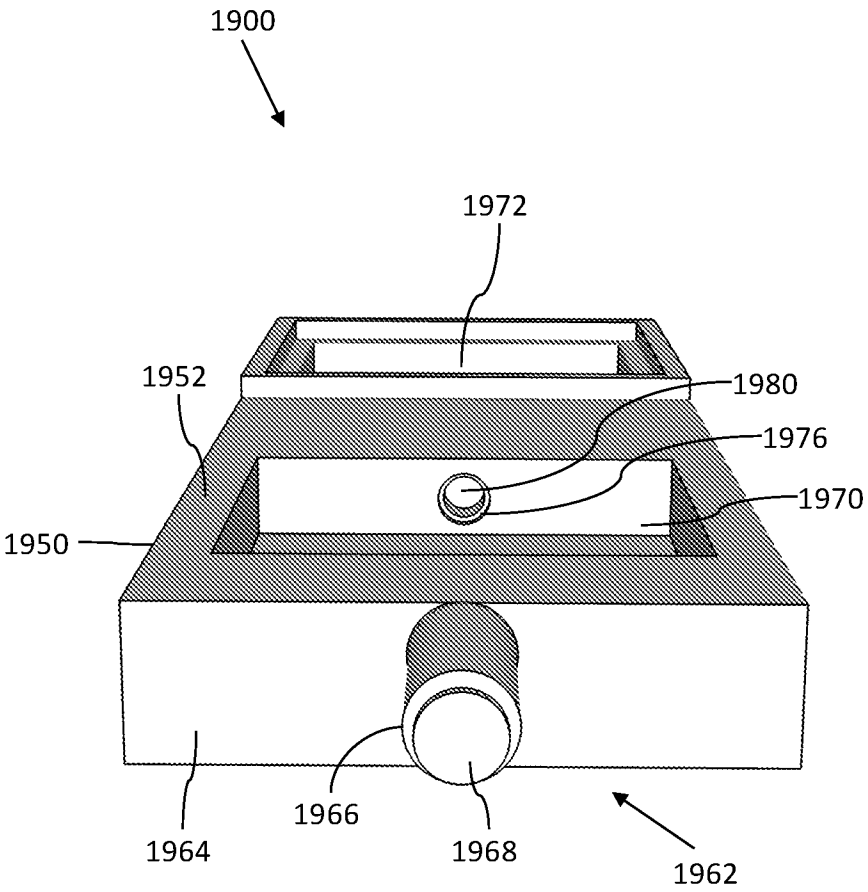

FIG. 19F

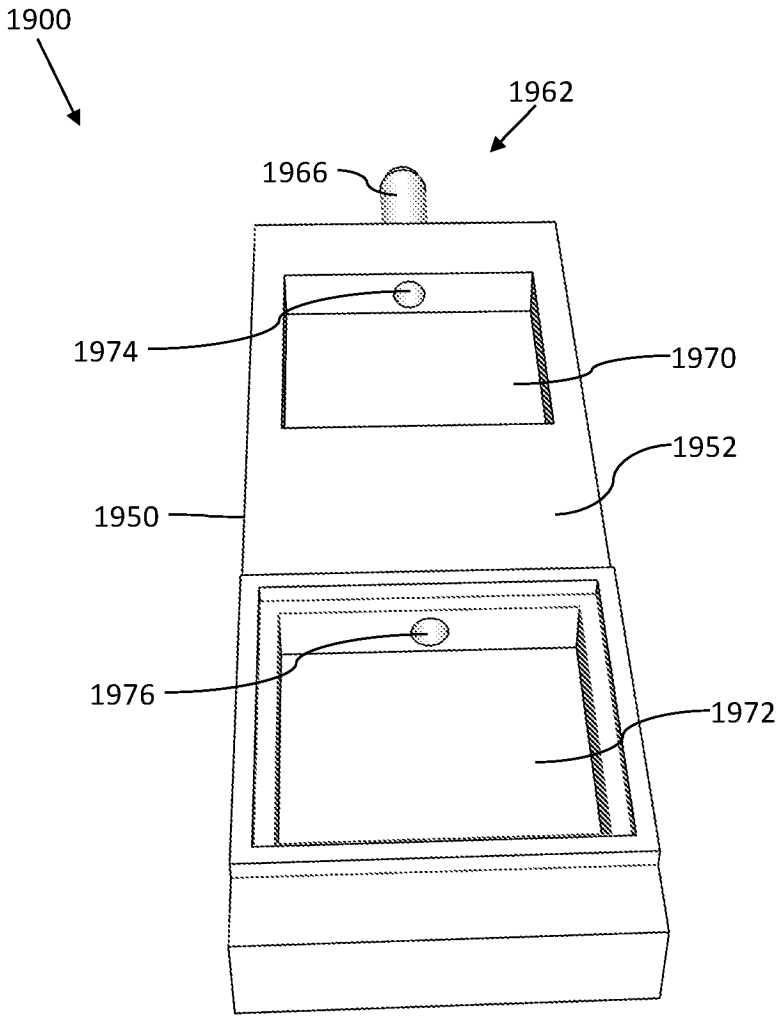

FIG. 19G

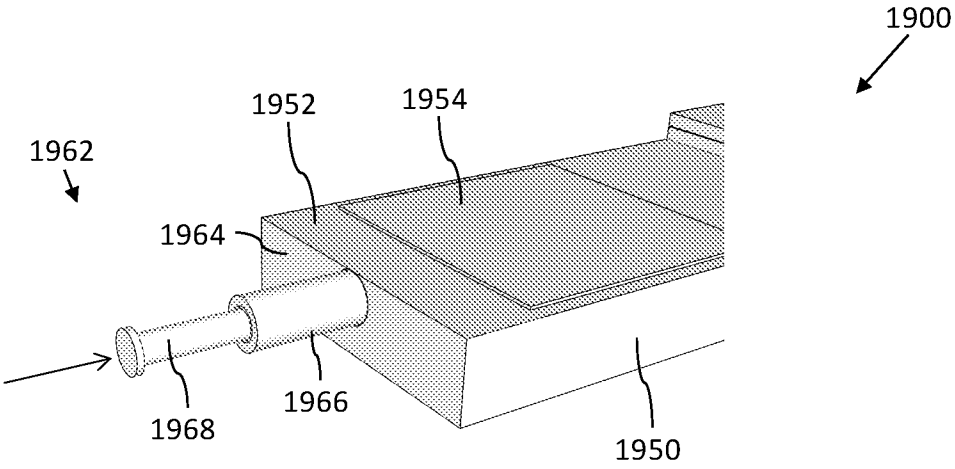

FIG. 19H

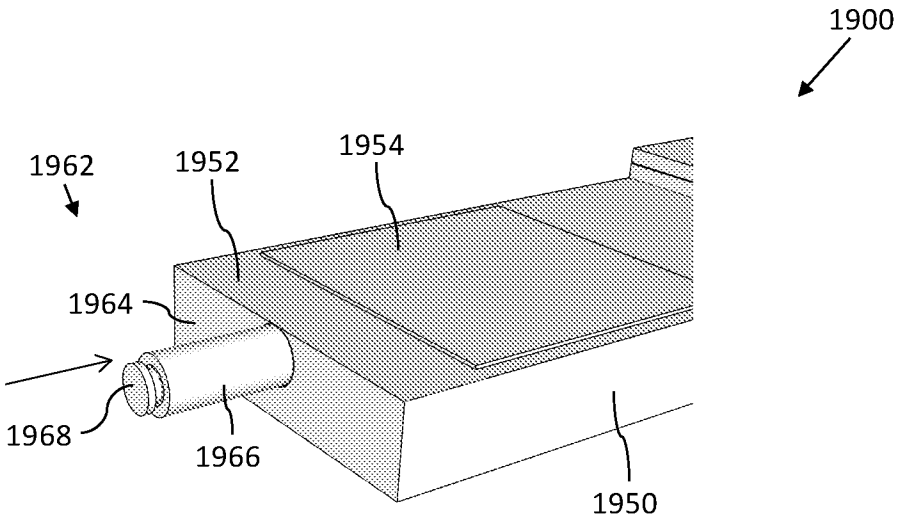

FIG. 19I

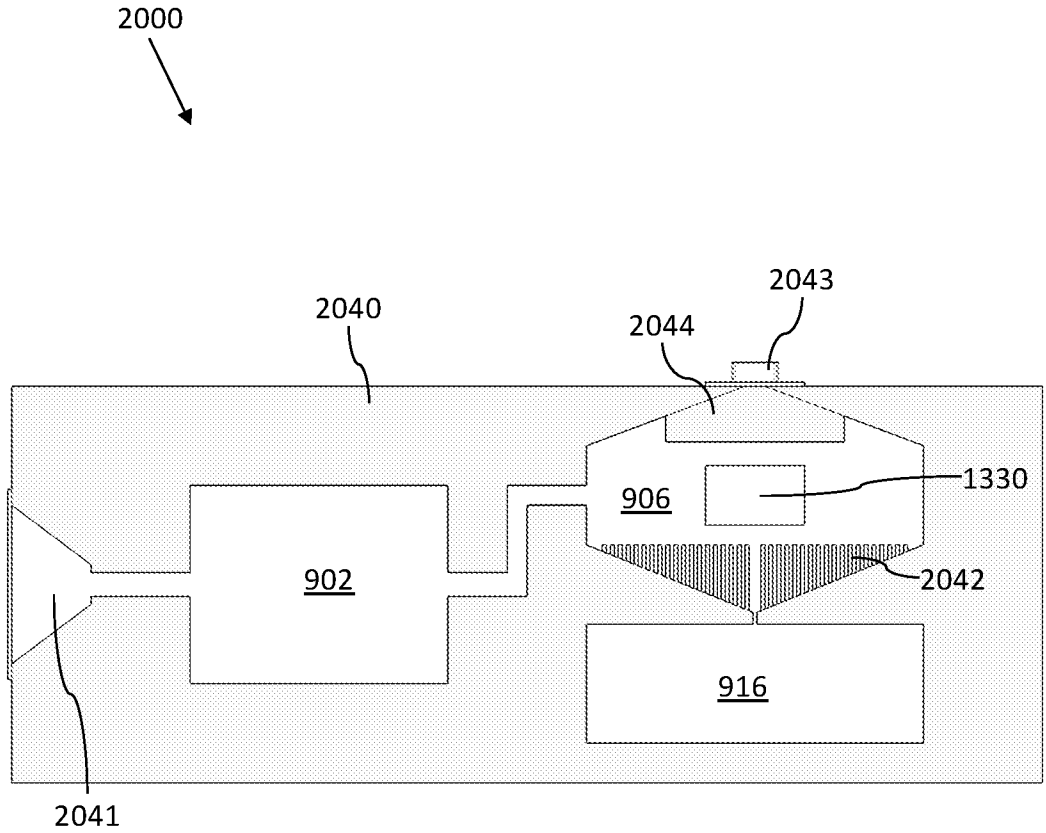

FIG. 20A

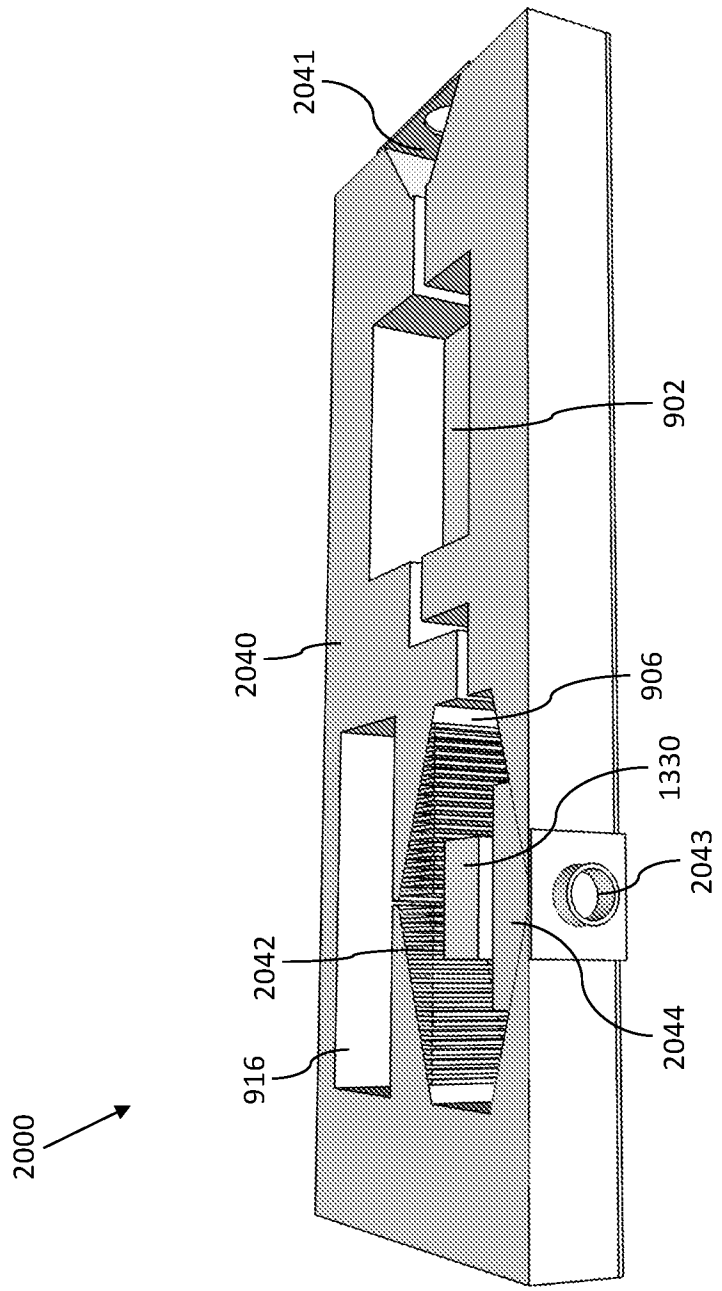

FIG. 20B

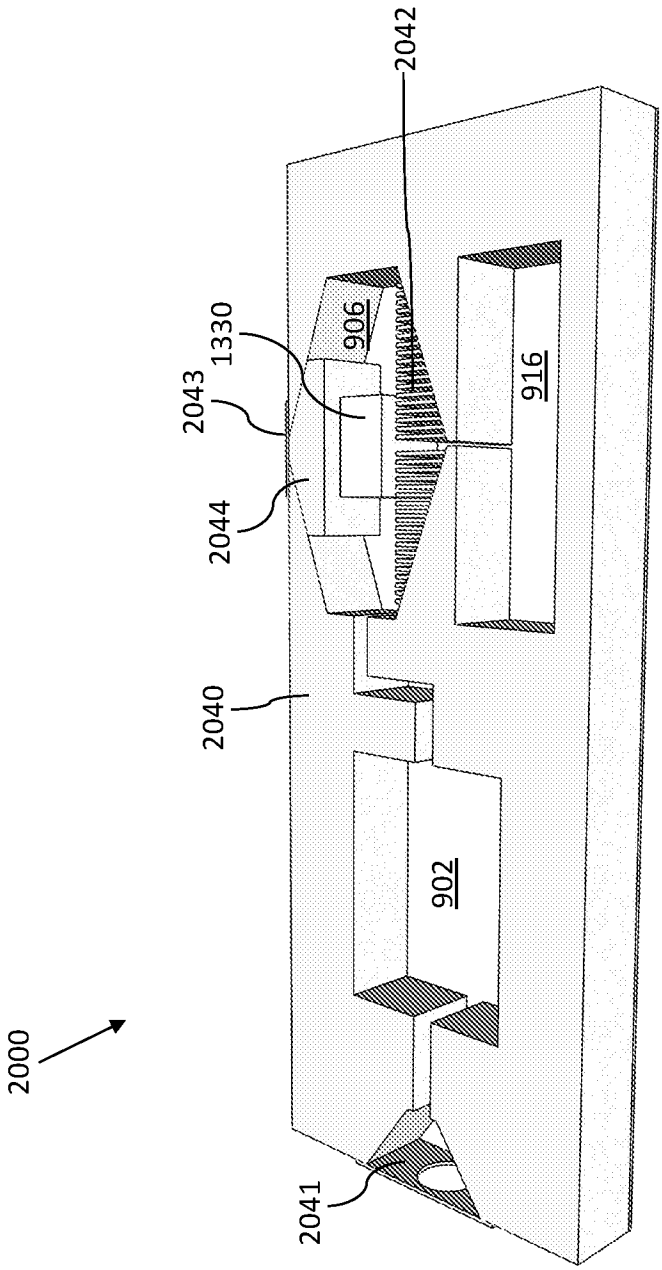

FIG. 20C

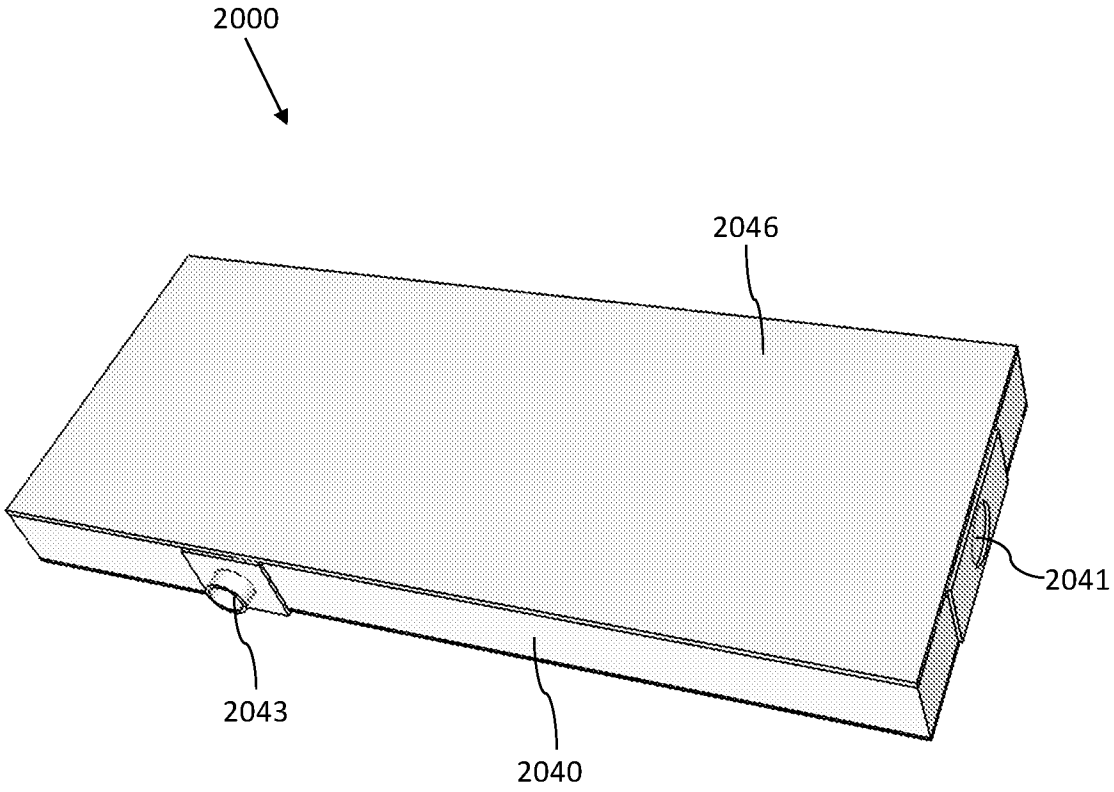

FIG. 20D

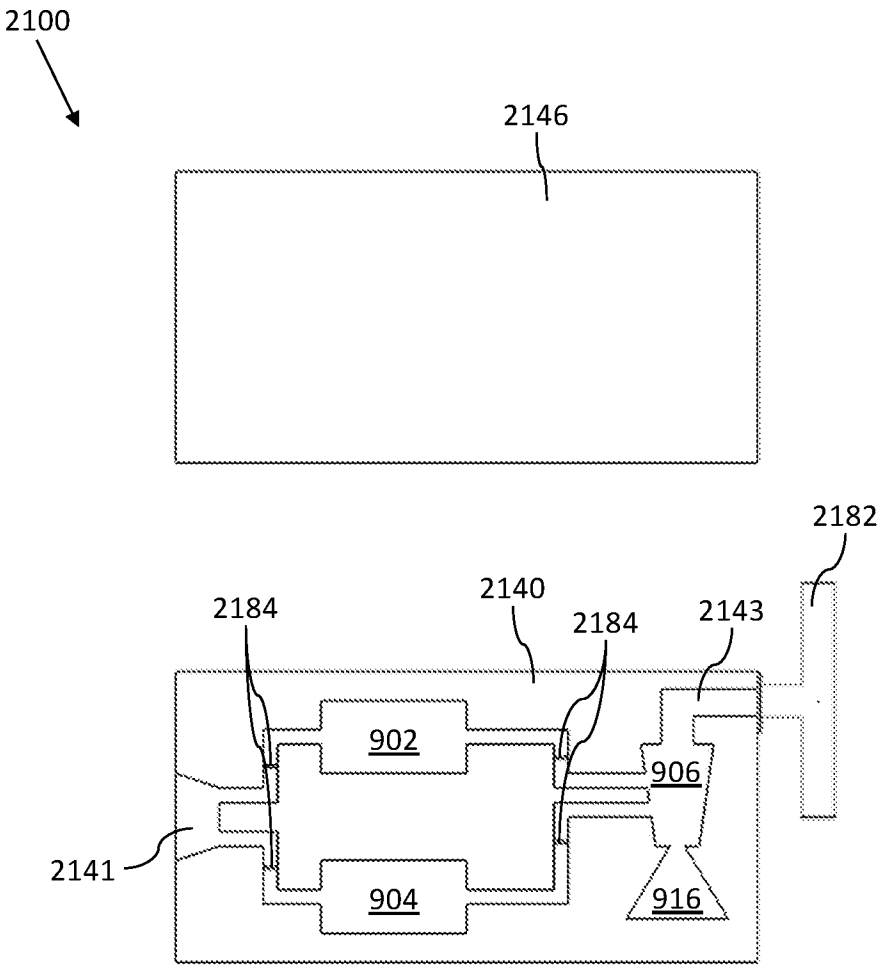

FIG. 21A

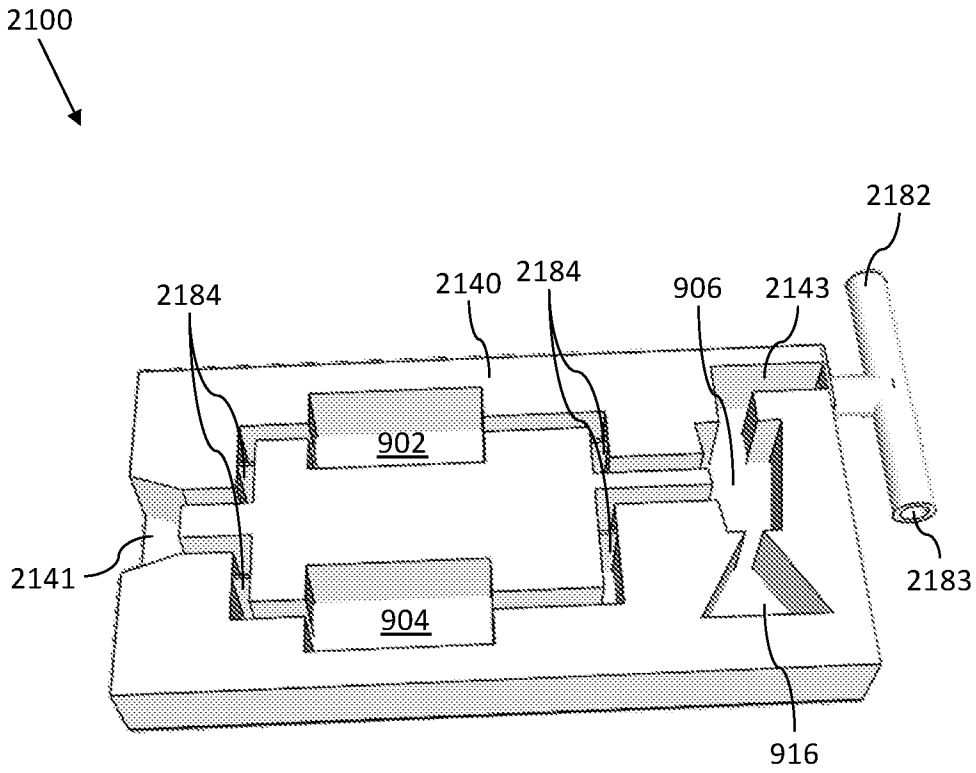

FIG. 21B

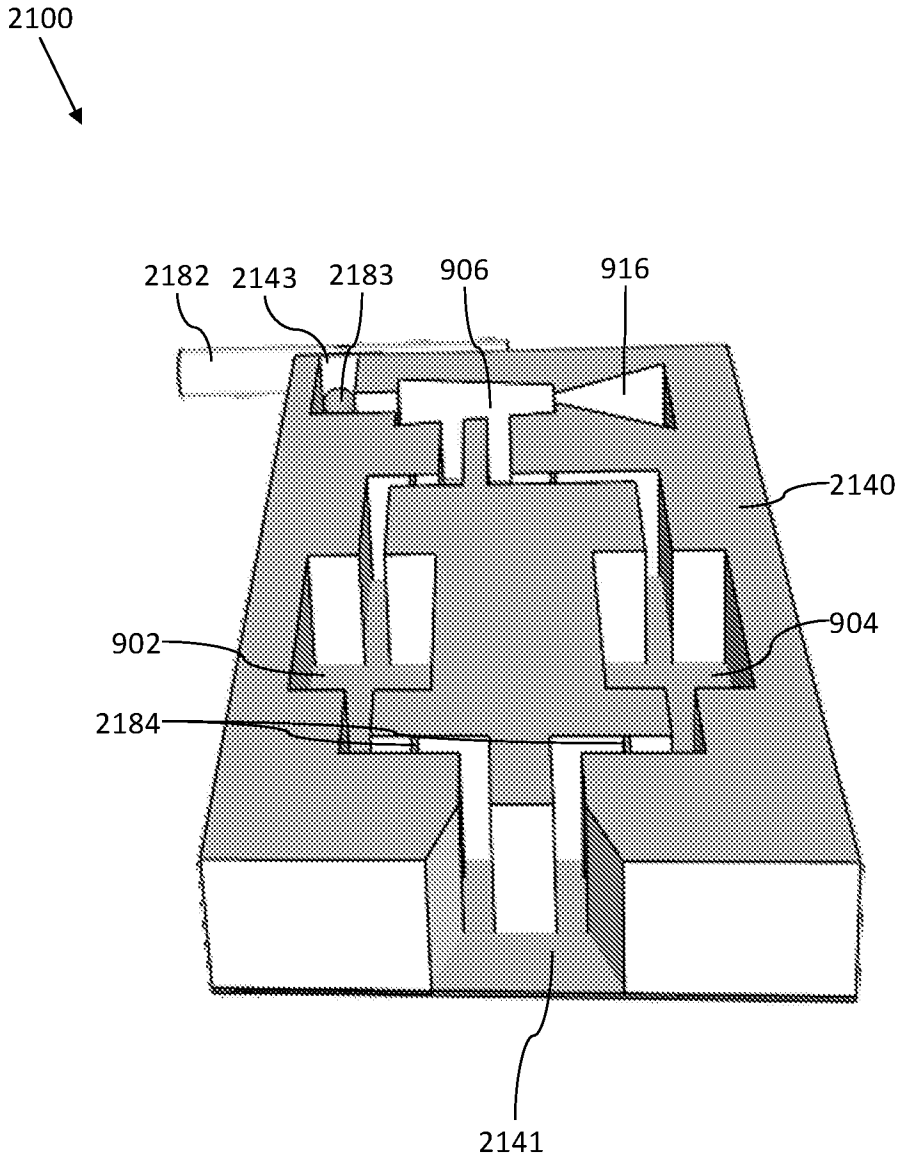

FIG. 21C

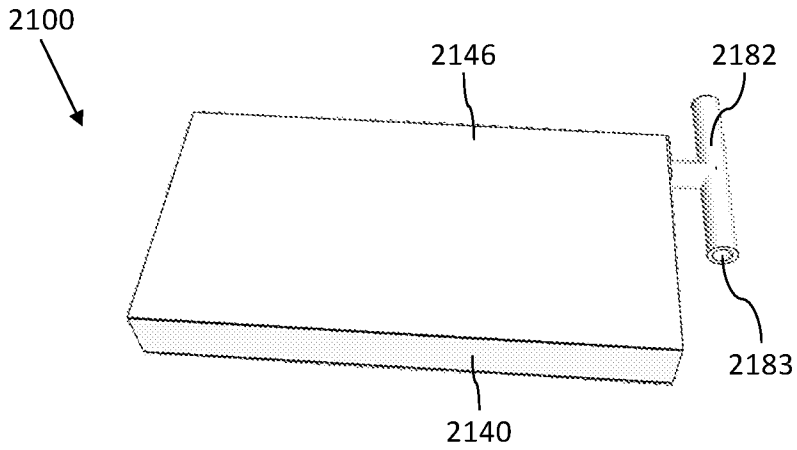

FIG. 21D

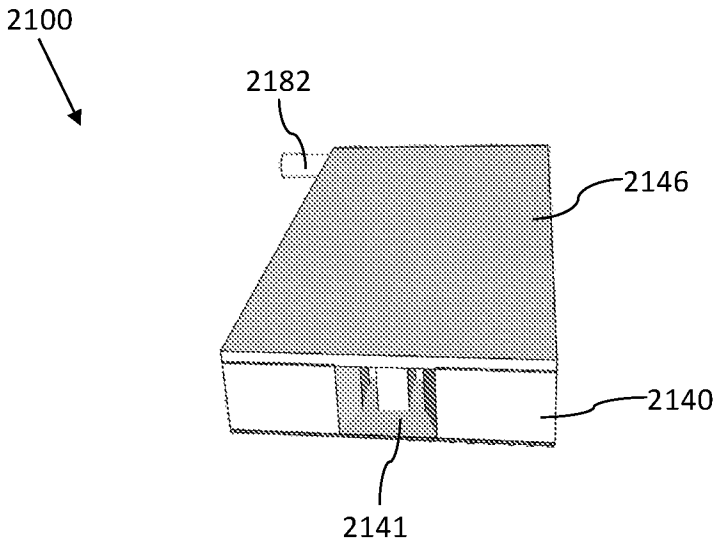

FIG. 21E

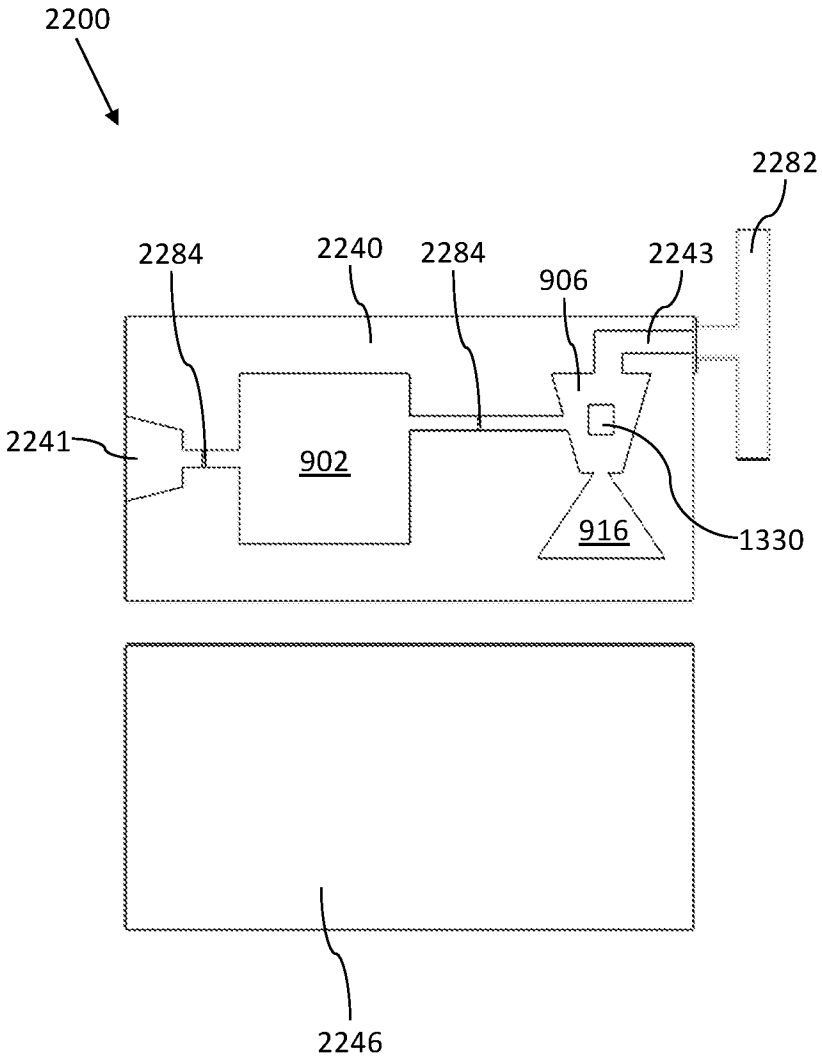

