



(51) International Patent Classification:

B01D 53/14 (2006.01) B01D 53/62 (2006.01)

B01D 53/18 (2006.01) B01D 53/74 (2006.01)

(21) International Application Number:

PCT/US2018/016966

(22) International Filing Date:

06 February 2018 (06.02.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

62/523,658 22 June 2017 (22.06.2017) US

(71) Applicant: ALLIED HEALTHCARE PRODUCTS, INC. [US/US]; 1720 Sublette Avenue, St. Louis, Missouri 63110 (US).

(72) Inventor: RILEY, Andrew D.; c/o ALLIED HEALTHCARE PRODUCTS, INC., 1720 Sublette Avenue, St. Louis, Missouri 63110 (US).

(74) Agent: BAI, Ari et al.; POLSINELLI PC, 105 West Vandalia, Suite 400, Edwardsville, Illinois 62025 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,

CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

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

(54) Title: PORTABLE CARBON DIOXIDE ABSORPTION SYSTEM

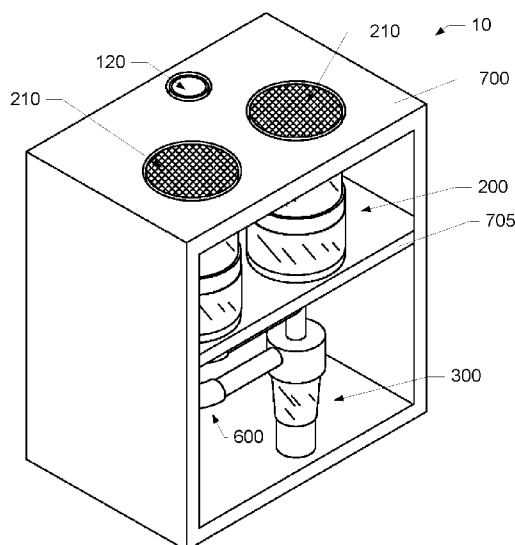


FIG. 1

(57) Abstract: Various embodiments of a portable carbon dioxide (CO₂) absorption device that may remove excess CO₂ from a closed environment are disclosed herein. The absorption device is reusable and configured for many environments.



PORTABLE CARBON DIOXIDE ABSORPTION SYSTEM

FIELD

[0001] The present disclosure generally relates to a portable carbon dioxide (CO₂) absorption device that may remove excess CO₂ from a closed environment. The absorption device is reusable and configured for many environments.

BACKGROUND

[0002] Use of frozen carbon dioxide (CO₂), commonly called dry ice, to maintain low temperatures during the transport of perishable items, is a common practice in many industries. However, during transit and periods of loading and or unloading, the dry ice may sublime to CO₂ gas. In many environments, such as sealed or poorly ventilated areas of an airplane, truck, or shipping container, increased CO₂ concentrations may have detrimental consequences. Present technology is not portable; it is large, heavy, cumbersome, and arduous to set up and requires a large footprint or committed space for use. The present technology cannot be brought to the problem or area where carbon dioxide (CO₂) gas levels are increasing, but this invention can be brought to the problem where carbon dioxide (CO₂) gas levels are increasing and scrub out the dangerous CO₂ gas levels to reasonable permissible levels. The present technology requires large canisters or cartridges that are heavy and difficult to change.

[0003] This invention will keep aircrews safe from toxic levels of carbon dioxide gas produced from the sublimation of dry ice required for perishable shipments during engine starts and de-icing events. This is especially dangerous in confined/small/limited/enclosed spaces such as the cockpit and supernumerary of a plane where the flight crew resides. Once the exposure to CO₂ in the cockpit and or supernumerary exceeds 0.5% CO₂ by volume (v/v), the aircrew, per policy and safety procedure, has to don oxygen masks, and bring the plane back to the gate where the aircrew leaves the plane, the plane is ventilated, and shipments are delayed. In addition, this invention will increase the air transport dry ice capacity and reduce the number of delayed shipments due to increased carbon dioxide gas levels in aircrew occupied areas, i.e., cockpit and supernumerary.