FIG. 22A

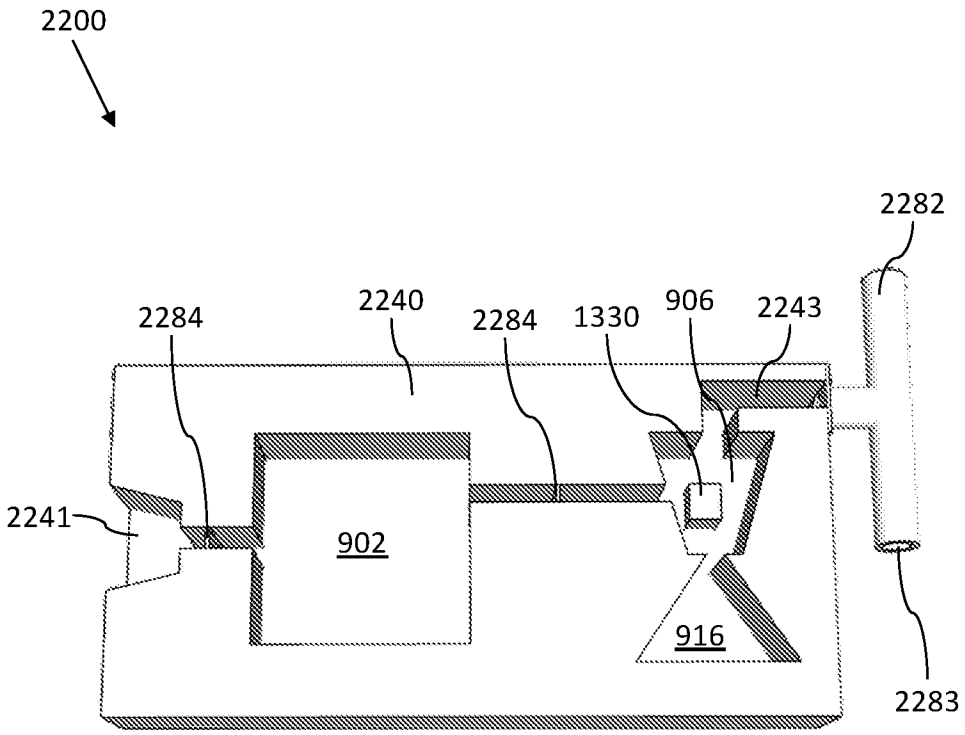

FIG. 22B

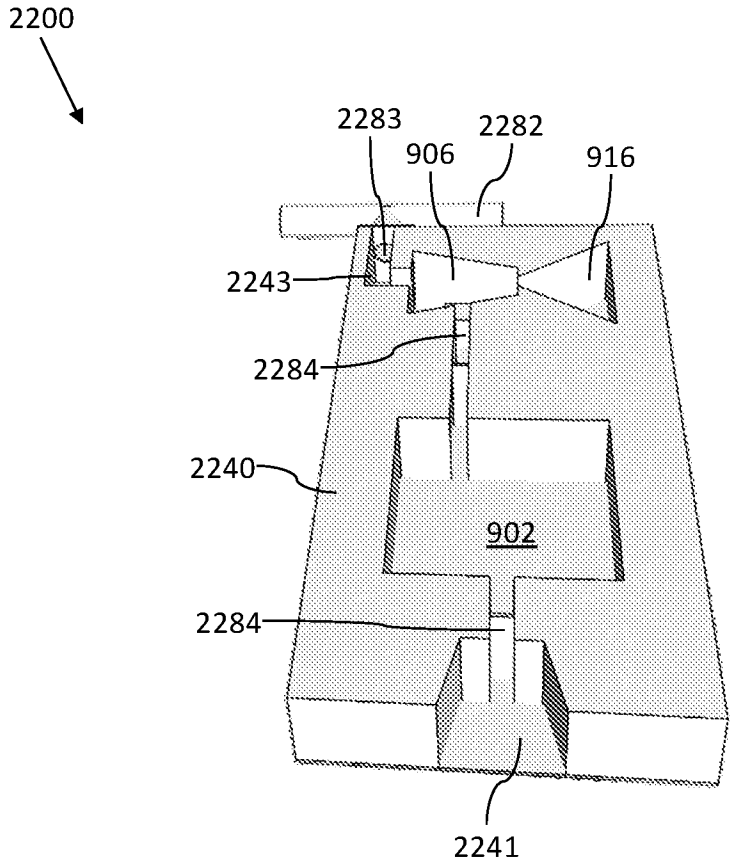

FIG. 22C

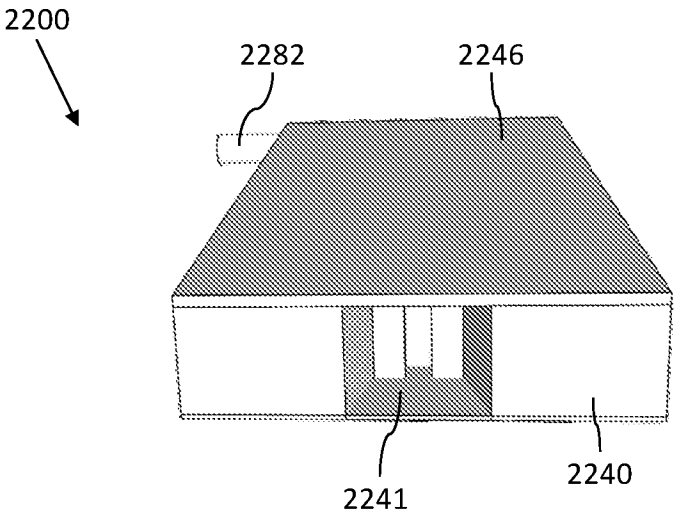

FIG. 22D

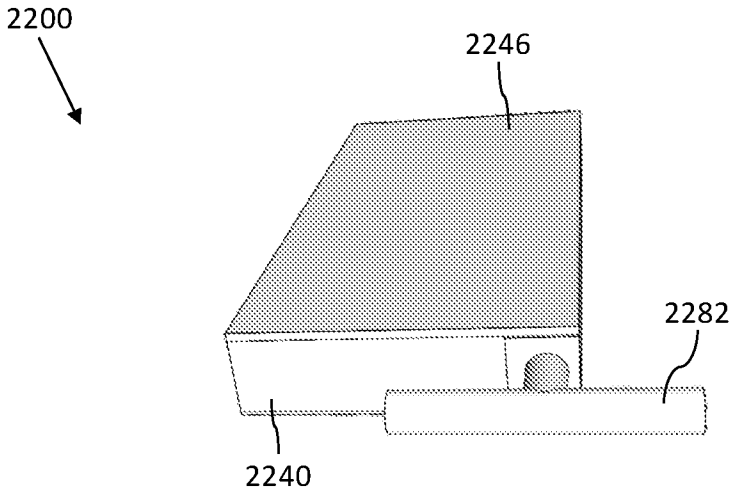

FIG. 22E

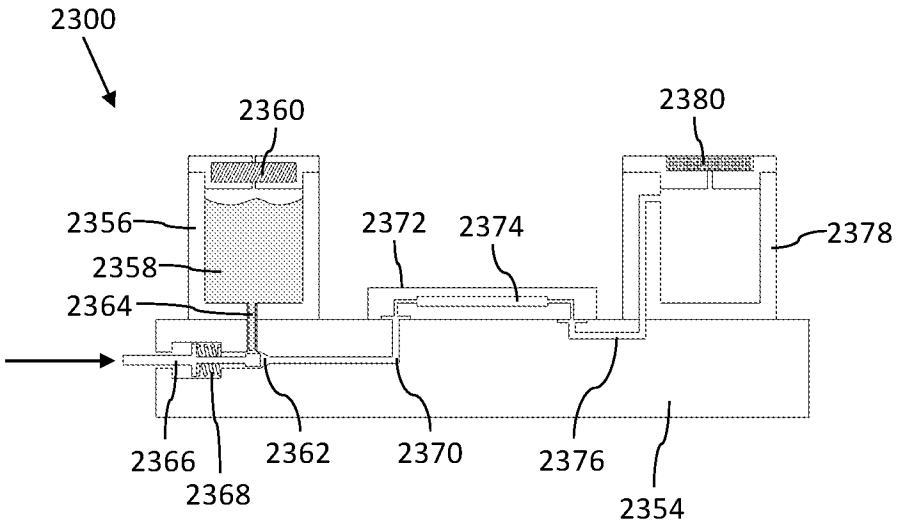

FIG. 23A

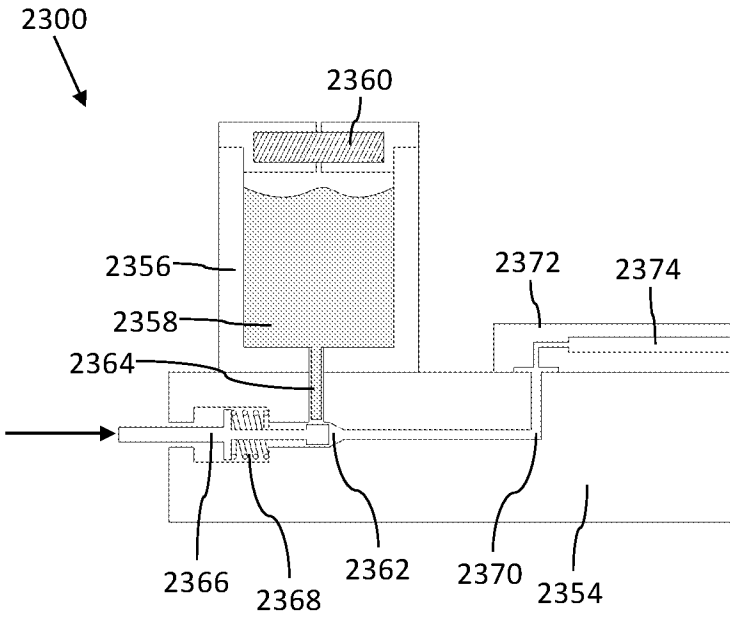

FIG. 23B

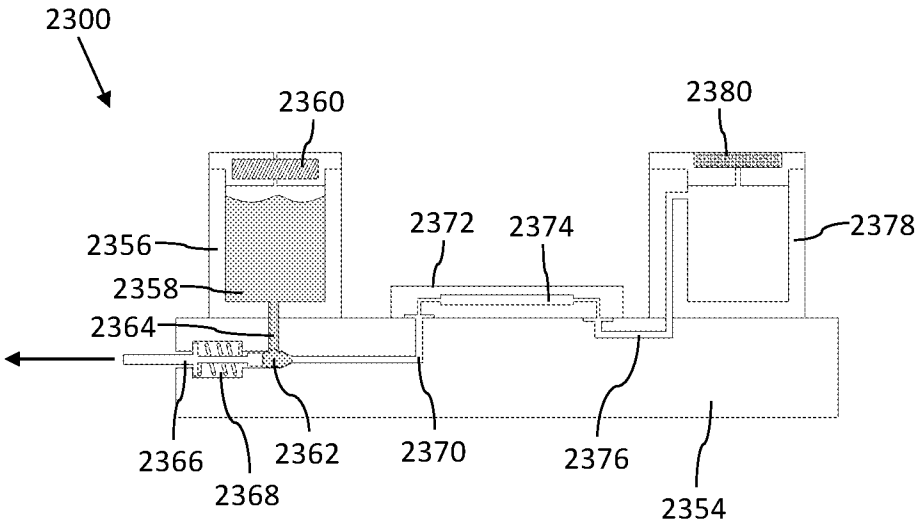

FIG. 23C

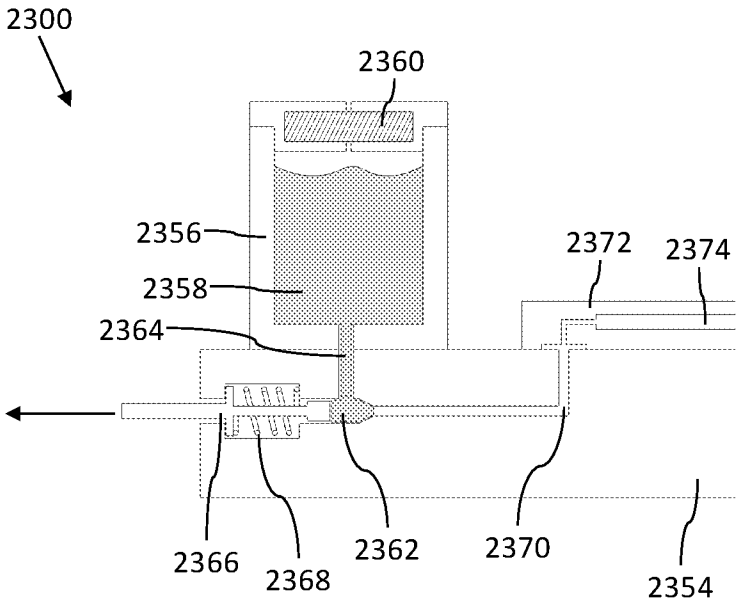

FIG. 23D

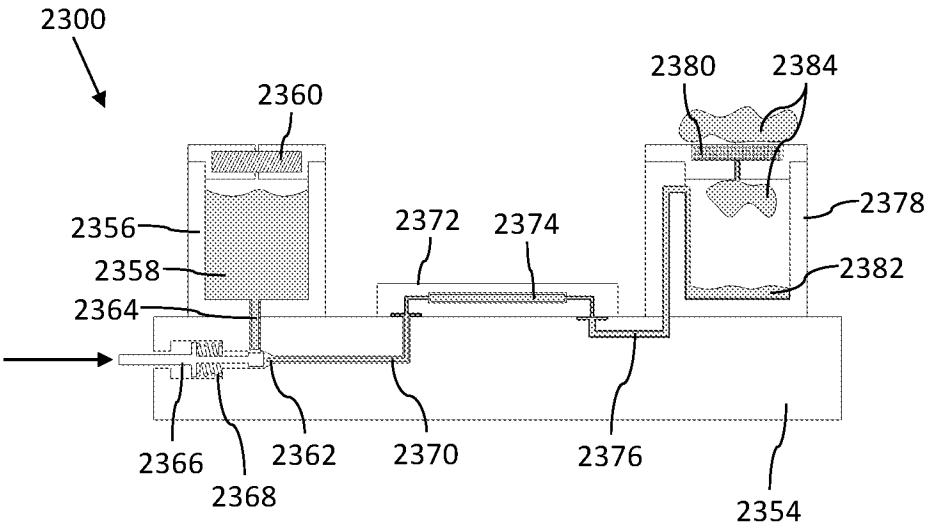

FIG. 23E

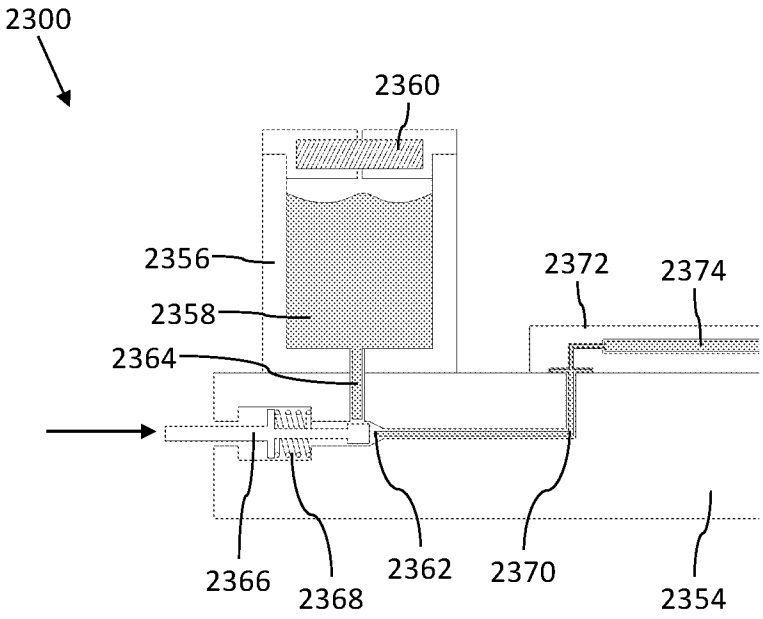

FIG. 23F

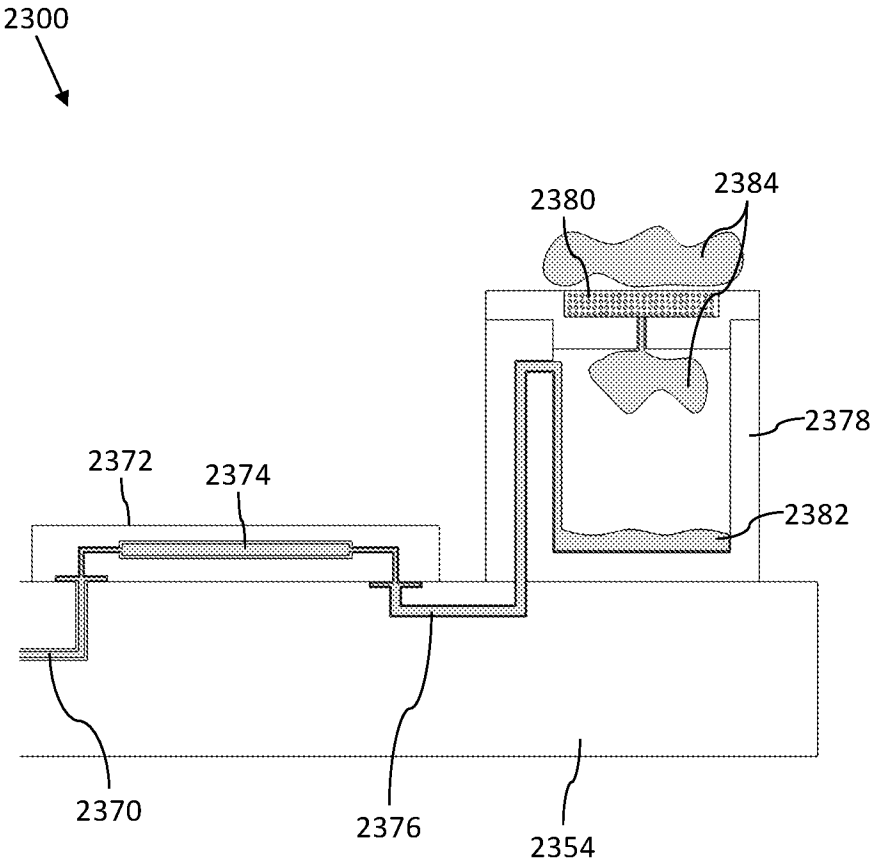

FIG. 23G

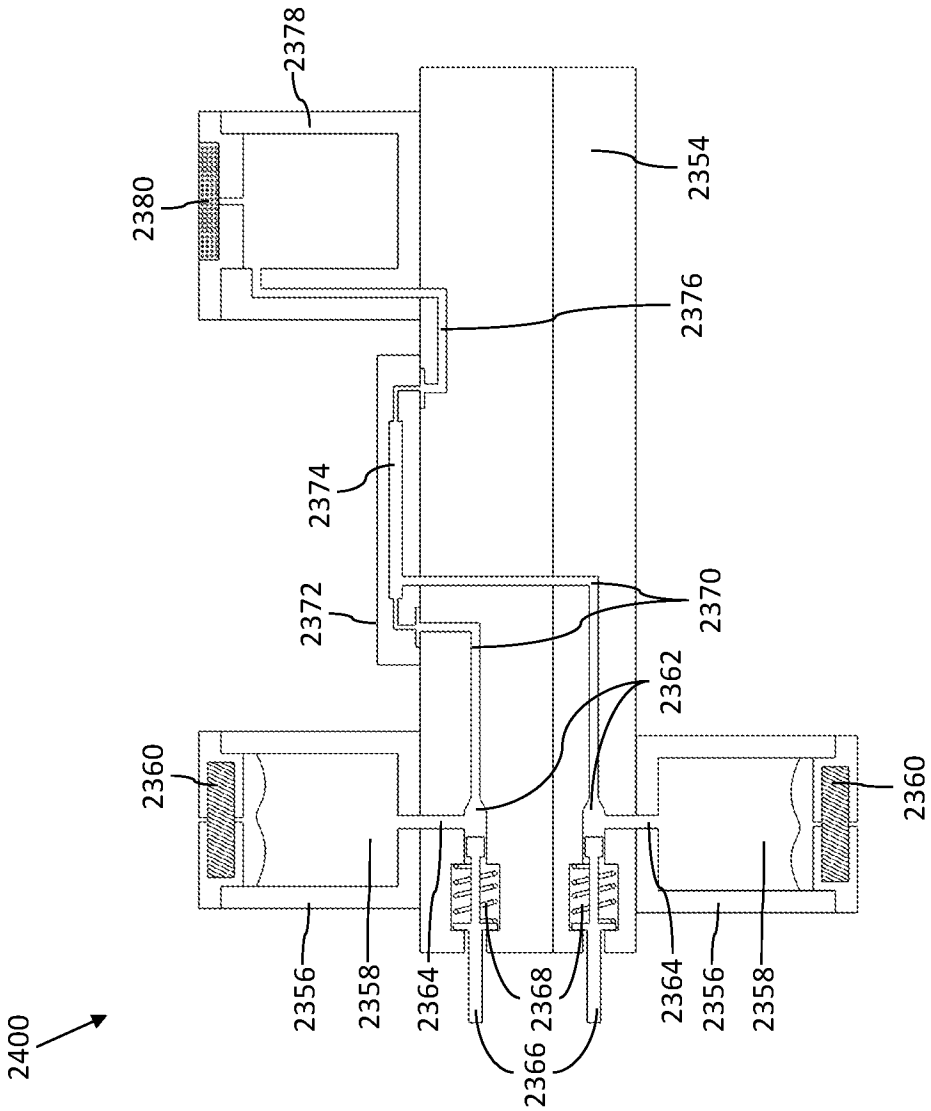
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FIG. 24

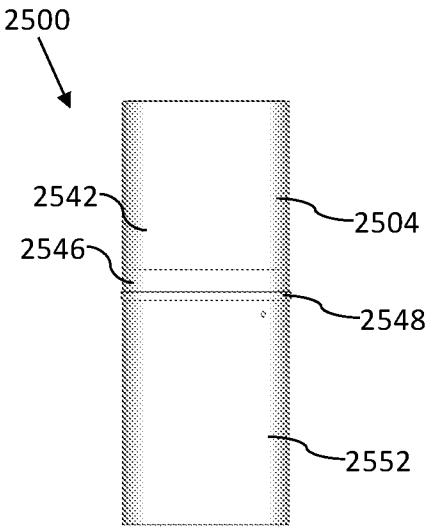

FIG. 25A

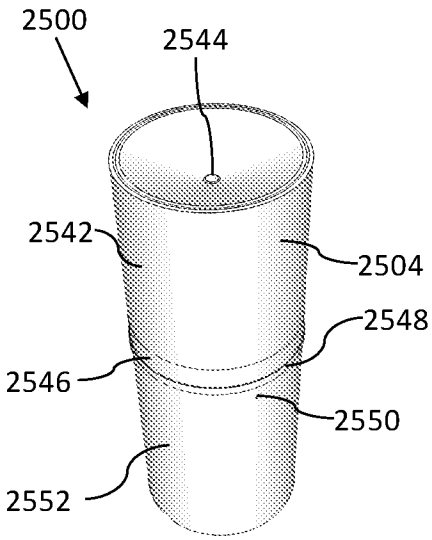

FIG. 25B

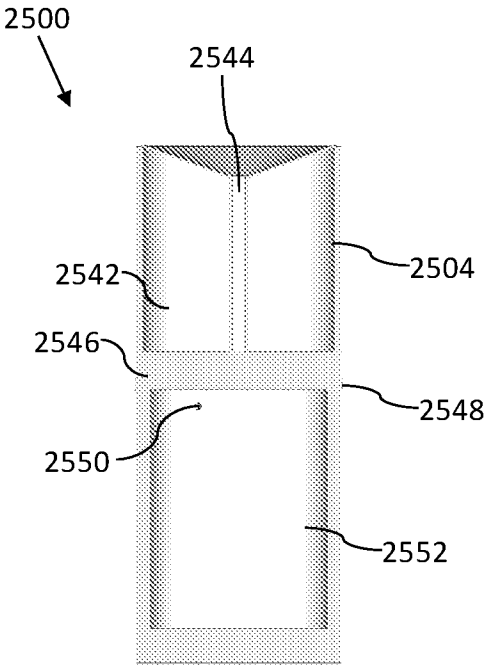

FIG. 25C

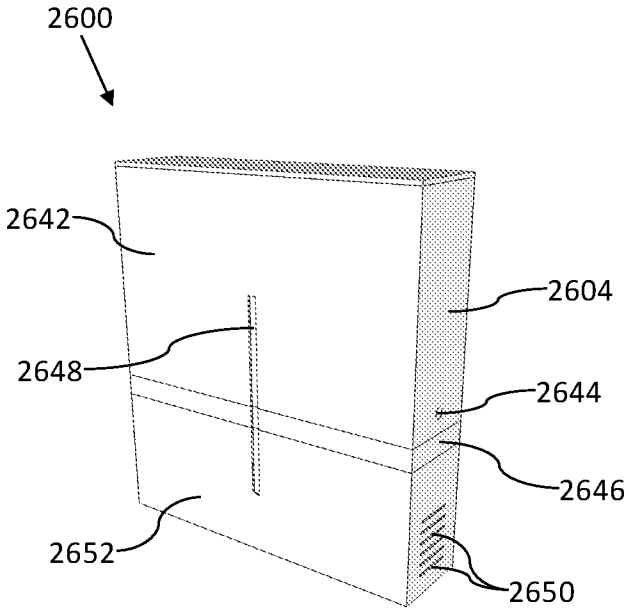

FIG. 26A

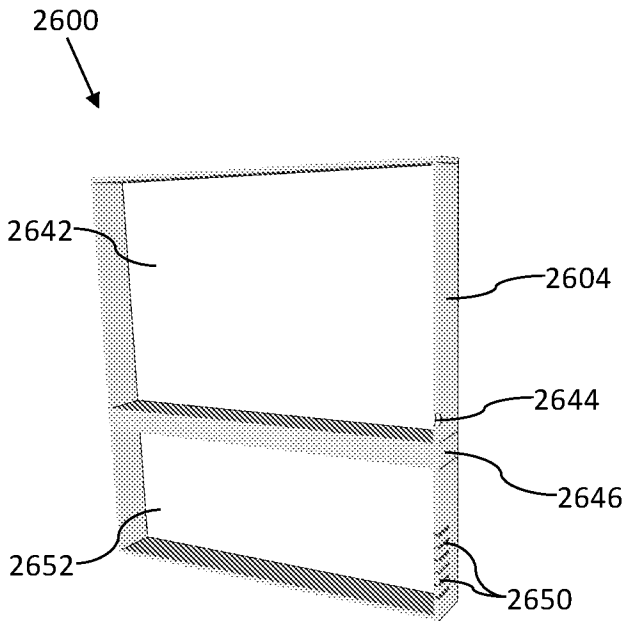

FIG. 26B

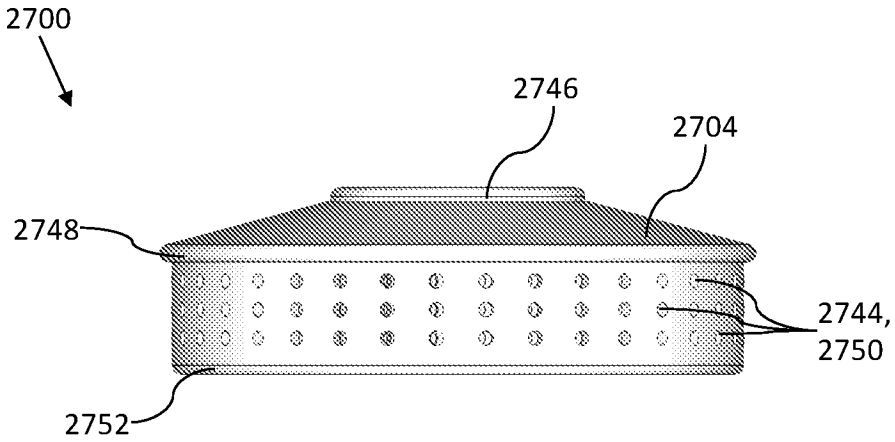

FIG. 27A

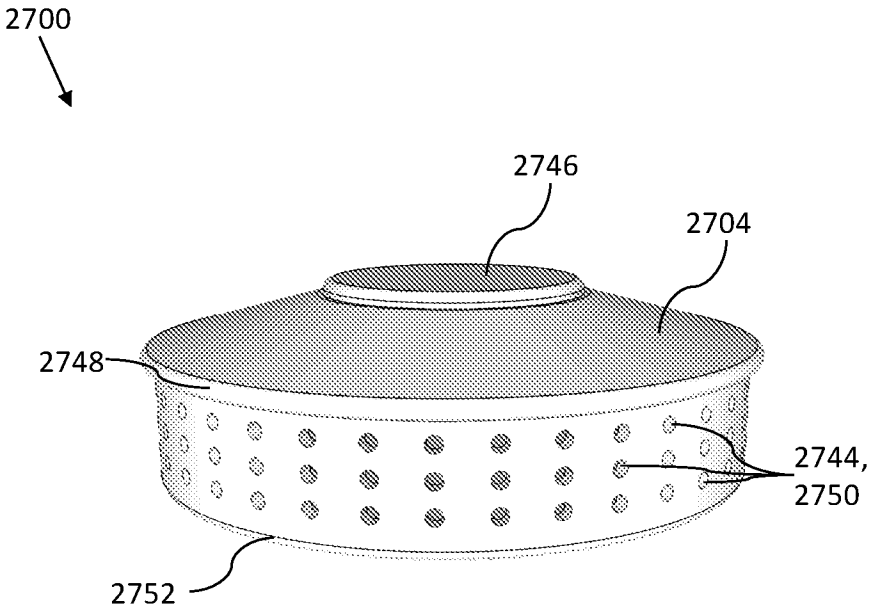

FIG. 27B

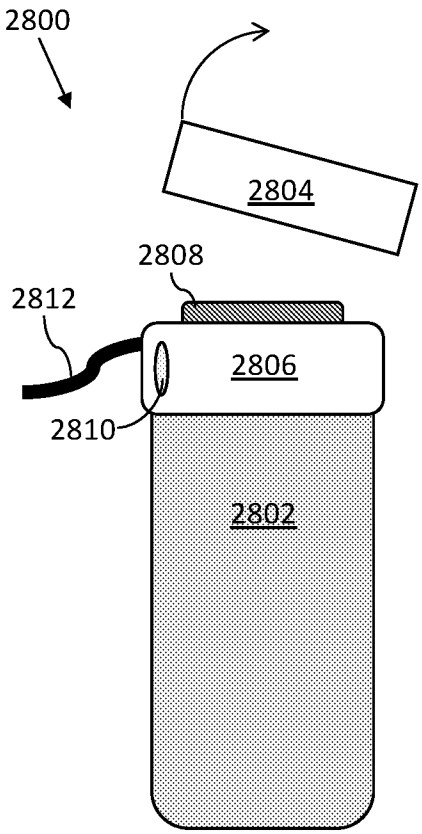

FIG. 28A

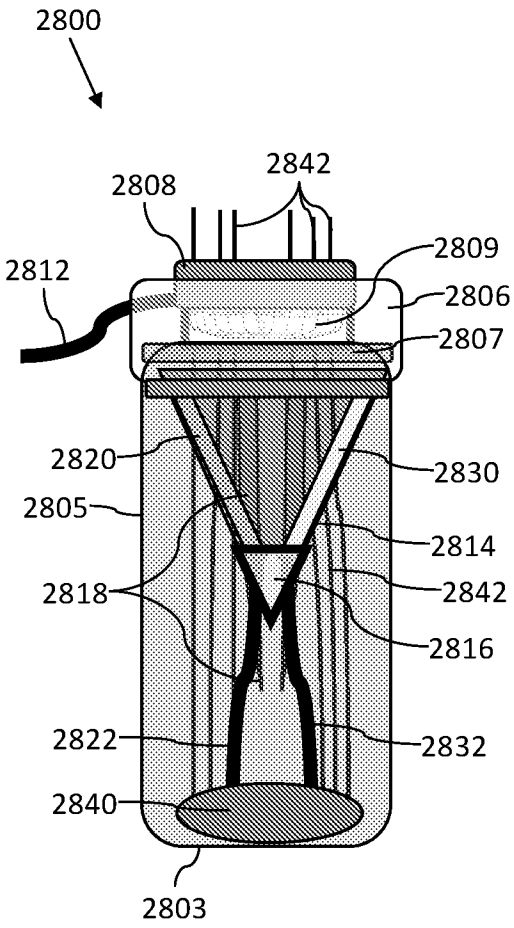

FIG. 28B

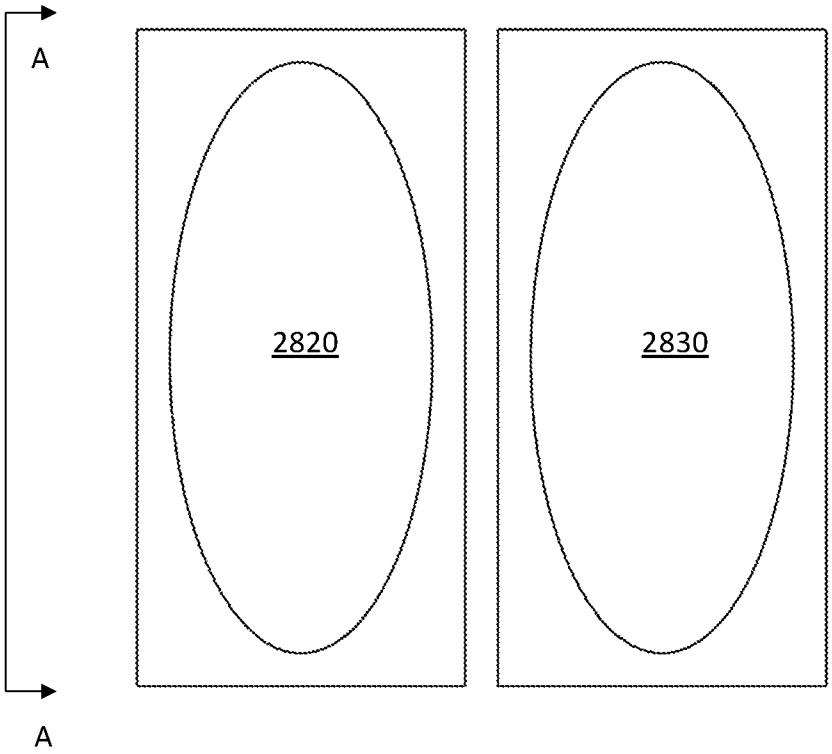

FIG. 29A

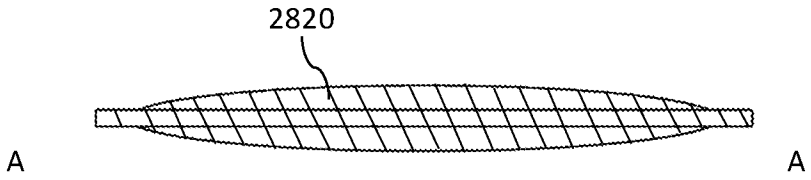

FIG. 29B

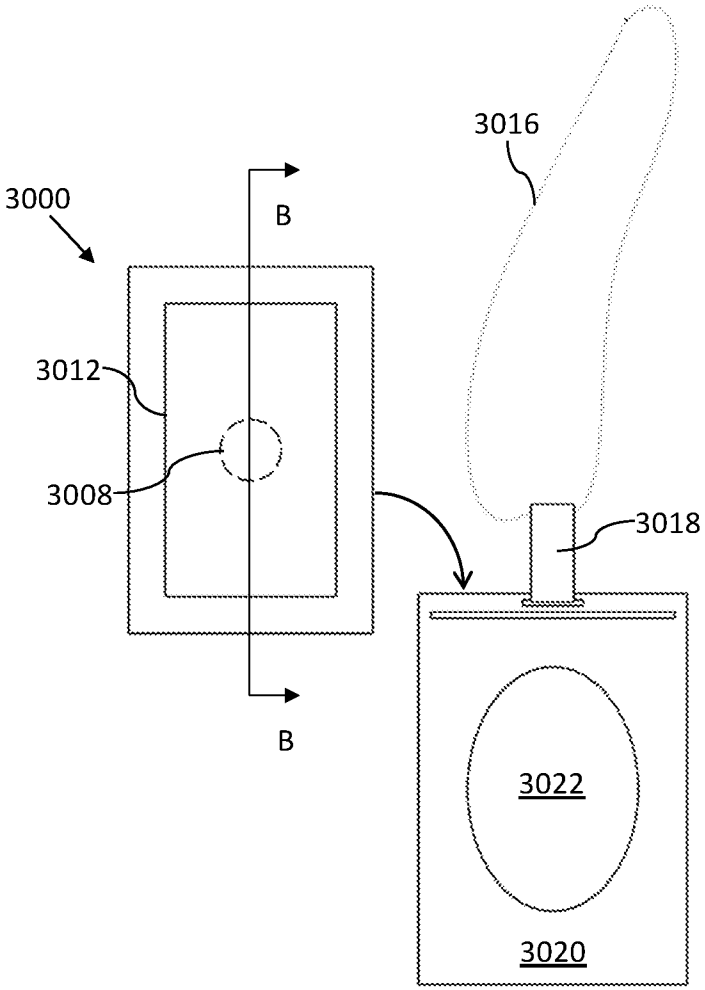

FIG. 30A

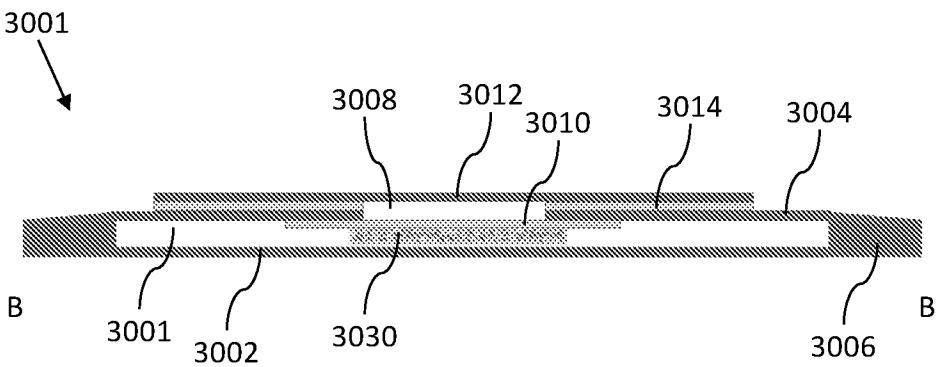

FIG. 30B

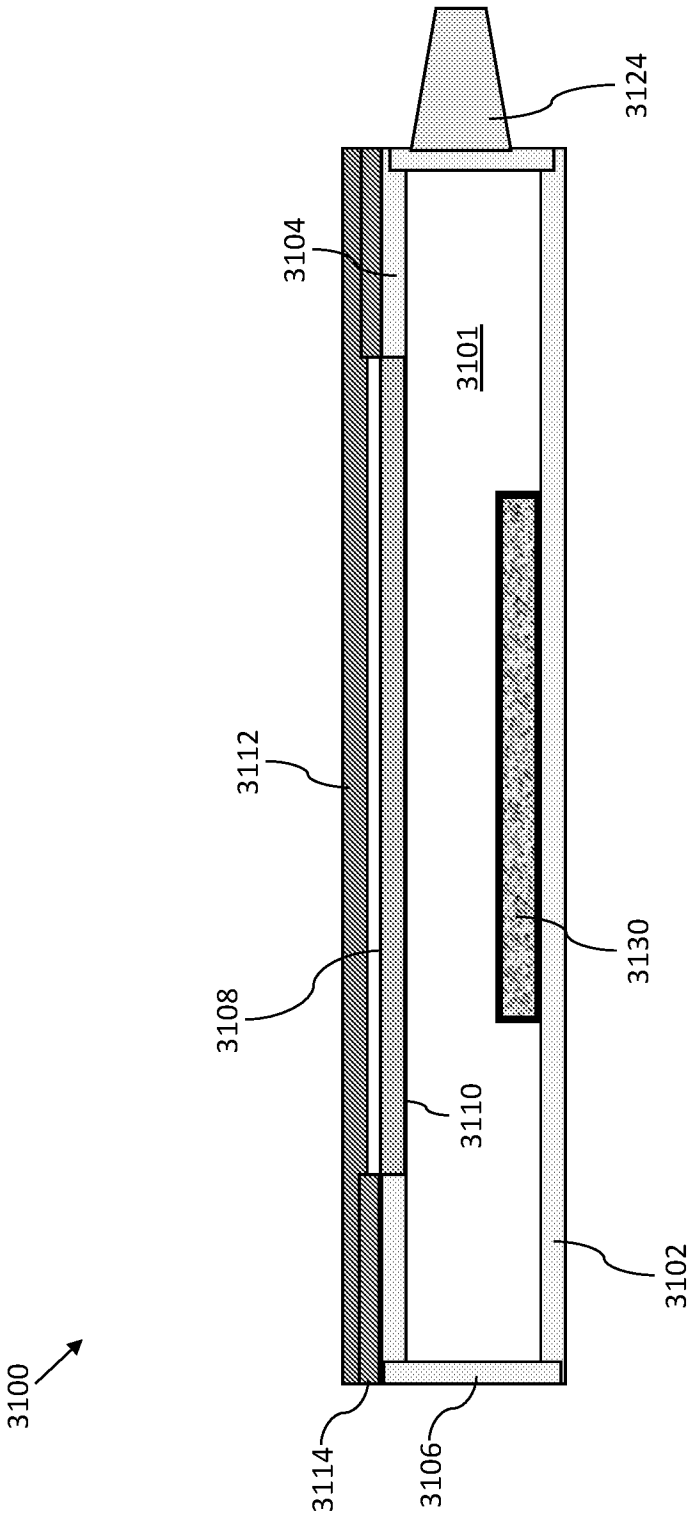

FIG. 31

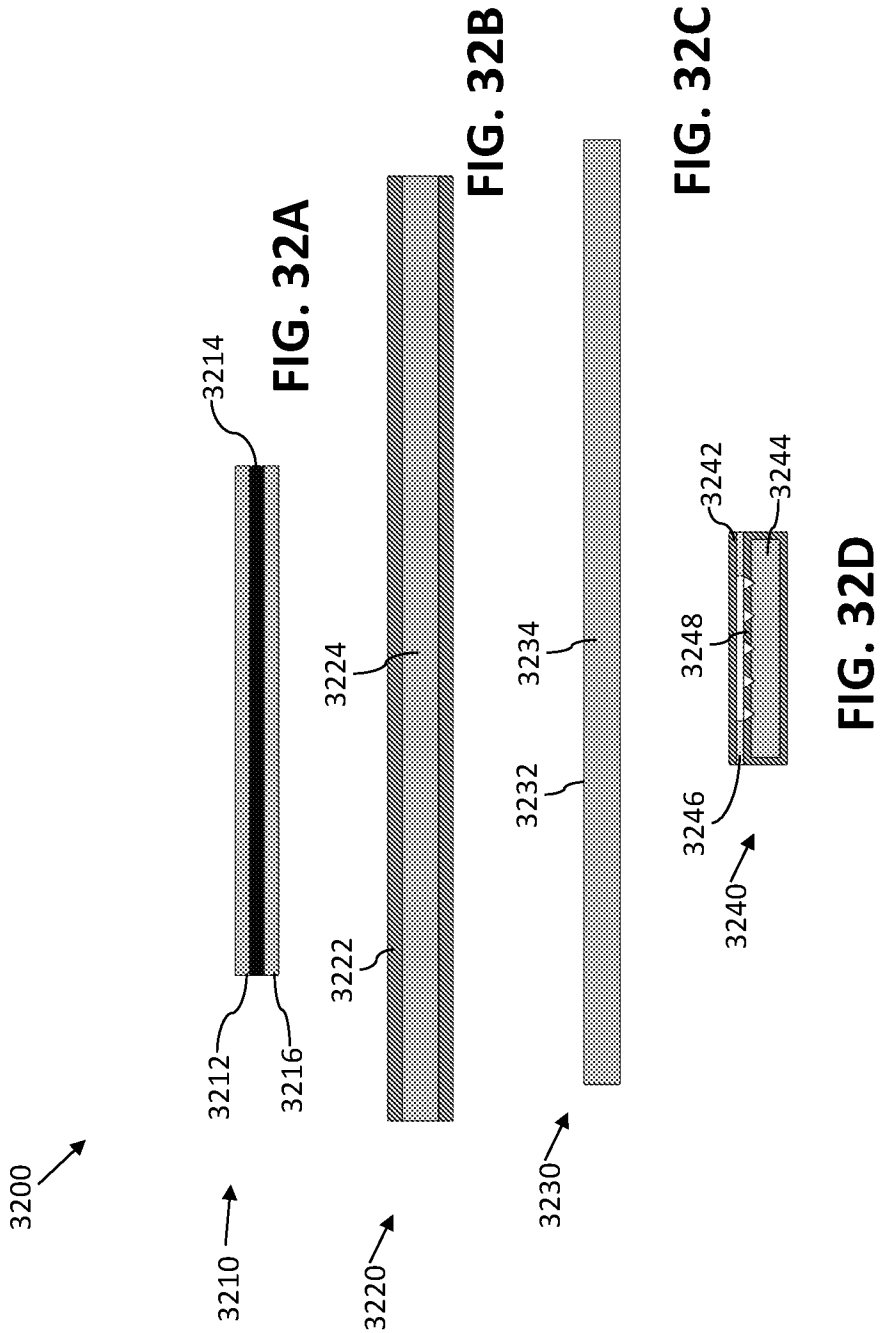

FIG. 32A

FIG. 32B

FIG. 32C

FIG. 32D

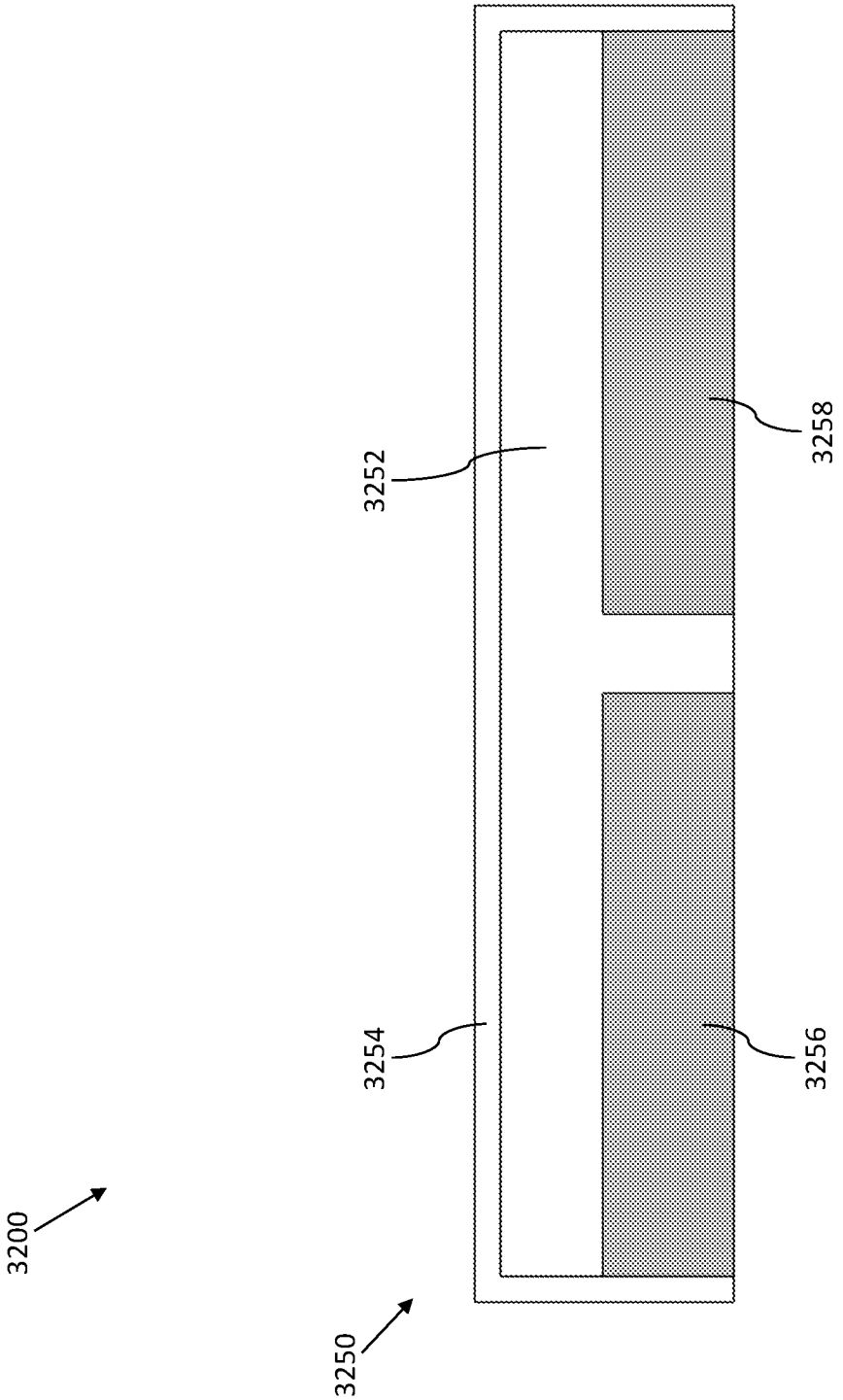

FIG. 32E

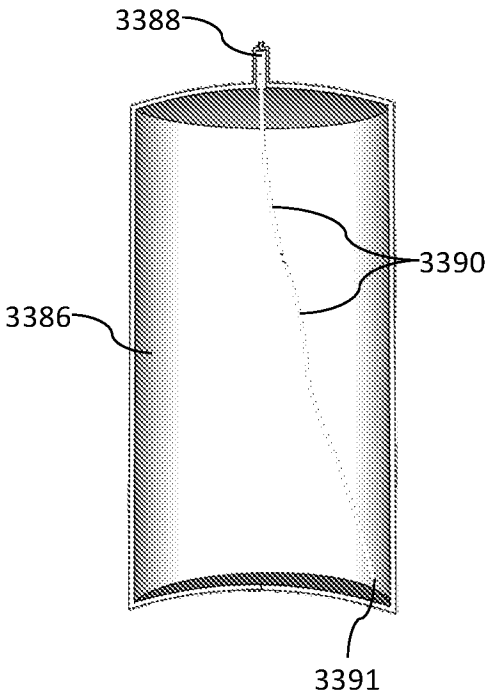

FIG. 33A

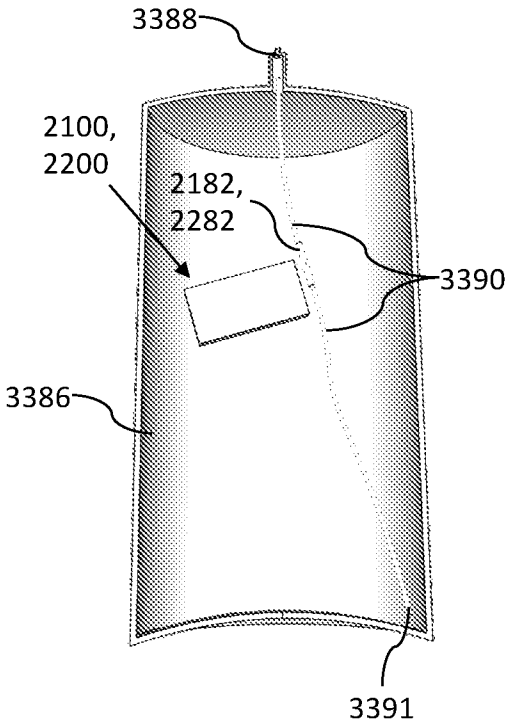

FIG. 33B

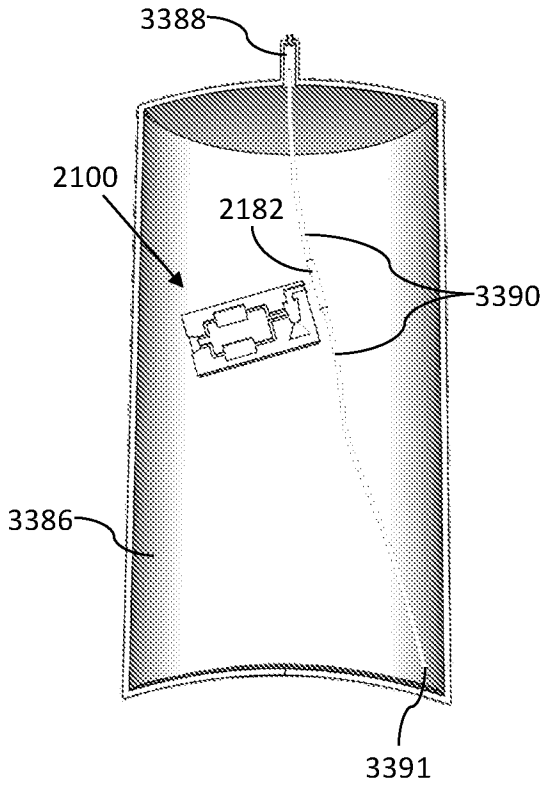