SUMMARY

[0004] The disclosure generally relates to a portable device that reduces the level of carbon dioxide in an environment. In various embodiments, the device operates automatically to continuously monitor and reduce the concentration of carbon dioxide in an environment. The device may be battery operated or powered by an external power supply. The device is durable and suitable for many industrial applications.

BRIEF DESCRIPTION OF FIGURES

[0005] The application file contains at least one photograph executed in color. Copies of this patent application publication with color photographs will be provided by the Office upon request and payment of the necessary fee.

[0006] FIG. 1 is a front perspective view of a portable carbon dioxide absorption system with portions of the exterior housing removed according to one embodiment.

[0007] FIG. 2 is a rear perspective view of a portable carbon dioxide absorption system with portions of the exterior housing removed according to one embodiment.

[0008] FIG. 3 is a rear elevation view of a portable carbon dioxide absorption system with portions of the exterior housing removed according to one embodiment.

[0009] FIG. 4 is a side elevation view of a portable carbon dioxide absorption system with portions of the exterior housing removed according to one embodiment.

[0010] FIG. 5 is a top plan view of a portable carbon dioxide absorption system according to one embodiment.

[0011] FIG. 6 is a front elevation view of a portable carbon dioxide absorption system with portions of the exterior housing removed according to one embodiment.

[0012] FIG. 7 is a front perspective view of a portable carbon dioxide absorption system with the exterior housing in place according to one embodiment.

[0013] FIG. 8 is a front perspective view of a portable carbon dioxide absorption system with the exterior housing in place according to one embodiment.

[0014] FIGS. **9-14** are various views of an internal component assembly of a portable carbon dioxide absorption system according to various embodiments.

[0015] FIG. **15** is a schematic drawing of a control system and power system according to one embodiment.

[0016] FIGS. **16-17** are example schematics of a controller and control circuit, respectively.

[0017] FIGS. **18-31** are photographs of another embodiment of the portable carbon dioxide absorption system according to another embodiment.

[0018] FIG. **32** is a graph showing CO₂ absorption levels over time with the portable carbon dioxide absorption system operating in various states, of according to one embodiment.

[0019] FIG. **33** is a table showing CO₂ absorption levels over time with the portable carbon dioxide absorption system operating in various states, of according to one embodiment.

[0020] Any dimensions in the figures are merely for example and do not necessarily limit the size of the devices depicted.

DETAILED DESCRIPTION

[0021] The present disclosure relates to a lightweight and portable carbon dioxide absorbing system for removing or scrubbing carbon dioxide gas from the air. The system may be configured for a wide variety of environments. For example, the carbon dioxide absorbing system may maintain or reduce CO₂ levels in airplanes before, during, and after flight.

[0022] The United States Federal Aviation Administration (FAA) classifies dry ice as a hazardous material. The FAA has published guidelines for determining dry ice capacities in aircraft. Per the FAA Advisory Circular, 91-76A, Hazard Associated with Sublimation of Solid Carbon Dioxide (dry Ice) Aboard Aircraft, the exposure to CO₂ in the aircraft should not exceed 0.5% CO₂ by volume (v/v). Sublimed CO₂ is colorless and odorless and at high concentrations in a confined/small/limited/enclosed space, such as an airplane, can cause aircrew incapacitation.

[0023] Gaseous CO₂ produced from the sublimation of dry ice or produced from other sources is also regulated. The FAA notes that sublimed solid

CO₂ produces excess CO₂ gas and this may be dangerous in confined spaces where there is no ventilation or ventilation rates are low. This condition is exacerbated during airplane engine starts and de-icing of the airplane where the power packs or electrical infrastructure is shut down and all ventilation and air exchange is stopped.

[0024] The sublimation rate depends on environmental conditions such as temperature and pressure, the physical properties of the dry ice such as surface area, and the quality of the packaging such as insulated versus non-insulated materials. The FAA has developed a standard formula to provide a rule of thumb for dry ice loading; the product of the desired CO₂ concentration, 0.5% v/v, the total volume of the aircraft and the complete number of air exchanges per hour proportional to two standard sublimation rates: 1% per hour and 2% per hour.