FIG. 33C

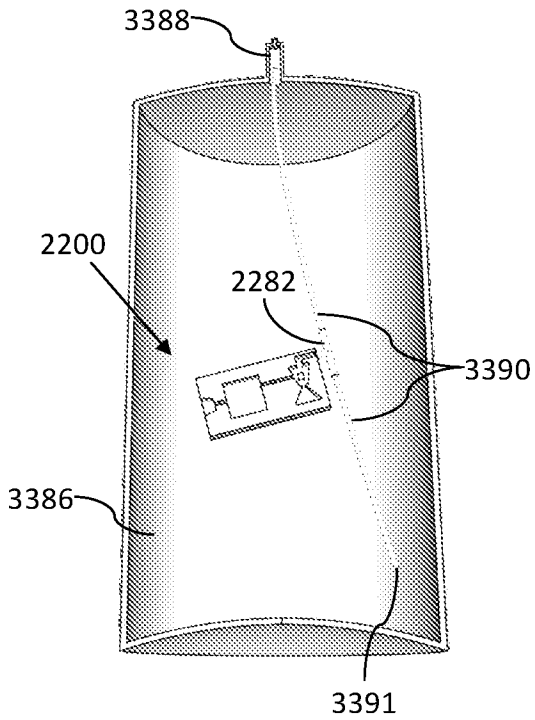

FIG. 33D

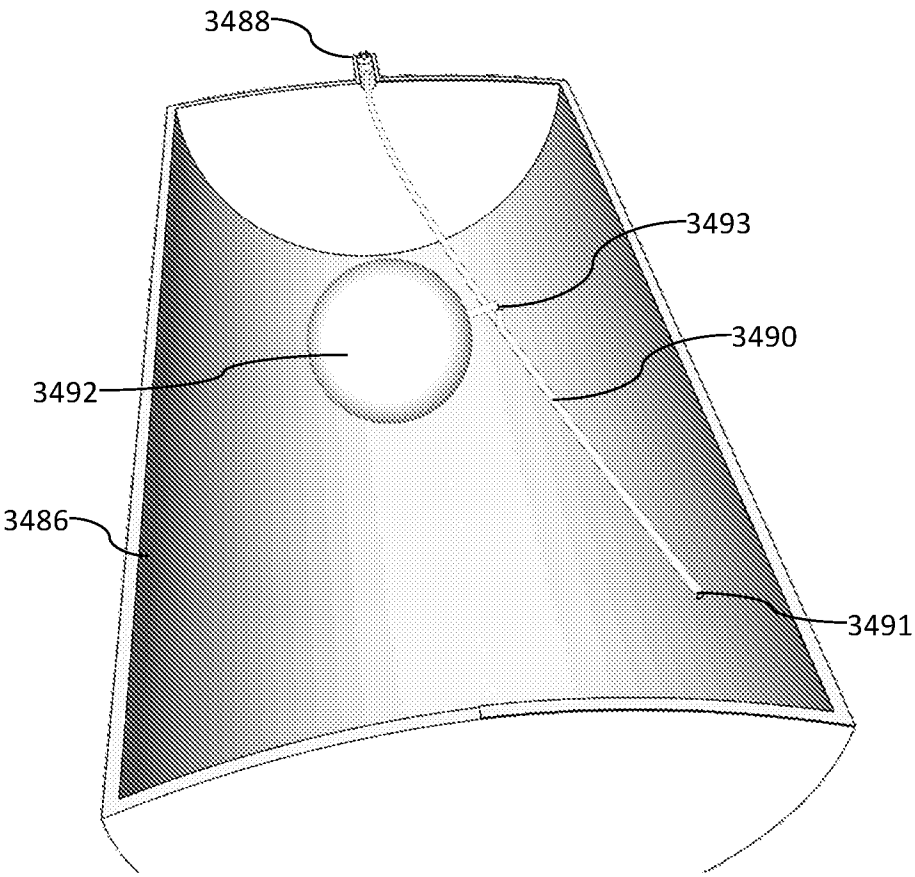

FIG. 34

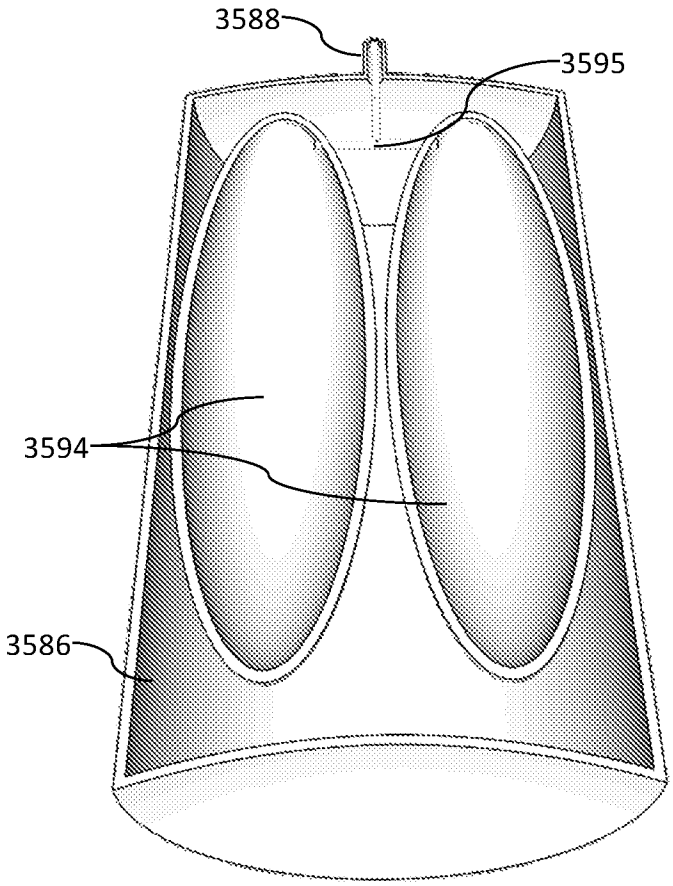

FIG. 35A

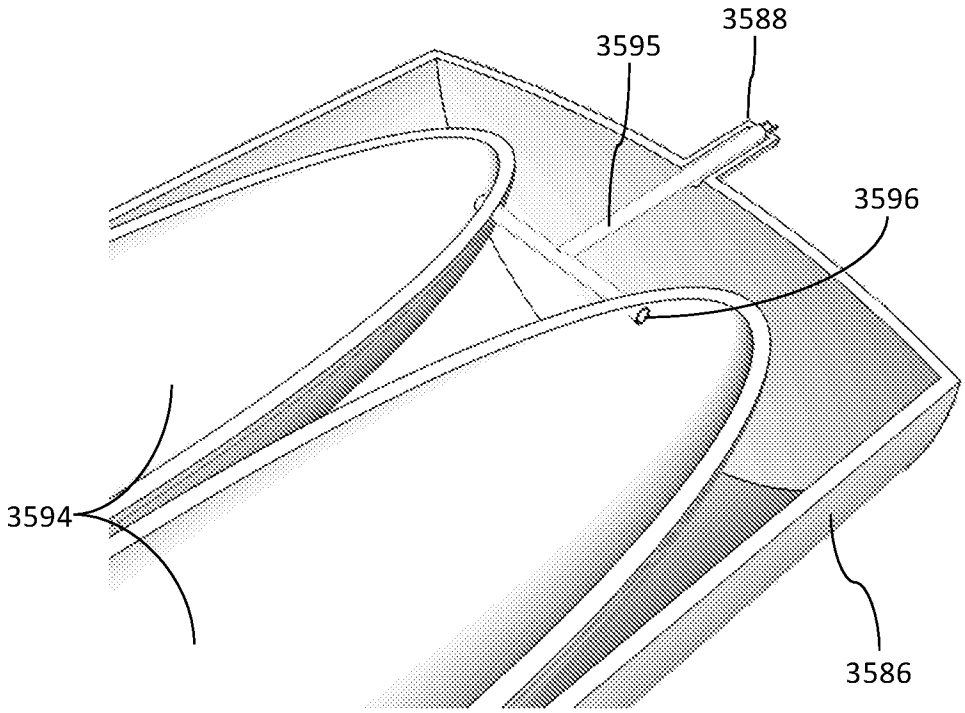

FIG. 35B

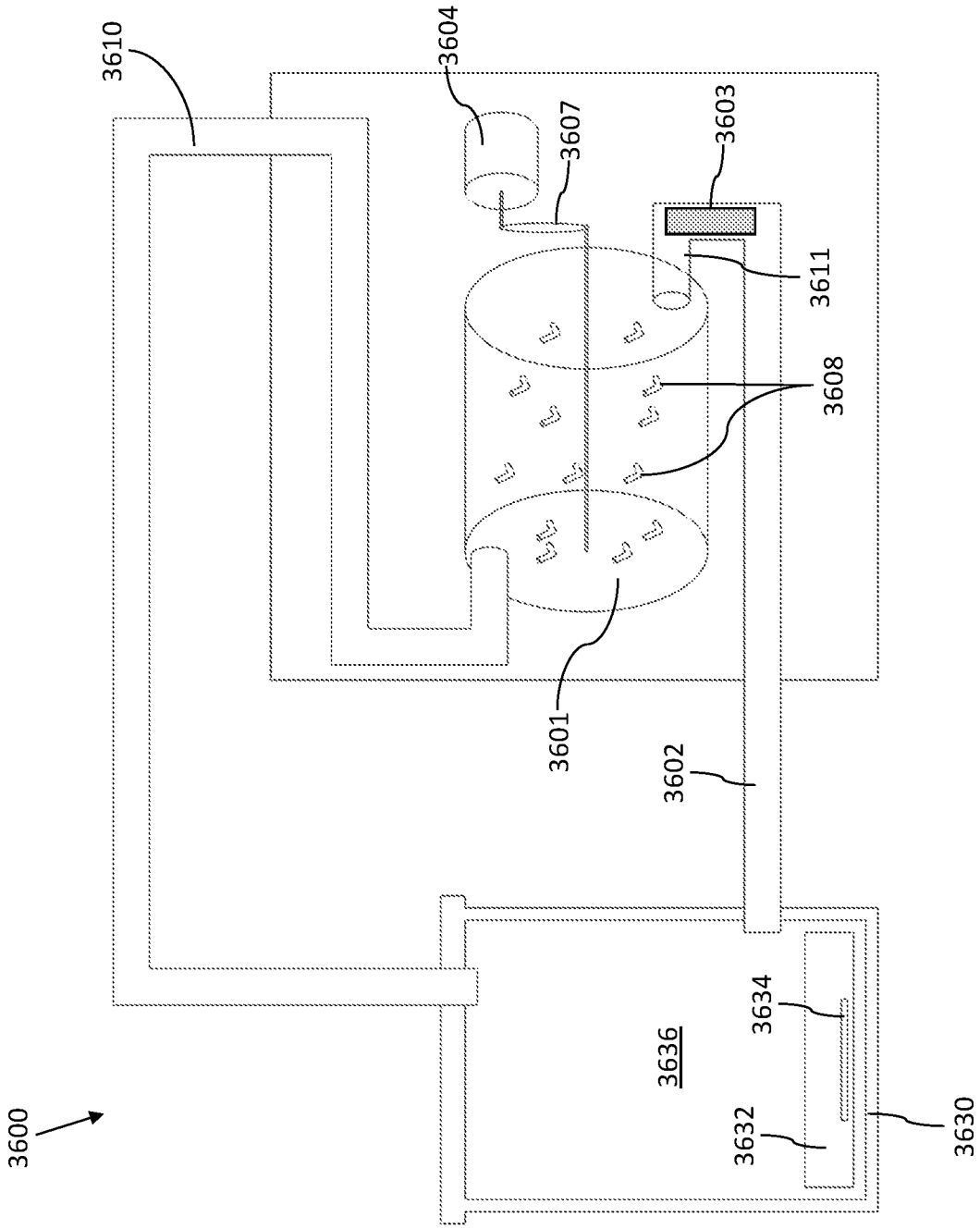
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FIG. 36

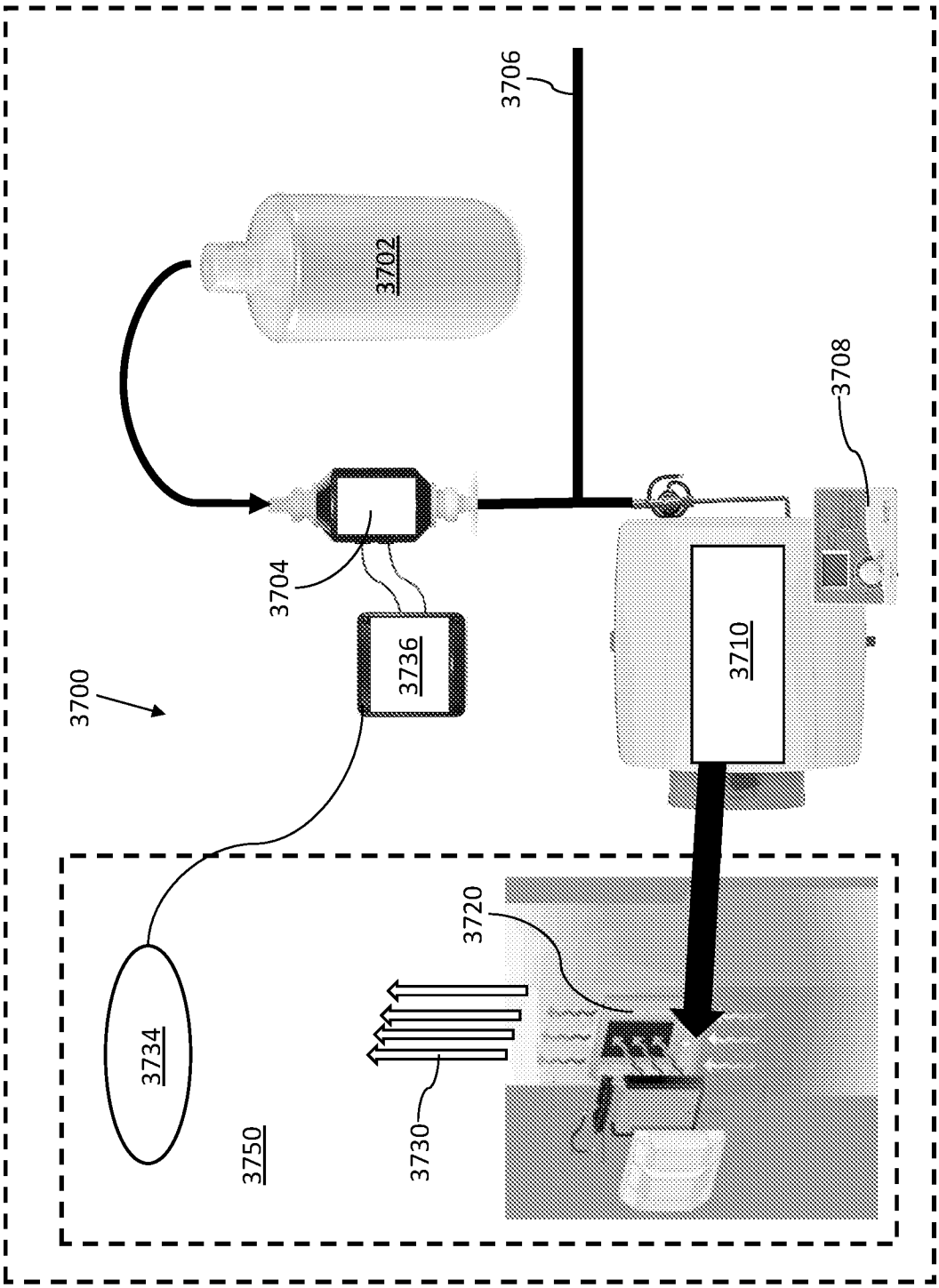


FIG. 37

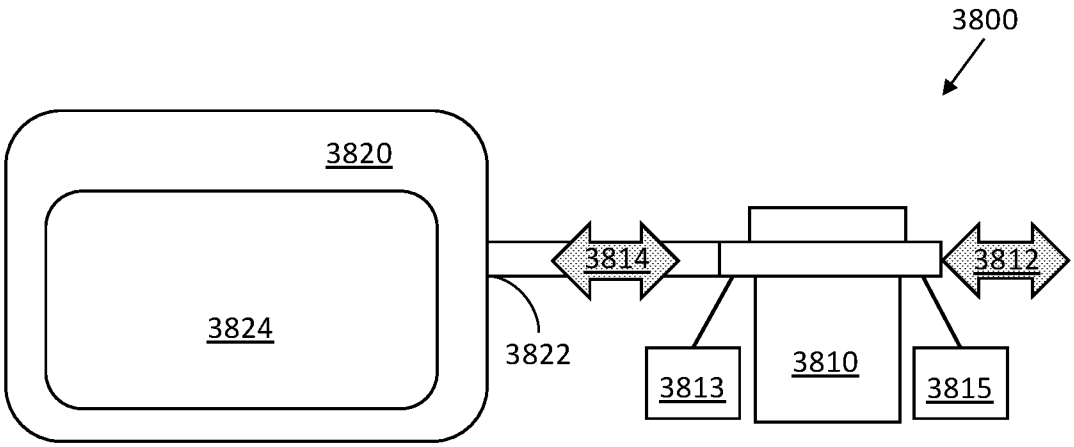


FIG. 38A

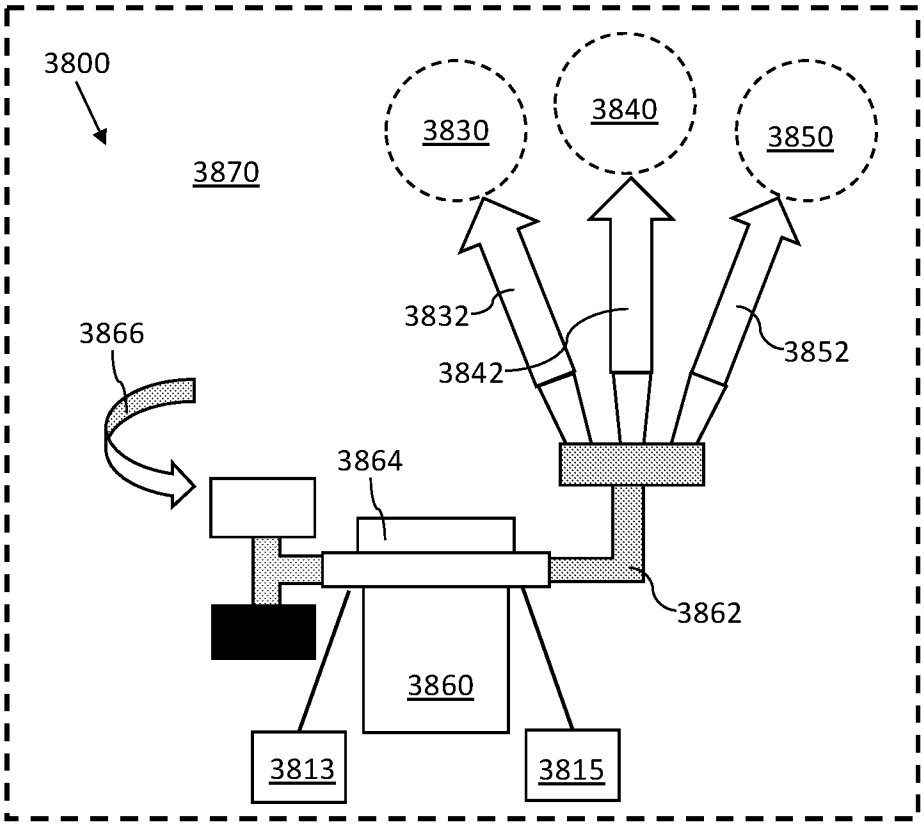


FIG. 38B

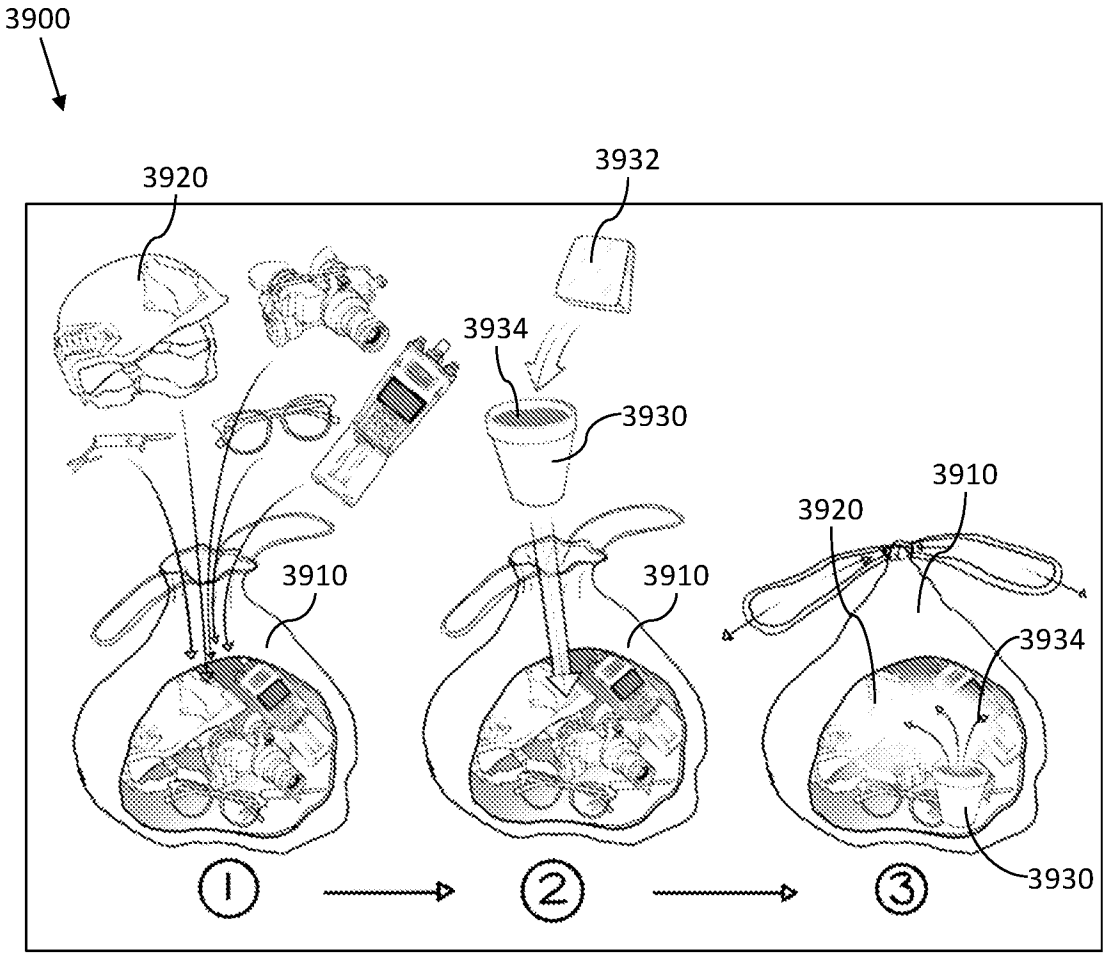


FIG. 39A FIG. 39B FIG. 39C

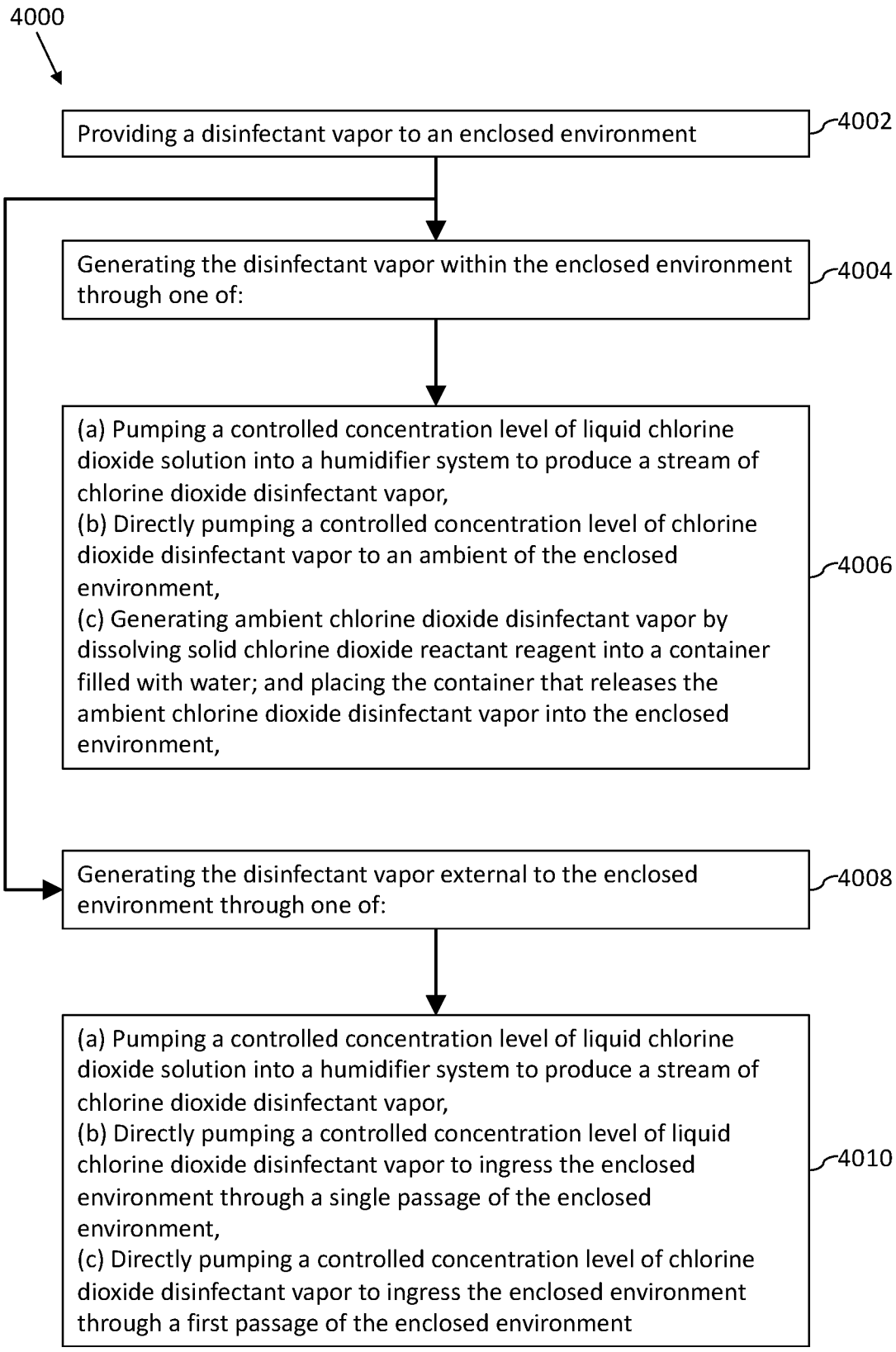

4000
Providing a disinfectant vapor to an enclosed environment
4002
Generating the disinfectant vapor within the enclosed environment through one of:
4004
(a) Pumping a controlled concentration level of liquid chlorine dioxide solution into a humidifier system to produce a stream of chlorine dioxide disinfectant vapor,
(b) Directly pumping a controlled concentration level of chlorine dioxide disinfectant vapor to an ambient of the enclosed environment,
(c) Generating ambient chlorine dioxide disinfectant vapor by dissolving solid chlorine dioxide reactant reagent into a container filled with water; and placing the container that releases the ambient chlorine dioxide disinfectant vapor into the enclosed environment,
4006
Generating the disinfectant vapor external to the enclosed environment through one of:
4008
(a) Pumping a controlled concentration level of liquid chlorine dioxide solution into a humidifier system to produce a stream of chlorine dioxide disinfectant vapor,
(b) Directly pumping a controlled concentration level of liquid chlorine dioxide disinfectant vapor to ingress the enclosed environment through a single passage of the enclosed environment,
(c) Directly pumping a controlled concentration level of chlorine dioxide disinfectant vapor to ingress the enclosed environment through a first passage of the enclosed environment
4010

FIG. 40

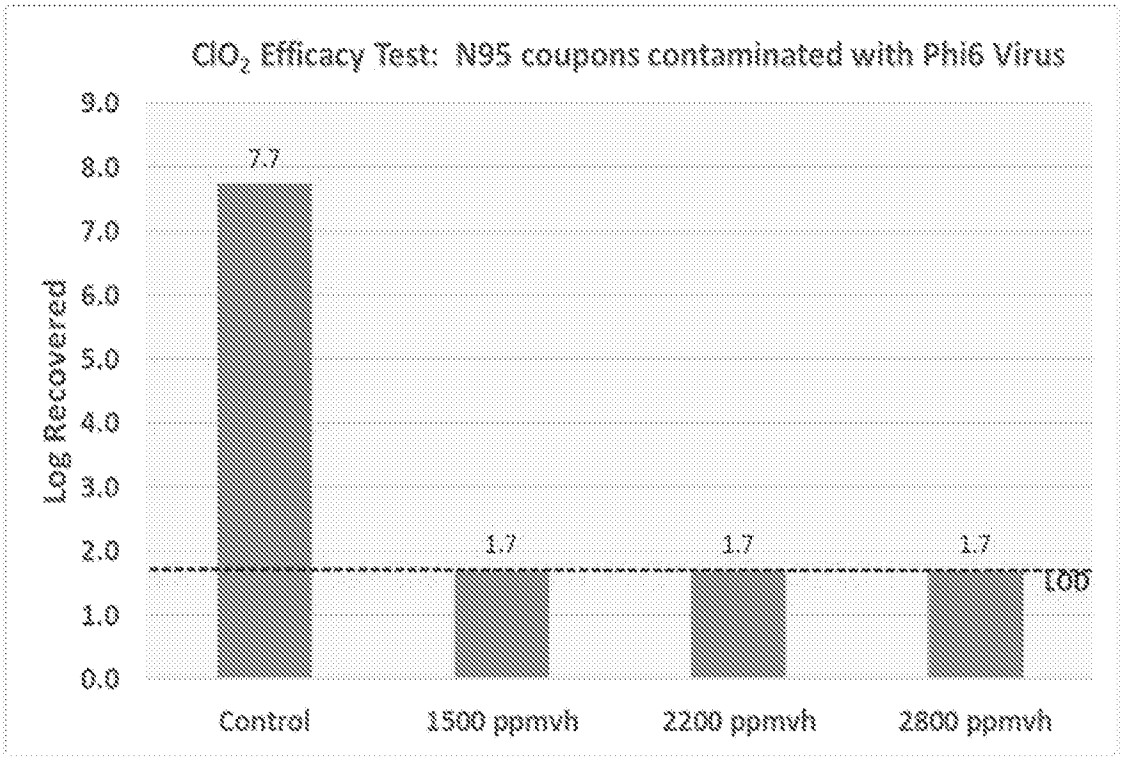


FIG. 41A

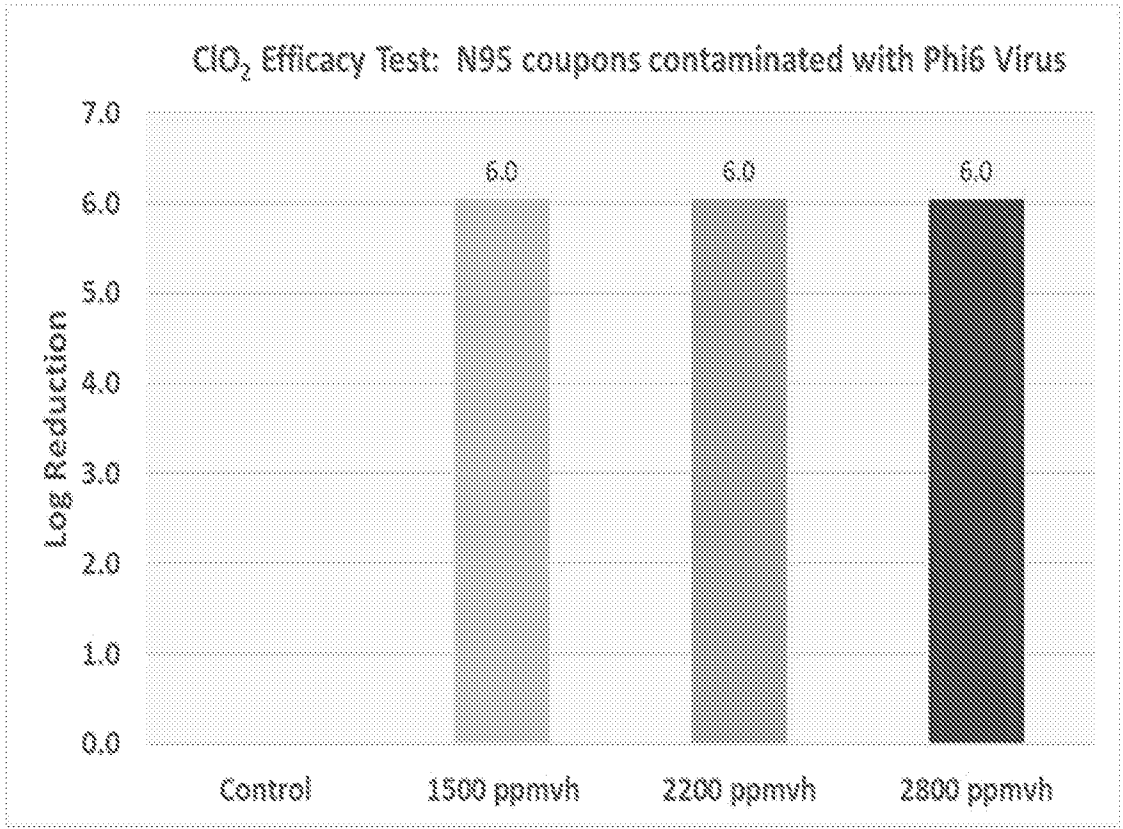
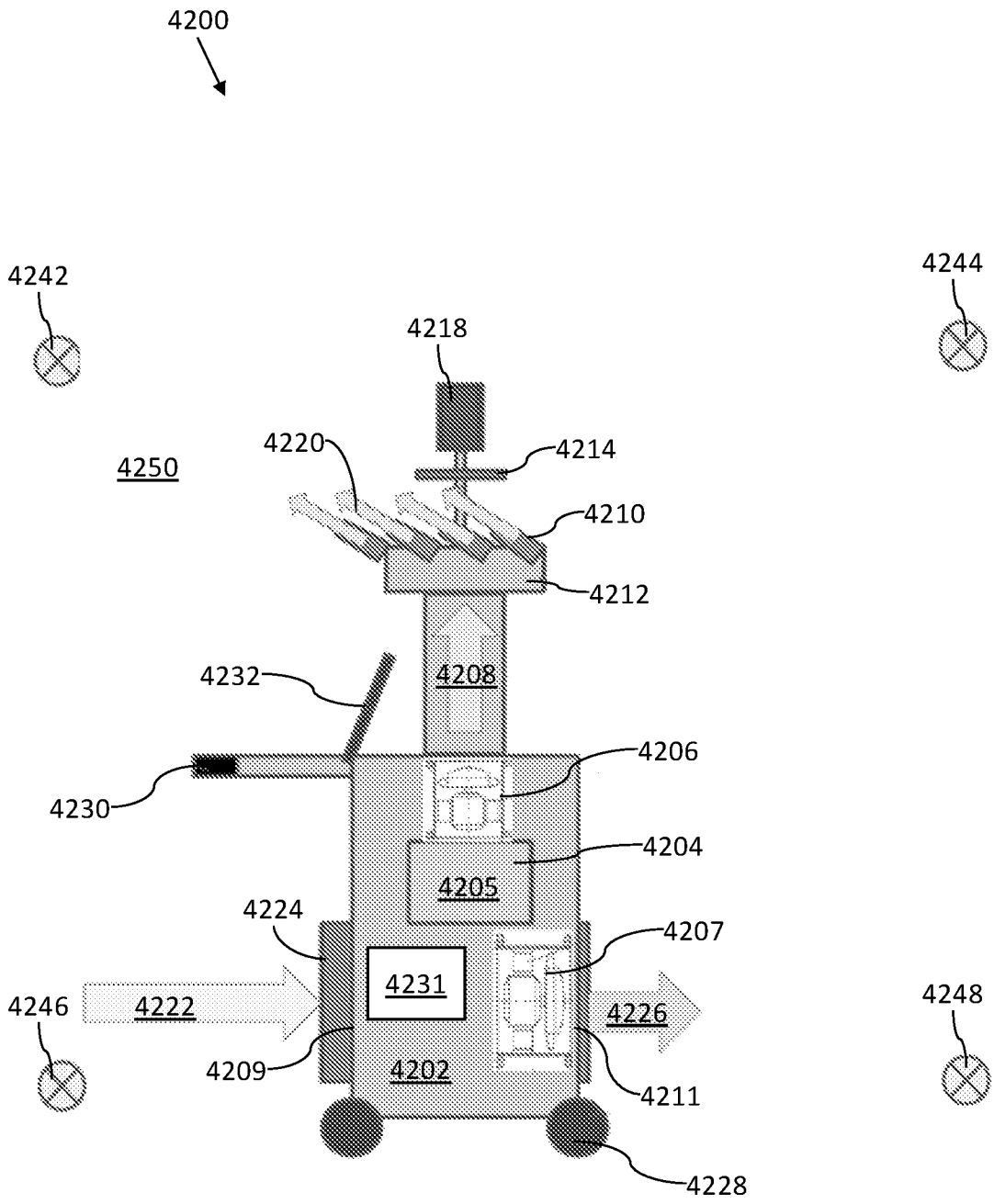


FIG. 41B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4228

FIG. 42

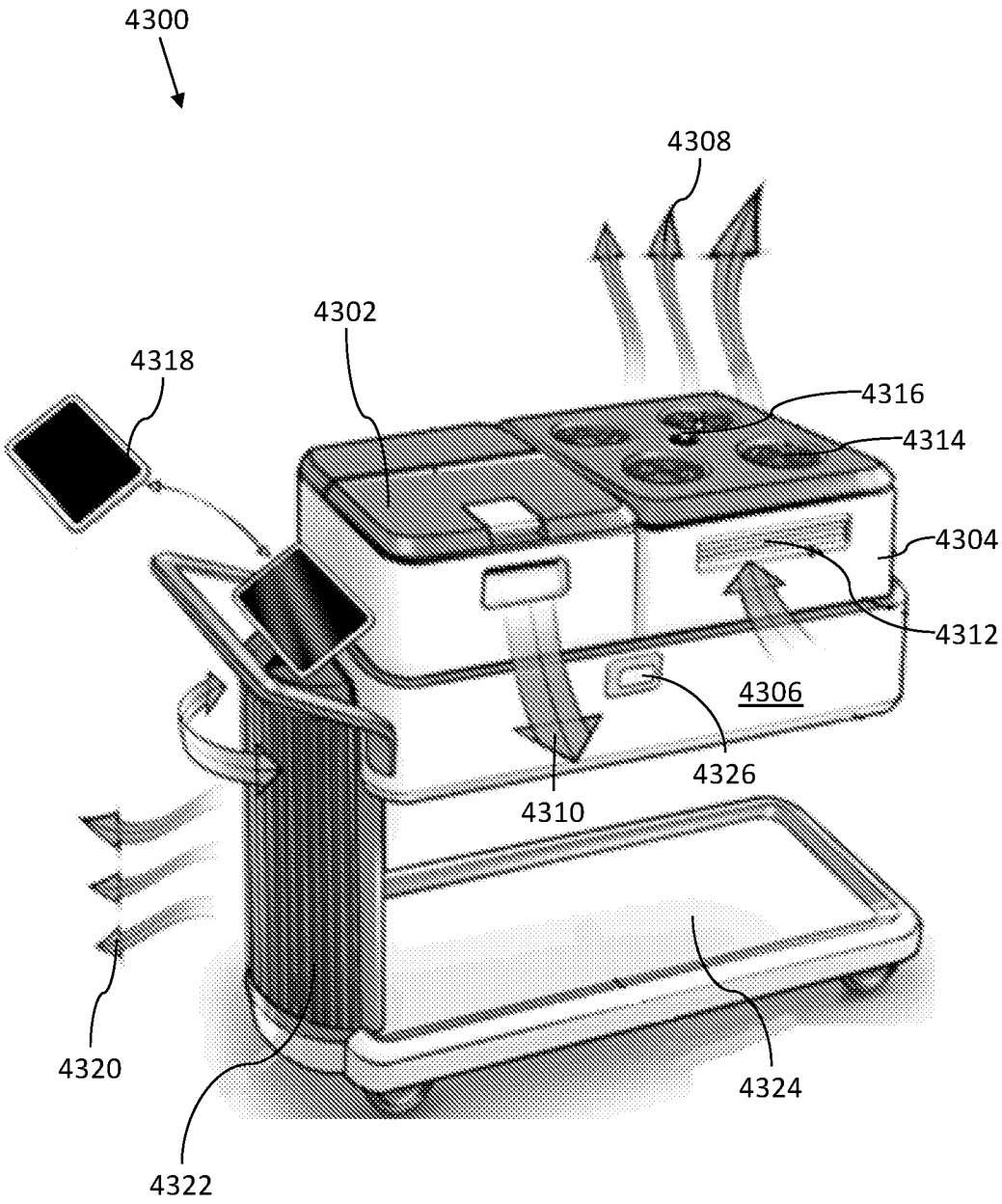
4300
4308
4302
4318
4316
4314
4304
4312
4306
4326
4310
4320
4324
4322

FIG. 43

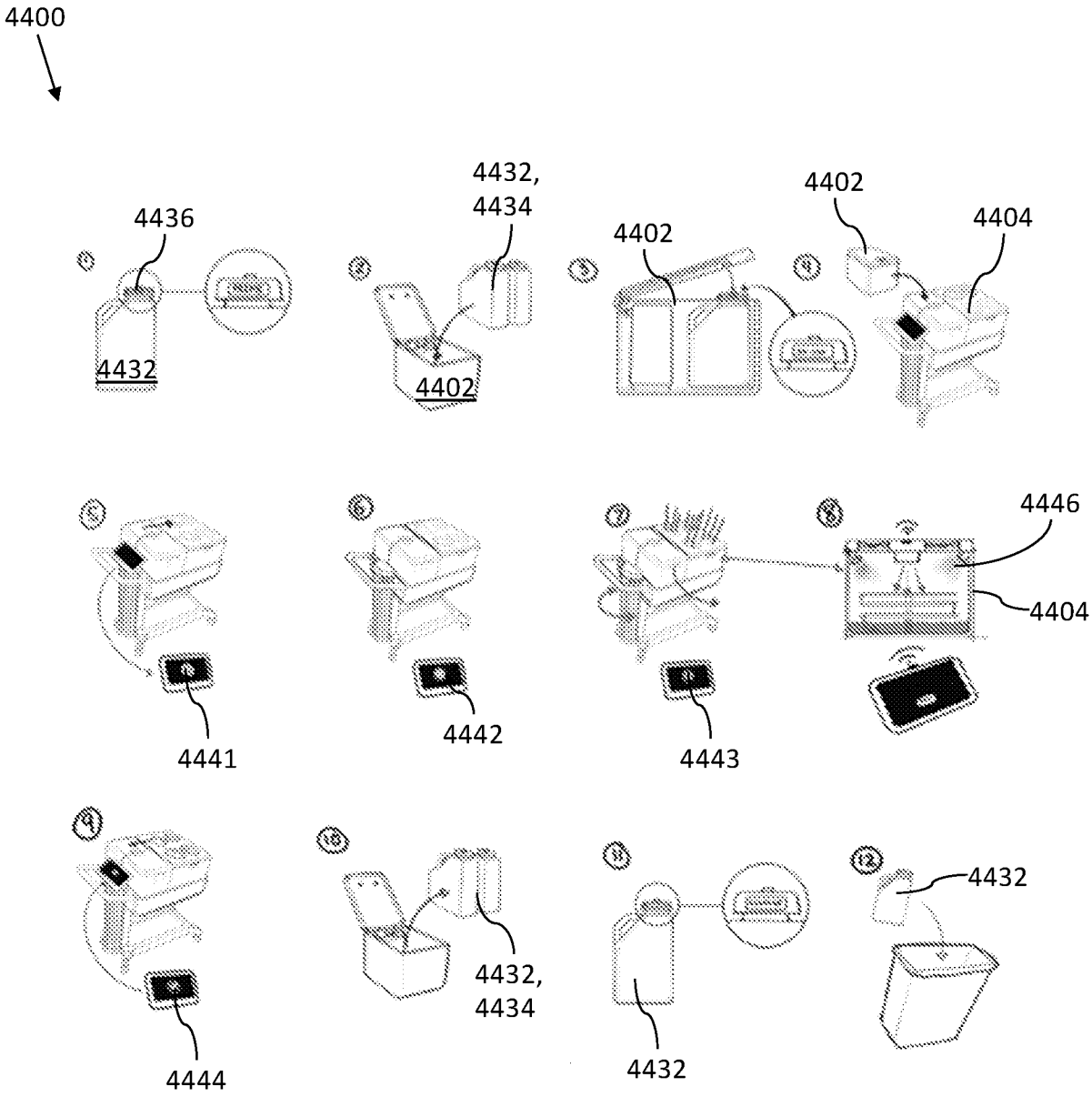
4400
4436
4432
4432,
4434
4402
4402
4402
4404
4441
4442
4446
4404
4443
4444
4432,
4434
4432
4432

FIG. 44

Chlorine Dioxide: Prediction of Gas in Water and Air

Volume converter		
L (ft)	W (ft)	H (ft)
11.2	7.7	7.4
Volume =	18.001	Liters

Volume of water	4	Liters
Volume of air	18.001	Liters
Start ClO2 conc. in H2O	500	ppm
Mass of ClO2 produced	2000	mg

mol wt ClO2 67.451

Total moles ClO2 0.029651

Gallons	1
Liters	3.78541

Temp (C)	H (T)	Vm (T)	x, mol frac in H2O	y, mol frac in gas	mg/l ClO2 in H2O	ppm ClO2 air	mg/m3 in air	mg ClO2 in air
0	21.96	22.3983	1.66892E-06	0.0000364	6.22	36.44	109.7	1975.1342
5	27.46	22.8083	1.36426E-06	0.0000372	5.07	37.19	110.0	1979.7008
10	34.06	23.2183	1.11341E-06	0.0000379	4.17	37.93	110.2	1983.3110
15	41.94	23.6283	9.21628E-07	0.0000387	3.45	38.65	110.3	1986.1856
20	51.27	24.0383	7.67860E-07	0.0000394	2.88	39.37	110.5	1988.4905
25	62.26	24.4483	6.43740E-07	0.0000401	2.41	40.08	110.6	1990.3609
30	75.11	24.8583	5.42903E-07	0.0000408	2.03	40.78	110.7	1991.8624
35	90.08	25.2683	4.60470E-07	0.0000415	1.73	41.48	110.7	1993.0980
40	107.40	25.6783	3.92679E-07	0.0000422	1.47	42.17	110.8	1994.1141
50	150.19	26.4983	2.89977E-07	0.0000436	1.09	43.55	110.9	1995.6535
60	205.86	27.3183	2.18232E-07	0.0000449	0.82	44.92	110.9	1996.7269

Henry's law states that the solubility of a gas in a liquid is directly proportional to the partial pressure of the gas above the liquid. In a mixture of gases, each gas has a partial pressure which is the hypothetical pressure of that gas if it alone occupied the volume of the mixture at the same temperature. The total pressure of an ideal gas mixture is the sum of the partial pressures of each individual gas in the mixture.

p=kH x c ; p partial pressure of the solute in the gas above the solution (atm); kH a constant with the dimensions of pressure divided by concentration. The constant, known as the Henry's law constant, depends on the solute, the solvent and the temperature. (L*atm/mol); c concentration of the solute (mol/L)

FIG. 45

TEST T13 - Gas Uniformity Test

Date: 2/11/20
Furnished room w/ fan and elevated RH (80% set point (max))
Yellow Jacket with one 12G
Portasens datalogger inadvertantly not activated for logging

Gas Uniformity					
Port ID	Concentration Measurements (ppm)				
	Round 1	Round 2	Round 3	Mean	Std. Dev.
1	216	186	156	186	21
2	218	186	152	185	23
3	211	176	152	180	21
4	210	178	151	180	21
5	224	171	161	185	24
6	227	191	162	193	23
7	194	164	145	168	17
8	201	170	148	173	19
9	223	183	152	186	25
10	206	172	151	176	20
11	230	184	163	192	24
12	194	180	157	177	13
Mean	213	178	154	182	n/a
Std. Dev.	12	8	6	8	n/a

When making rounds, I tried to follow the same pattern. I started with the door (port 11), moved clockwise and started at the top (port 6), then bottom (port 5), continued clockwise (port 9), and continued this way around the container. However, I did not follow this pattern perfectly (ex. In the first round, forgetting port 12 until I had done the rest).

*Port 5, round 2 was observed to fluctuate between 180 and 180 ppm, never settling at a specific value for very long. This could have been caused by the position of the fan in the room, however it did not fluctuate like this in round 1 or 3.

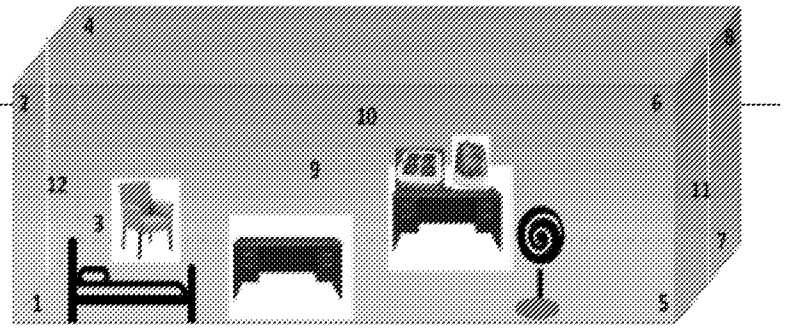

FIG. 46

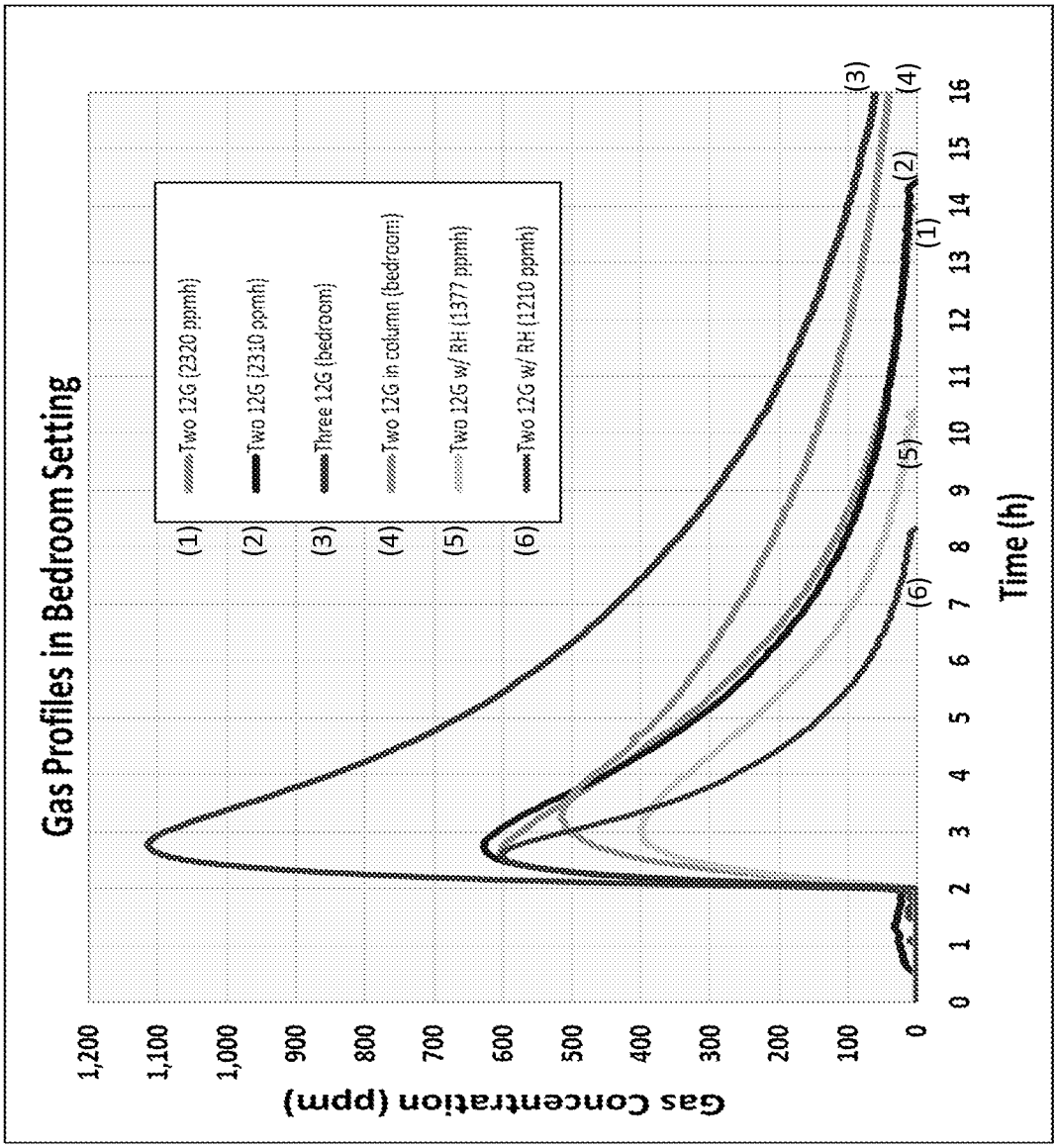
Gas Profiles in Bedroom Setting
Gas Concentration (ppm)
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (h)
(1) Two 12G (2320 ppmh)
(2) Two 12G (2310 ppmh)
(3) Three 12G (bedroom)
(4) Two 12G in column (bedroom)
(5) Two 12G w/ RH (1377 ppmh)
(6) Two 12G w/ RH (1210 ppmh)
(1)
(2)
(3)
(4)
(5)
(6)