Therefore, for a sublimation rate, when the number of air exchanges is doubled, then the permissible capacity for transported volumes of dry ice also doubles. Conversely, if the air exchanges are reduced relative to a determined sublimation rate, then the permissible capacity of dry ice that can be transported is also reduced by half.

[0025] In various aspects, modern aircraft may recycle as much as 50% of cabin-ventilated air, instead of providing 100% fresh air exchange. This reduction in volume of complete air exchanges per hour therefore leads to a reduction in permissible dry ice shipping capacities. As a reduced dry ice capacity would affect the volume and timeline for the transport of perishable items, food, medicine, and/or biological materials, a means to maintain safe CO₂ levels is needed.

[0026] The Portable Carbon Dioxide Absorption Machine (PCDAM) of the present disclosure is well suited to reduce or maintain CO₂ levels in confined environments. As CO₂ gas is denser than air, the CO₂ gas displaces air and remains low to the floor or ground. The PCDAM can be conveniently and easily placed in the cockpit and supernumerary and operated even when the plane is powered down, without the airplane's power packs or network, to maintain safe CO₂ concentration levels. The PCDAM can be turned on during de-icing and engine starting events where it will maintain a safe environment for the aircrew, reduce the number of delayed shipments, and increase the overall air transport dry ice capacity where employed.

[0027] The PCDAM may also be scaled up or down or reconfigured to fit a variety of spaces and environments. For example, besides freighter or cargo

airplanes, the PCDAM may also be used in food processing environments, where carbon dioxide is a food additive, a propellant, acidity regulator, leavening agent, or used to remove caffeine. Similarly, the PCDAM may be used in beverage manufacturing facilities and breweries where CO₂ is used to carbonate soft drinks, aid in fermentation, and to rapidly cool grapes to prevent spontaneous fermentation prior to processing. The PCDAM is also suitable for many other industrial applications. These include, but are not limited to, facilities where welding, metal working and construction are performed, as CO₂ gas is a shielding gas for welding or a pressurized propellant for portable pneumatic tools. These industrial applications also include any facility with a fire suppression system, as these typically include large amounts of liquid and gas carbon dioxide at various pressures. After a fire, it is desirable to remove the dense carbon dioxide gas to aid in rescue and recovery. The PCDAM may also be used in a biological facilities, slaughterhouses, and laboratories where high rates of photosynthesis or bacterial and waste decomposition generate volumes of CO₂.

[0028] In commercial refrigeration applications, a carbon dioxide based refrigerant may be used, while in oil extraction operations, carbon dioxide gas may be injected into wells at high pressures. Both applications involve large volumes of CO₂ that may adversely affect operators if a leak or other accident occurs. Similarly, large volumes of CO₂ are used or produced in cement production, foundries, and power plants, all of which benefit from controlling levels of CO₂ in the local environment.

[0029] In general, the PCDAM has a small portable configuration. By way of example and not limitation, the PCDAM may be lightweight (approximately less than 18 kg or 40 lb.) and compact (approximately the size of a carry-on suitcase). In one example, the PCDAM 10 may be approximately 14 inches wide x 9 inches deep x 24 inches tall.

[0030] In various embodiments, The Portable Carbon Dioxide Absorption Machine (PCDAM) **10**, as shown in FIGS. **1-8**, includes one or more blower/fans **100**, one or more CO₂ absorbing devices **200**, a manifold **300**, a power system **400**, a control system **500**, a fluid conduit arrangement **600**, and a housing **700**. Embodiments of the one or more blower/fans **100**, the one or more CO₂ absorbing devices **200**, the manifold **300**, and the fluid conduit arrangement **600** as assembled are shown without the housing in FIGS. **9-14**.

[0031] The blower/fan **100** is an air-moving device capable of flow rates in the range of 20–60 cubic feet per minute, according to one embodiment. The blower includes an inlet that is in fluid communication with the CO₂ devices **200** and the manifold **300** via the fluid conduit system **600**. According to one embodiment, when in operation, the blower/fan **100** generates a positive pressure to push air, generally indicated by air flow **800** in FIG. **2**, through the manifold **300** and out through the CO₂ devices **200**. Alternately, in other embodiments, the blower/fan **100** generates a negative pressure to draw air, indicated by airflow **900**, in through the CO₂ devices **200**, through the manifold **300**, and out of the housing **700**.