FIG. 47

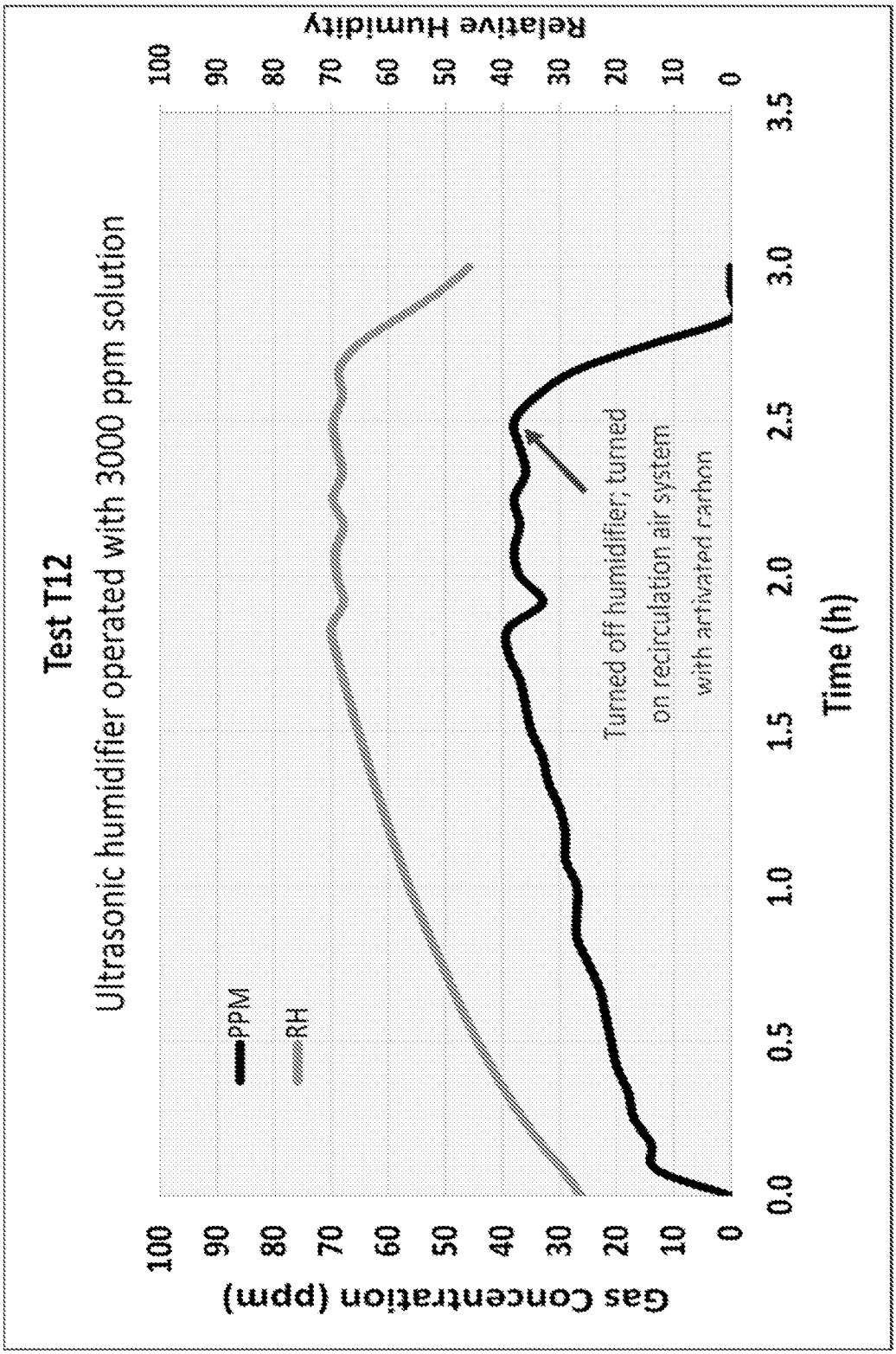
Test T12
Ultrasonic humidifier operated with 3000 ppm solution
PPM
RH
Turned off humidifier, turned on recirculation air system with activated carbon
Gas Concentration (ppm)
Relative Humidity
Time (h)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
10
20
30
40
50
60
70
80
90
100

FIG. 48

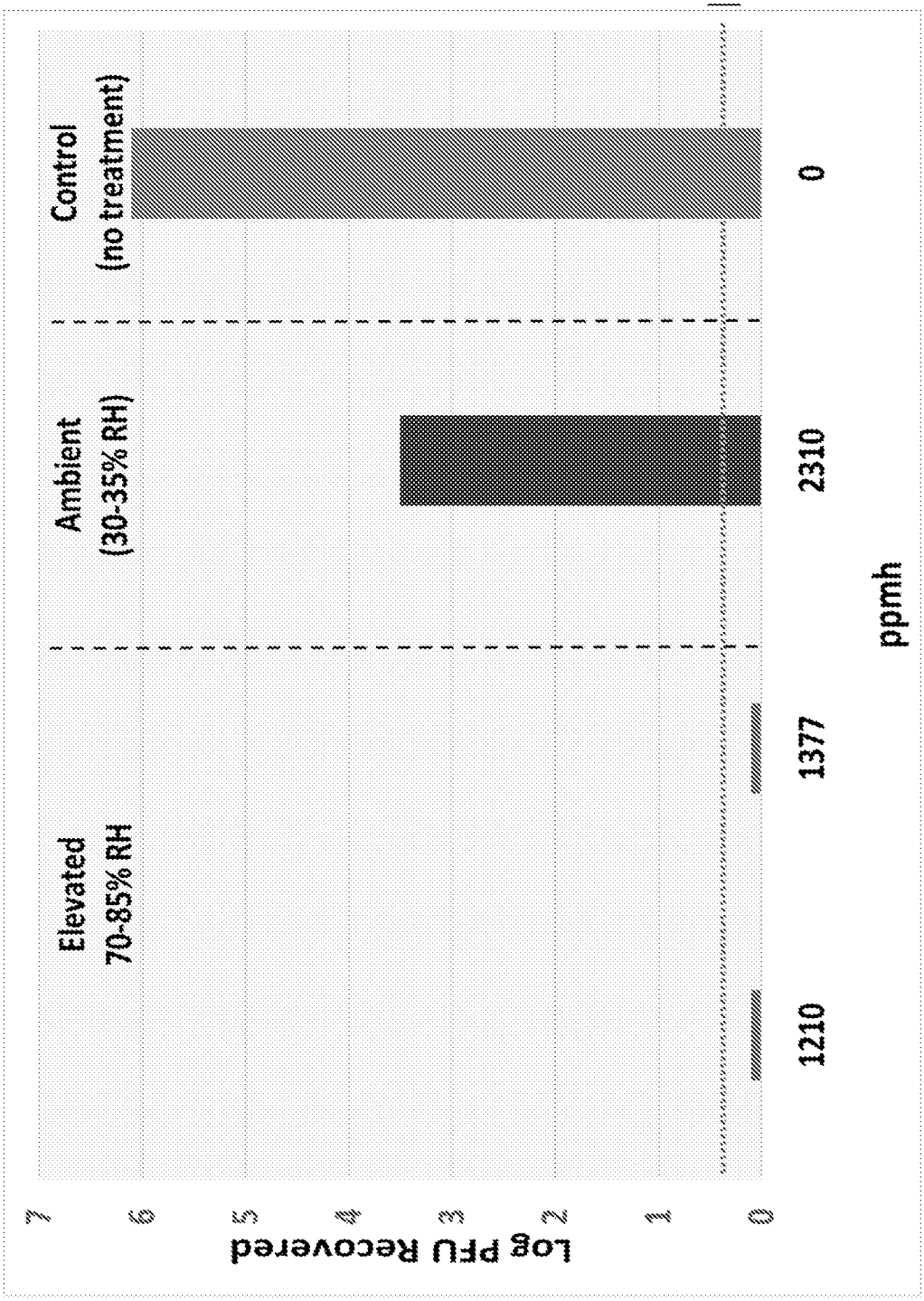
Log PFU Recovered
0
1
2
3
4
5
6
7
Elevated
70-85% RH
Ambient
(30-35% RH)
Control
(no treatment)
1210
1377
2310
0
ppmh

FIG. 49

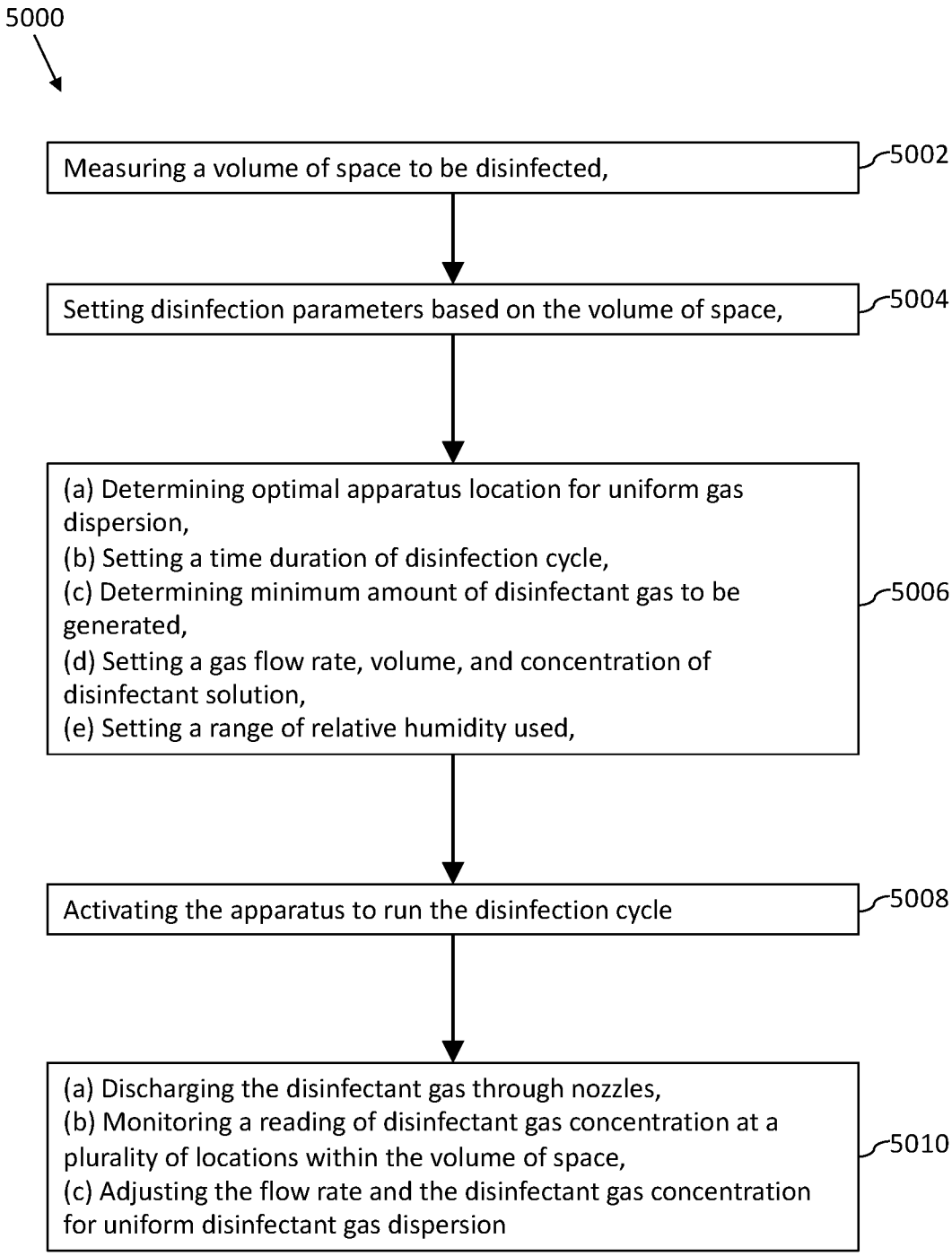
5000
Measuring a volume of space to be disinfected,
5002
Setting disinfection parameters based on the volume of space,
5004
(a) Determining optimal apparatus location for uniform gas dispersion,
(b) Setting a time duration of disinfection cycle,
(c) Determining minimum amount of disinfectant gas to be generated,
(d) Setting a gas flow rate, volume, and concentration of disinfectant solution,
(e) Setting a range of relative humidity used,
5006
Activating the apparatus to run the disinfection cycle
5008
(a) Discharging the disinfectant gas through nozzles,
(b) Monitoring a reading of disinfectant gas concentration at a plurality of locations within the volume of space,
(c) Adjusting the flow rate and the disinfectant gas concentration for uniform disinfectant gas dispersion
5010

FIG. 50

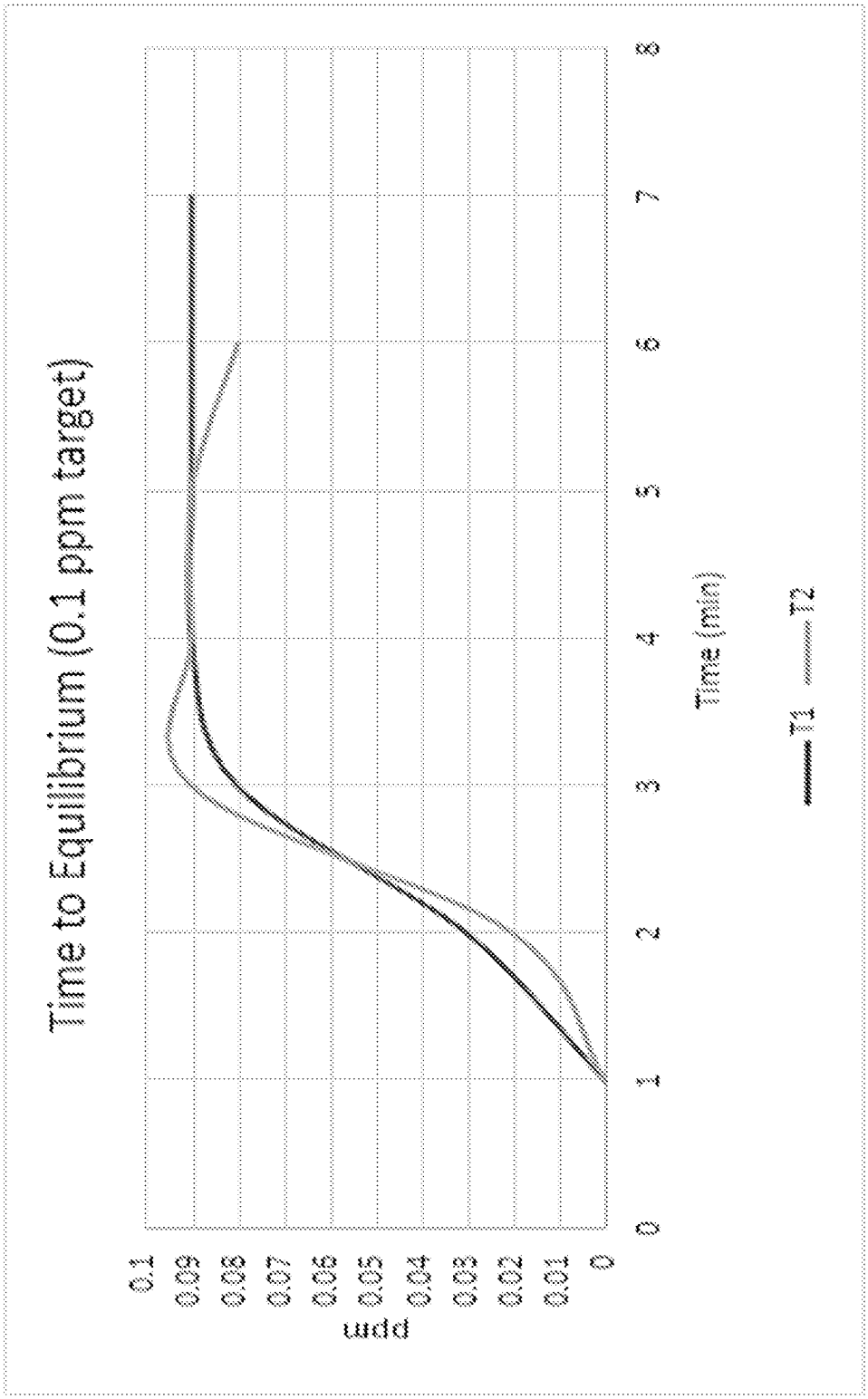
Time to Equilibrium (0.1 ppm target)
ppm
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
1
2
3
4
5
6
7
8
Time (min)
T1
T2

FIG. 51A

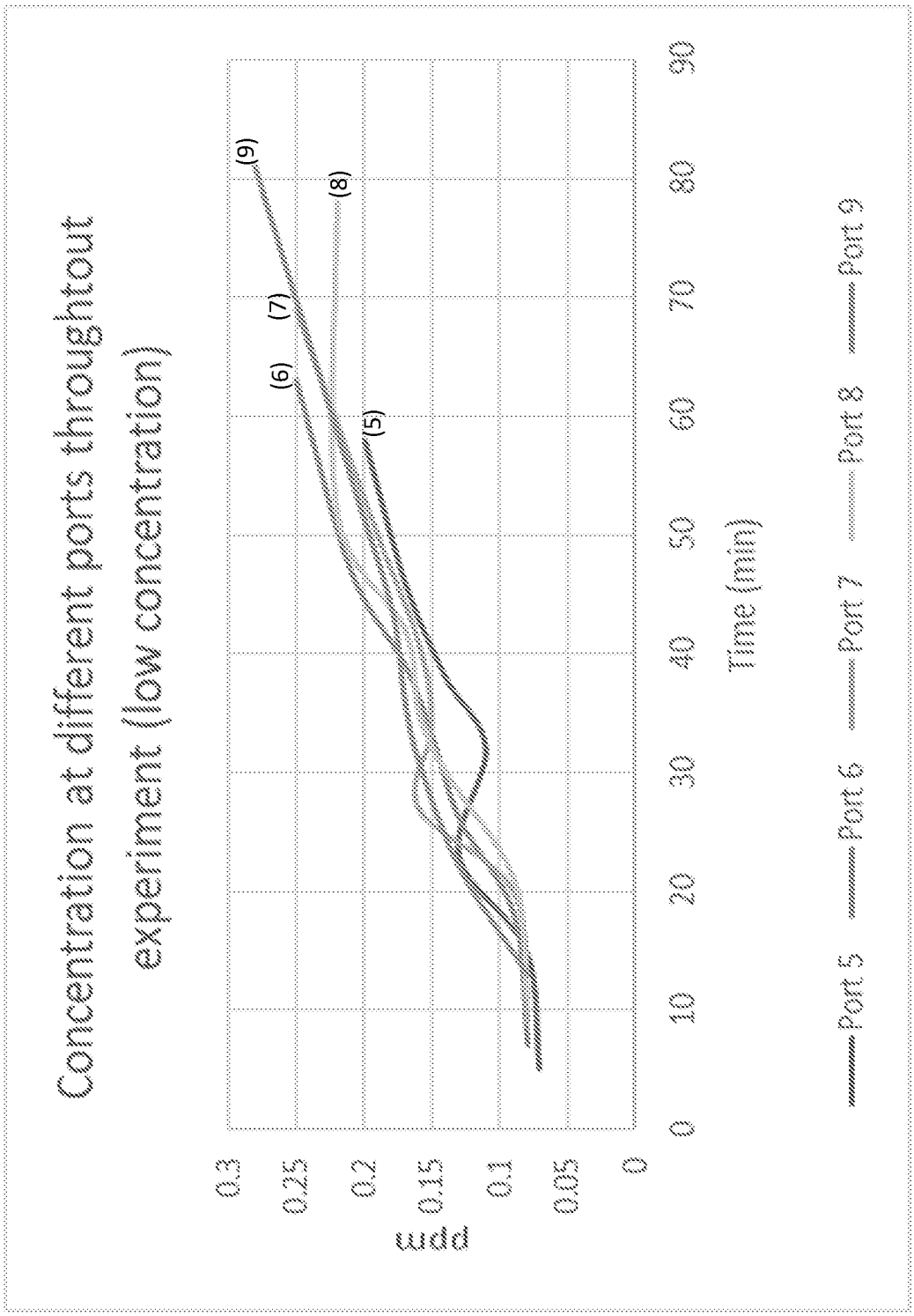
Concentration at different ports throughout experiment (low concentration)
ppm
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50
60
70
80
90
Time (min)
(5)
(6)
(7)
(8)
(9)
Port 5
Port 6
Port 7
Port 8
Port 9