[0032] During operation, the air in the local environment is recycled at approximately 20–50 cubic feet per minute. The PCDAM **10** may reduce the level of CO₂ by 0.05 – 0.15% (v/v) per minute or to acceptable levels. In other embodiments, the PCDAM device operates at a maximum flow rate for maximum CO₂ absorption. Alternatively, the PCDAM may operate to provide a gradual or metered reduction in CO₂ concentration. In this embodiment, the PCDAM may continuously monitor the environment and maintain a specific CO₂ concentration by varying the flow rate of air through the absorbing devices. By way of example, the flow rate may be varied via a potentiometer or similar component.

[0033] In various embodiments, the blower/fan **100** has a blower configuration wherein air is counter-currently pushed by a blower/fan by a wheel (not shown) driven by a fully enclosed brushless motor that is suitable for dirty, dusty and/or damp environments. In various other embodiments, the blower/fan **100** has a fan configuration wherein a propeller pushes air out of the blower/fan.

[0034] In operation, the PCDAM reduced CO₂ levels using a variety of means. In one embodiment, the PCDAM **10** includes one or more CO₂ absorbing devices **200** configured to permit air to drawn in through an inlet portion **120** and an outlet portion **210**. The outlet portion **210** generally has a width greater than that of the inlet portion **120** to decrease the velocity of air leaving the absorbing device **200**; this ensures laminar flow, consistent rates of reaction and low buoyancy to prevent the release of dust, dirt, or particulates to the surrounding environment. In various embodiments, the outlet portion **210** includes a screen, mesh, or multiple openings **230**, as shown in FIG. **5** and FIG. **22**, to permit the release of air, while preventing undesired objects from entering or leaving the devices. The outlet portion **210** may

be positioned generally opposite the inlet **120** and contain a CO₂ absorbing material in such a configuration to maximize airflow therethrough.

[0035] For example, the CO₂ absorbing device **200** may incorporate a solid CO₂ absorbing material **240**. For example, the CO₂ absorbent **240** may include one or more derivatives of ammonia (i.e., an amine such as monoethanolamine, among others). In other embodiments, the CO₂ absorbent **240** may be composed of one or more minerals. The mineral or minerals are typically provided in powder form, while in other embodiments, forms of the mineral material may be provided. These include, but are not limited to solid, semi-solid, or liquid compositions. Typically, the minerals are chemically configured as oxides, so the CO₂ reacts with the minerals to form carbonate. Preferably, the absorbent material **240** is suitable for disposal with general waste and not subject to hazardous waste procedures.

[0036] One advantage of the PCDAM **10** is the interchangeability of the CO₂ absorbing devices **200**. After a period of operation, each CO₂ absorbing device **200** may be removed and replaced to provide continual reduction of CO₂ levels in the environment. In one embodiment, The CO₂ absorbent devices house the absorbent **240** in convenient canister cartridges for practical and quick replacement of the media. In other embodiments, the absorbing device **200** may use refillable canisters.

[0037] After air entering the PCDAM flows through the blower/fan **100**, the airflow enters a filtering manifold system **300** where it is expanded and thus filtered to capture dust or other particulates prior to flowing through the CO₂ absorbing devices **200**, preventing this potential matter from being emitted to the surrounding environment through the outlet portion **210**. In one aspect, the positive pressure generated by the blower/fan **100** draws environmental air into the manifold system **300** and then through the CO₂ absorbing devices **200**. As shown in FIGS. **6** and **11-12**, the manifold system **300** includes a manifold housing **310** that defines an expansion chamber **320** having an expanded control volume sufficient to momentarily reduce the velocity of air traversing the manifold **300** system. In other embodiments, the manifold system **300** may be configured to use baffles or cyclonic separation. Residual dust from CO₂ absorbent **240**, any other foreign particulates, and/or moisture produced from the absorption of CO₂ in the CO₂ absorbing device **200**, are collected within the manifold chamber **320**. In one embodiment, the manifold system **300** functions similar to a vacuum trap, and separates the blower/fan **100** input portion **110** of the fluid conduit system **600** from the manifold

inlet side **320** of the fluid conduit system, thus protecting the blower/fan **100** and the external environment **20**. In another embodiment, the manifold system **300** functions similar to a dropout box, flash evaporator or expansion chamber, and separates the blower/fan **100** input portion **120** of the fluid conduit system **600** from the manifold inlet side **320** of the fluid conduit system.