FIG. 51B

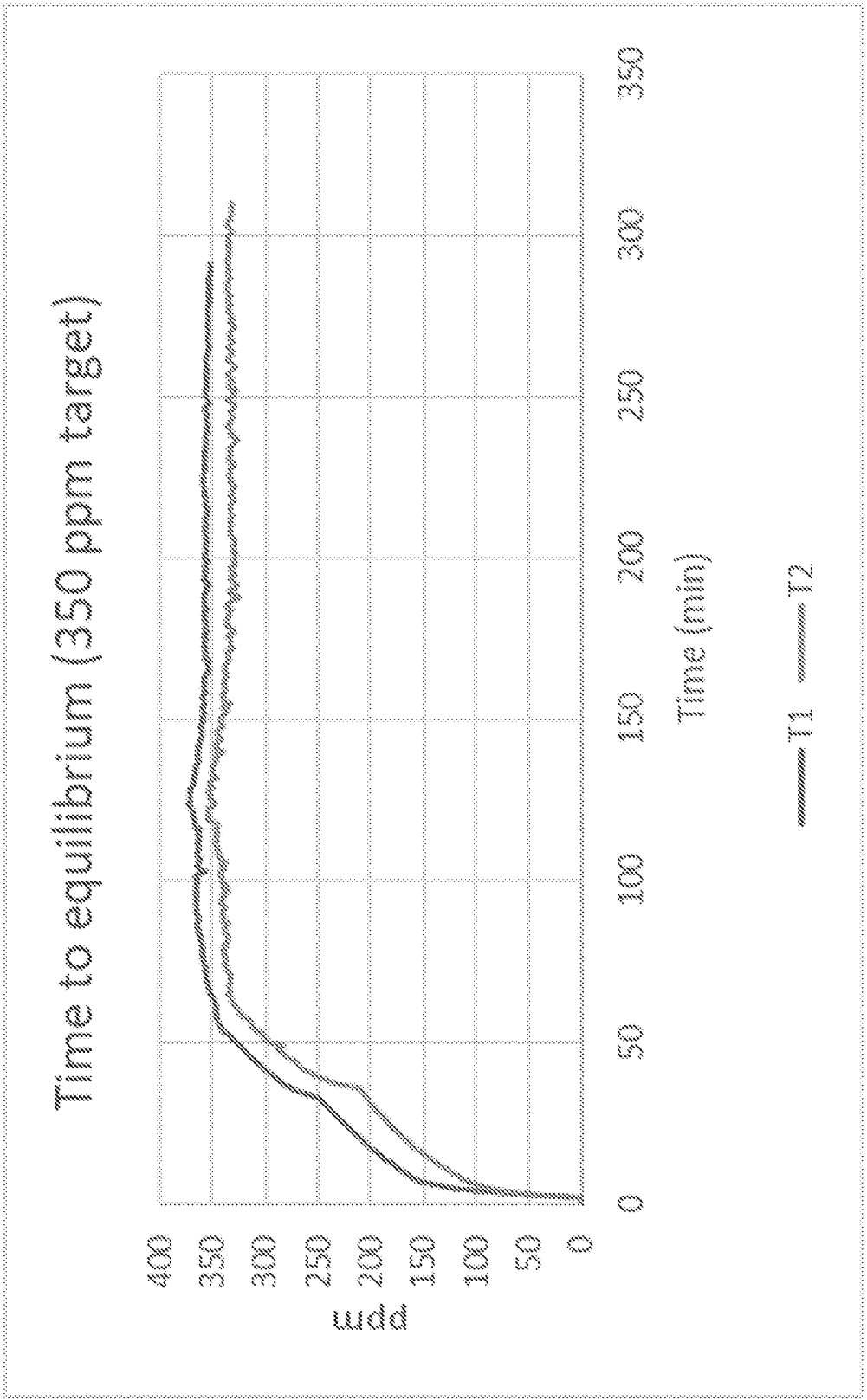
Time to equilibrium (350 ppm target)
ppm
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
Time (min)
T1
T2

FIG. 52A

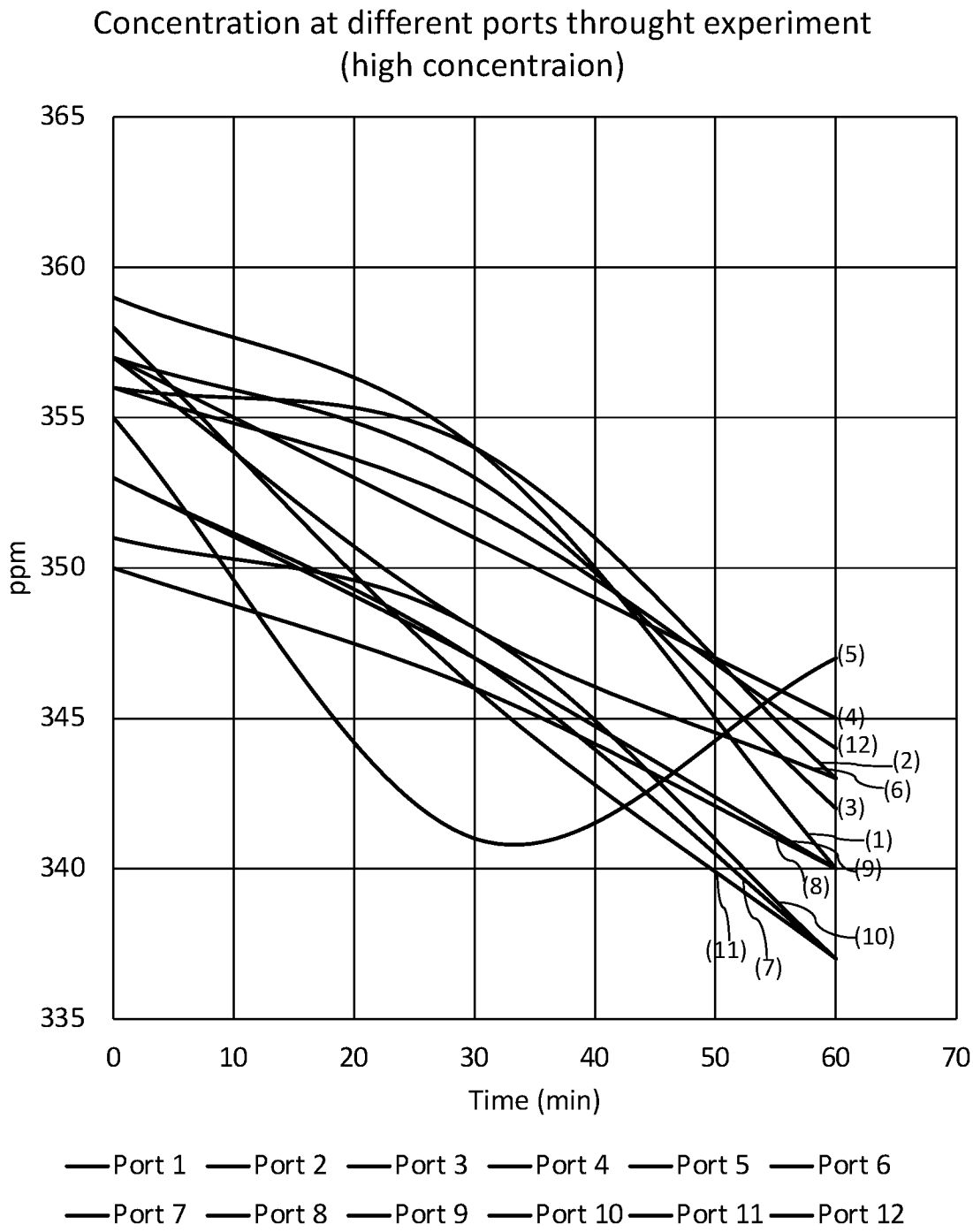
Concentration at different ports throught experiment
(high concentraion)
365
360
355
350
345
340
335
ppm
0
10
20
30
40
50
60
70
Time (min)
(5)
(4)
(12)
(2)
(6)
(3)
(1)
(9)
(8)
(10)
(11)
(7)
Port 1
Port 2
Port 3
Port 4
Port 5
Port 6
Port 7
Port 8
Port 9
Port 10
Port 11
Port 12

FIG. 52B

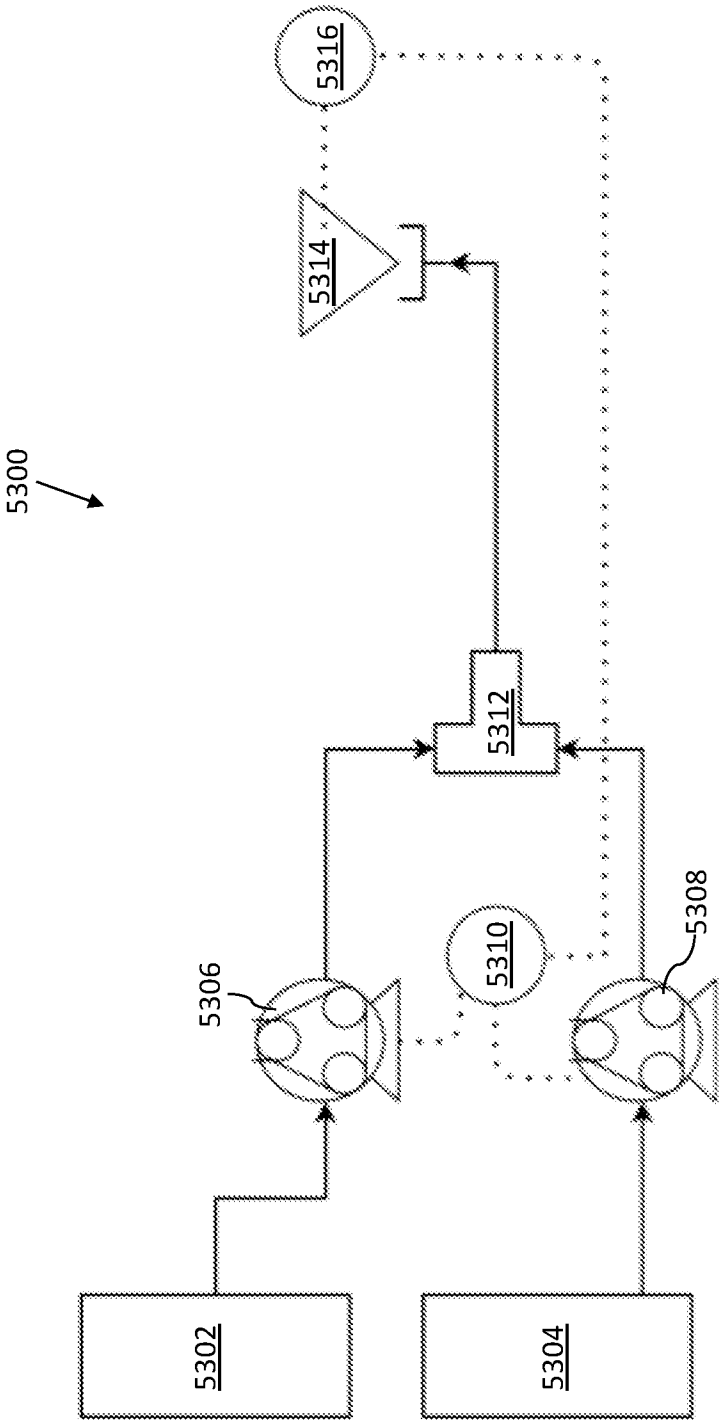

FIG. 53A

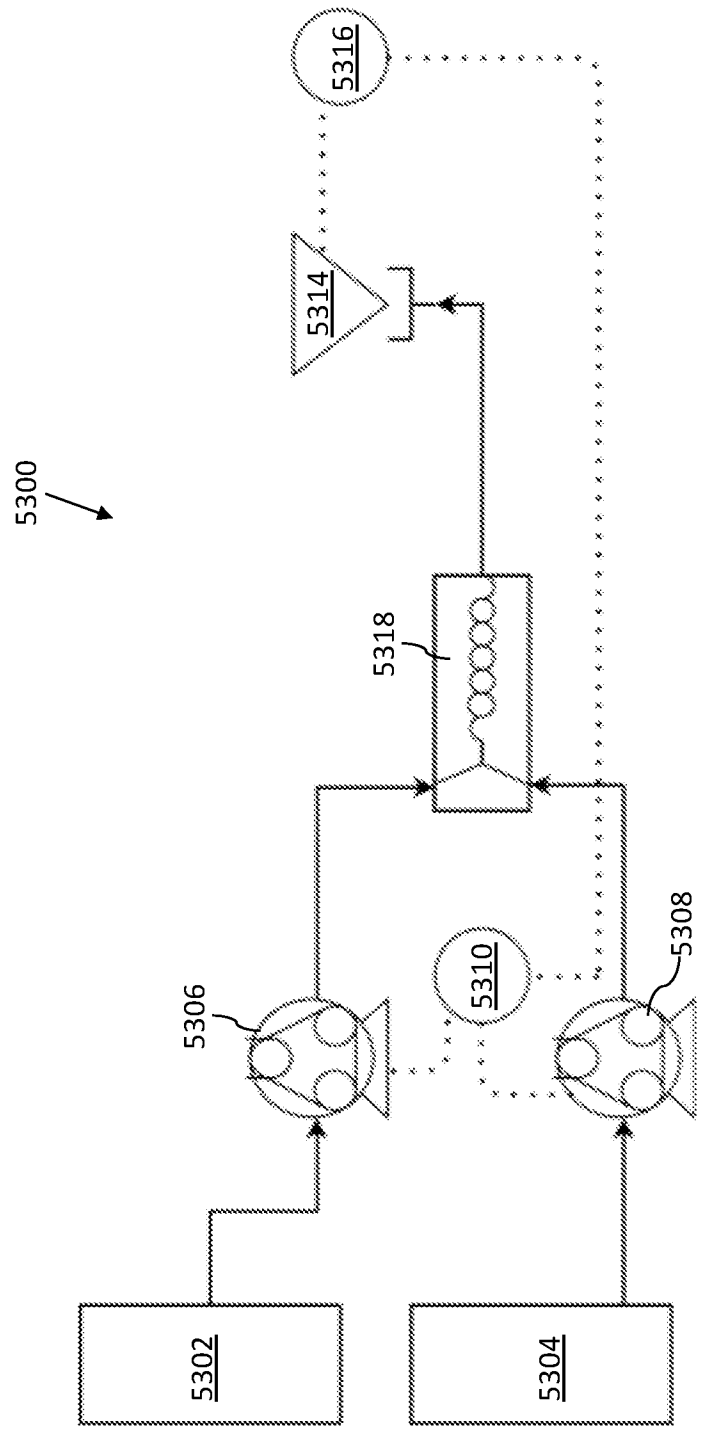

FIG. 53B

Acid Generation	NaClO2 Solution (80%) g/mL	Volume NaClO2 Solution ul	Activator	Activator Conc.	Volume Activator ul	Molar Ratio [NaClO2: Activator]	ClO2 Conc. In Tote ppm	Complete Conversion (mg ClO2)	Measured (mg ClO2)	Measured Efficiency
1	0.75	22	Na2S2O8	0.5 g/mL	139	2	48.6	9.84	10.15	103%
2	0.75	22	HCl	12 M	36	3	44.3	7.88	9.25	117%
3	0.75	22	CH2O2	100%	33	6	54	9.84	11.28	115%

FIG. 54A

Electrolysis Generation	Cell Type	Anolyte: NaClO2 Solution (80%) g/mL	Catholyte: NaNO3 Solution g/mL	Potential (V)	Current (A)	Time On (min)	Power (W)	Energy (J)	ClO2 Conc. In Tote ppm	ClO2 (mg) Generated	ClO2 Measured (mg)	Measured Efficiency
5	Membrane	0.25	0.19	12	0.468	3	5.6	1011	114	24.99	23.81	95%
	Membrane	0.50	0.38	12	0.600	1.5	7.2	648	73	16.50	15.00	91%
4	No Membrane	0.50	None	5	1.6	1.35	8.0	648	44	16.50	9.00	55%

FIG. 54B

Chemical Use - 1000 ft3 room

Single Dose - 0.10 ppm in 1000 ft3

Generation Method	Activator	Molar Ratio	Volume Ratio	Efficiency	NaClO2 Volume (ul)	Activator Volume (ul)	Total Volume (ul)	Total Volume (ml)	1000 ft3 30 days continuous operation 5 air exchanges per hr 250% makeup air Total Volume (ml)	1000 ft3 30 days continuous operation 5 air exchanges per hr 100% makeup air Total Volume (ml)
1	Na2S2O8	2	6.32	100%	17.46	110.27	127.73		114.96	459.82
2	HCl	3	1.64	100%	17.46	28.95	46.41	0.05	41.77	167.08
3	CH2O2	6	1.50	100%	17.46	26.22	43.68	0.04	39.31	157.23
4	Electrolysis	N/A	N/A	55%	31.74	None	31.74	0.03	28.57	114.27
5	Membrane	N/A	N/A	100%	17.46	None	17.46	0.02	15.71	62.85

FIG. 54C

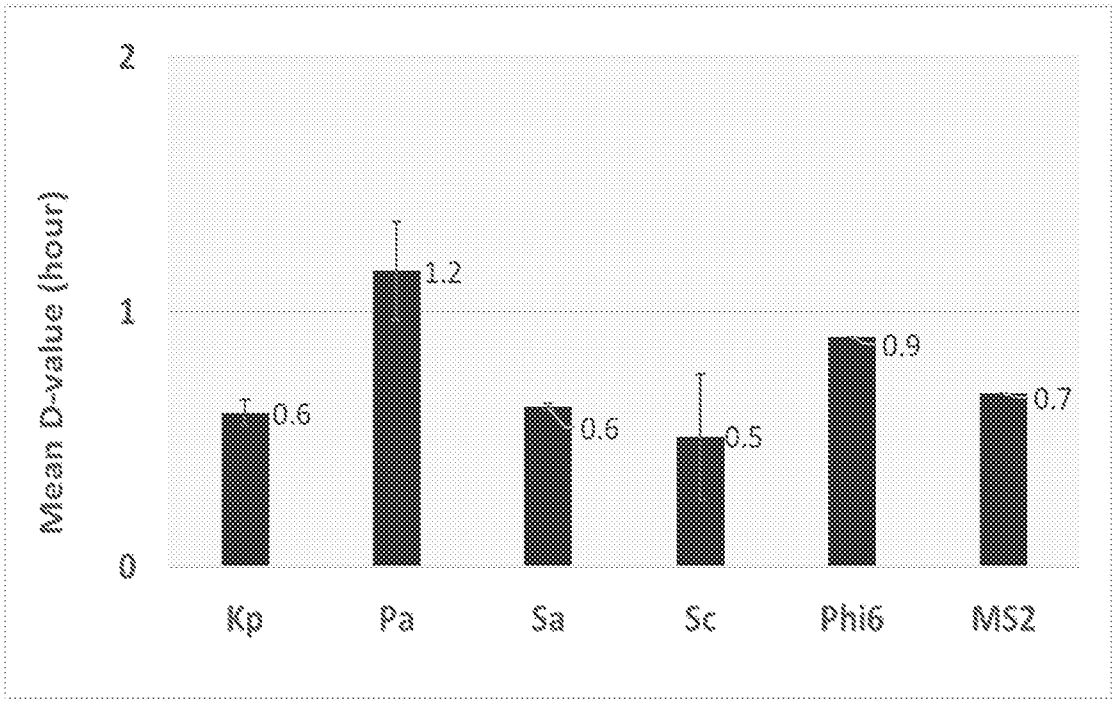

FIG. 55A

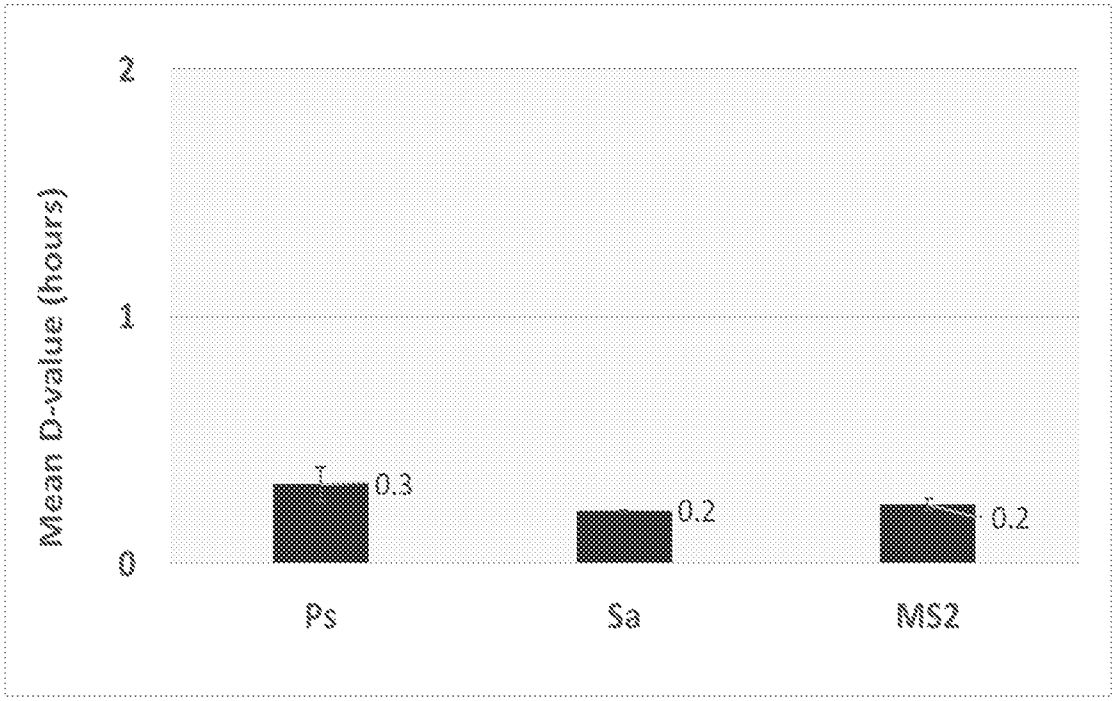

FIG. 55B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/036501

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A61B 5/00; A61B 5/01; A61B 5/145; A61B 5/1486; A61B 5/1495 (2021.01)
CPC - C11D 3/48; A61L 2202/25; A61B 5/00; A61B 5/14532; A61B 5/14546 (2021.08)

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)
see Search History document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/0271450 A1 (DEXCOM INC.) 27 September 2018 (27.09.2018) entire document	1-3
---		---
Y		18, 21, 22
---		---
A		4-14, 32, 34
X	US 2006/0051285 A1 (HAWKER et al) 09 March 2006 (09.03.2006) entire document	15, 16
---		---
Y		17-19, 21, 22, 25-30
---		---
A		4-14, 20, 23, 24
Y	US 2005/0233198 A1 (NUZZO et al) 20 October 2005 (20.10.2005) entire document	17, 22, 31, 33
---		---
A		32, 34
Y	US 2016/0251219 A1 (CHEMTREAT INC.) 01 September 2016 (01.09.2016) entire document	19
---		---
A		20
Y	US 4,852,613 A (TIPPETTS et al) 01 August 1989 (01.08.1989) entire document	25
Y	US 2016/0110657 A1 (SKYTREE INC.) 21 April 2016 (21.04.2016) entire document	26-31, 33
---		---
A		32, 34

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"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	Date of mailing of the international search report
13 October 2021	NOV 18 2021
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Harry Kim Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/036501

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y --- A	US 2012/0121731 A1 (PETERS et al) 17 May 2012 (17.05.2012) entire document	31, 33 --- 9-14, 24, 32, 34
A	US 2008/0167650 A1 (JOSHI et al) 10 July 2008 (10.07.2008) entire document	23

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/036501

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet(s).

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/036501

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-14, is drawn to a system for generating and monitoring an antimicrobial, comprising: a computational system.

Group II, claims 15-34, is drawn to a system for generating and monitoring ClO2, comprising: a device housing including an inlet

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: a computational system; an antimicrobial sensor; and an antimicrobial generator, wherein the computational system, the antimicrobial generator, and the antimicrobial sensor are operatively connected as claimed therein is not present in the invention of Group II. The special technical feature of the Group II invention: a device housing including an inlet; a microcontroller or microprocessor; a reagent container containing a reagent; a device for generating a ClO2 from the reagent as claimed therein is not present in the invention of Group I.

Groups I and II lack unity of invention because even though the inventions of these groups require the technical feature of a system for generating and monitoring a material, comprising a sensing system; a communication device, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2018/0271450 to DexCom, Inc. teaches a system for generating and monitoring a material, comprising a sensing system; a communication device (Paras. [0236], [0379-0380], [0394], [0412]).

Since none of the special technical features of the Group I or II inventions are found in more than one of the inventions, unity of invention is lacking.