[0038] As shown in several figures, the air drawn in to the PCDAM **10** is directed through the components of the system by the fluid conduit system **600**. The conduit system **600** includes plurality of fluid transporting conduits to permit controlled fluid communication between the external environment **20**, the fan/blower **100**, the CO₂ absorbing devices **200**, and the manifold device **300**. In various embodiments, the fluid conduit system **600** may be constructed of any suitable material including but not limited to poly (vinyl chloride) ("PVC") piping or tubing. In various embodiments, any other suitable materials may be used. To increase the lifespan of the PCDAM, it is desirable to use non-corrosive or non-reactive materials for the fluid conduit system, including the bushings, joints, or other fittings. By way of example, the conduit system may include flexible or rigid conduits composed of polypropylene, polycarbonate, polyethylene, fiberglass, chlorinated polyvinyl chloride (CPVC), polypipe, aluminum, copper, galvanized metal, rubber, butyl, nitrile rubber (e.g., buna-n), buna-s, silicone, neoprene, urethane, ethylene propylene diene monomer (EPDM) rubber, fluoroelastomer, or combinations thereof.

[0039] As shown in FIGS. **3**, **6**, and **15-17**, the PCDAM **10** is powered by a power system **400** and controlled by a control system **500**. In various embodiments, the power system **400** includes a battery **410**, which may be rechargeable according to at least one embodiment. In one embodiment, the battery may be charged off the plane and loaded prior to flight with a battery life of over 4 hours of continuous run time. In other embodiments, the battery may be charged by any external power supply. For example, the power system **400** may include an internal charger that charges the battery using any suitable external power supply, including those available on the plane. It has been observed that a critical time for CO₂ sublimation without proper ventilation is during de-icing or engine start events where the ventilation systems are shut down and closed off to the outside. The battery **410** may be secured to the housing, as shown in FIGS. **23-25**.

[0040] In other embodiments, the PCDAM **10** is powered by direct wiring to an external power supply or plugged into an outlet of an external power

system, generally indicated as **430**, as shown in Figs. **20-21**. Yet in other embodiments, a combination of a battery and external power supply may provide extended use in remote locations. For example, the PCDAM **10** may operate at maximum performance level when engaged to an external power source, such as an alternating current (AC) power source, when the battery is depleted or charging.

[0041] In various embodiments, the control system **500**, as shown in FIGS. **3**, **6**, and **15-17**, includes one or more processors or controllers **510** mounted on a printed circuit board **520**. The control system may include other components including, but not limited to, relays **530**, terminals **540**, converters **545**, switches **550**, and control modules **560**. As shown in various embodiments, the control system is in electrical communication with both the battery **410** and an external power system **420**. The control system may also include sensors to monitor CO₂ levels in the environmental air, alarms, displays, audio/visual indicators, generally indicated as **580**, or combinations thereof, that allow a user to observe operation of the PCDAM **10**, including the charging status of the battery **410**. By way of example and not limitation, a schematic for one embodiment of a controller **510** is shown in FIG. **16**, while FIG. **17** is an example circuit diagram of a control system circuit **570**. The controllers and circuits shown in FIGS. **16** and **17** are provided as illustrative examples only and do not limit the scope of the systems and components used to power and control the PCDAM **10**.

[0042] According to various embodiments, the PCDAM **10** may operate in a continuous operation mode to provide continual CO₂ monitoring and absorption. Alternatively, the control system **500** may operate the PCDAM in an intermittent mode where the environmental CO₂ levels are monitored and the blower/fan **100** is activated when a threshold value for CO₂ concentration has been reached and the PCDAM automatically operates to reduce the CO₂ level. In yet another configuration, the PCDAM **10** may be operated remotely as desired.

[0043] The housing **700** is typically a rigid structure that protects the internal components of the PCDAM **10**. By way of example and not limitation, the housing **700** may be composed primarily of aluminum. As shown in FIGS. **2** and **5**, among others, the top surface of the housing includes one or more apertures **720** aligned with each of the CO₂ absorption devices **200**. In one aspect, the housing **700** functions as a faraday cage to intrinsically shield the interior components from static electric fields and certain types of harmful electromagnetic pulses for reliable and

safe use in hospitals, laboratories, airplanes, and military applications where sensitive electronics may be present. As shown in FIGS. **1** and **2**, among others, the housing **700** may include one or more support structures **705** and one or more access panels **710** or vents **715** to permit access to the interior of the housing. Similarly, the housing may include several openings **720** where the exhaust portion **210** and the inlet portions **120** of the absorbing devices **200** are in fluid communication with the environment external to the housing **700**, as shown in FIGS. **5** and **22**. In one aspect, the outlet portions **210** and inlet portion **120** may protrude from the housing **700**. In other embodiments, the outlet portions **210** and inlet portion **120** may be flush with the exterior surface of the housing **700** or remain below the exterior surface of the housing. For example, when the outlet portions **210** and inlet portion **120** are recessed below the exterior surface, the openings **720** may remain separate and distinct or they may be configured as a single contiguous opening. Regardless of opening configuration, when the outlet portions **210** and inlet portion **120** are recessed below the exterior surface, the openings **720** may optionally have a protective screen or other vented covering.

[0044] In various other embodiments, the openings **720** and corresponding fan inlet portion **120** and absorbing device outlet port(s) **210** are not proximal to one another, nor are they limited to the top surface of the housing **700**. For example, the openings **720** and corresponding fan inlet port(s) **120** and absorbing device outlet portions **210** may be positioned on any other portion of the housing, including but not limited to the front, back, sides, and bottom portions (when the device is elevated or not resting on a solid surface).

[0045] Various embodiments of the PCDAM **10** may be used to perform to various processes and methods for automatically reduce CO₂ concentrations and maintain suitable CO₂ concentrations in an enclosed environment. By way of example, after placing the PCDAM **10** in the enclosed environment, the environmental concentration level of CO₂ in the enclosed environment may be continuously measured using a sensor in communication with the control system **500** of the PCDAM. Based upon the measured data, the processor **510** of the control system **500** determines if the environmental concentration level of CO₂ exceeds a predetermined threshold. In one aspect, the threshold is determined at least in part on the volume of the enclosed area and the anticipated increase in CO₂. While monitoring the environmental CO₂ levels, the processor **510** continuously or

intermittently operates the blower **100** to draw environmental air into the PCDAM **10**. As previously described, the PCDAM **10** absorbed CO₂ from air travelling through the device, thus the concentration of CO₂ in the air emitted from the PCDAM **10** is less than the environmental concentration level, thereby reducing the environmental concentration level. Lastly, once the environmental CO₂ level is below the threshold, the controller **510** automatically reduces or ceases operation of the blower **100**.

[0046] Figs. **32** and **33** display experimental performance data for an embodiment of the PCDAM **10**. In one experiment, an isolated controlled space or control volume (e.g. a room) was filled with carbon dioxide (CO₂) gas at a constant rate of 7.4 liters per minute. The experiment was conducted in two parts, both under the same conditions. In the first part, a control experiment was conducted where the PCDAM off, and in the second part the PCDAM was in operation. A calibrated CO₂ Data logger was used in the first part of the experiment to record real-time concentrations of CO₂, recorded as % volume/volume (v/v). Similarly, Drager Pac 7000 CO₂ gas monitor was used in the second part of the experiment to record real-time concentrations of CO₂, as % volume/volume (v/v). The Drager Pac 7000 CO₂ gas monitor was worn by a person, disposed in a seated position within the room to provide an accurate simulation.

[0047] As shown in FIG. **32**, the line **1000** indicated as the % CO₂ Alpha 1 level, illustrates the 0.5% CO₂ (5,000 parts of CO₂ per million parts of air) gas (v/v) concentration exposure limit used by the Department of Labor (DOL) and Occupational Safety and Health Administration (OSHA) as an 8-hour time weighted average Permissible Exposure Limit (PEL) in general industries. In one embodiment, the PCDAM **10** operates in an automated mode for continuous atmosphere monitoring where the PCDAM automatically initiates and stops absorption at a specific concentration or a specific threshold. This threshold data an instructions to operates the PCDAM **10** may be stored in memory and executed by a processor of a computing device. By way of example and not limitation the threshold may correspond to the DOL and OSHA PEL. Similarly, data related to the volume or absorbency of the CO₂ absorption material **240** may be stored in memory such that an alarm or other indicator is triggered when the absorbent material is at 10%, 5% or requires immediate replacement.

[0048] The elevated line **1002**, indicated as “% CO₂ with Machine Off-Part 1” represents the increase or rate of volumetric growth of % CO₂ gas (v/v)

concentration in the room while filling the room at a rate of approximately 7.4 liters of CO₂ per minute for approximately 89 minutes with the PCDAM **10** turned off. It can be deduced from the data shown that the concentration of CO₂ in the room quickly climbs to approximately 5% CO₂ gas (v/v) level in the first 71 minutes. Conversely, the line **1004**, indicated as “Drager Pac 7000 Readings – Part 2”, illustrates the actual readings taken in the room with the PCDAM on, while the room is filled with carbon dioxide (CO₂) gas at a constant rate of 7.4 liters of CO₂ per minute (similar to part 1). As shown, the PCDAM **10** held the % CO₂ gas (v/v) concentration level to 0.0% CO₂ gas (v/v) under these conditions for the first 71 minutes (11:29 am — 12:40 pm) and below the PEL for a full 75 minutes (11:29 am — 12:44 pm).

[0049] As shown, the PCDAM **10** kept the room under the alpha 1 PEL of 0.5% CO₂ gas (v/v) for the first 75 minutes. It can be extrapolated that approximately 530 total liters of CO₂ gas or over 7 liters of CO₂ gas / per minute was absorbed over this 75 minute period to achieve this control.

[0050] While the present disclosure has been described referring to various embodiments, it will be understood that these embodiments are illustrative and that the scope of the disclosure is not limited to them. Many variations, modifications, additions, and improvements are possible. More generally, embodiments in accordance with the present disclosure have been described in the context of particular implementations. Functionality may be separated or combined through components differently in various embodiments of the disclosure or described with different terminology. These and other variations, modifications, additions, and improvements may fall within the scope of the disclosure as defined in the claims that follow.

[0051] It is believed that the present disclosure and many of its attendant advantages will be understood by the foregoing description, and it will be apparent that various changes may be made in the form, construction, and arrangement of the components without departing from the disclosed subject matter or without sacrificing all of its material advantages. The form described is merely explanatory, and the following claims intend to encompass and include such changes.

CLAIMS

WHAT IS CLAIMED IS:

1. A portable carbon dioxide (CO₂) absorption device comprising:
 - an exterior housing defining an inlet and an outlet;
 - a blower in fluid communication with the inlet and with an expansion manifold, wherein the blower is disposed within the housing and draws air into the exterior housing through the inlet;
 - the expansion manifold comprising a manifold housing defining an expansion chamber; the expansion chamber, disposed within the housing, filters and reduces a velocity of air received from the blower by expanding a control volume traversing the portable carbon dioxide absorption device;
 - a carbon-dioxide absorbing apparatus disposed within the housing, the carbon-dioxide absorbing apparatus in fluid communication with the expansion manifold and the outlet, where the carbon-dioxide absorbing apparatus, absorbs carbon-dioxide from the air exiting the expansion manifold ; and,
 - a power supply also disposed within the housing, wherein the power supply is in electrical communication with the blower.
2. The portable carbon dioxide absorption device of claim 1, wherein the blower generates a positive pressure within the portable carbon dioxide absorption device to pull air into the inlet and push the air through the expansion manifold and the carbon dioxide absorbing apparatus.
3. The portable carbon dioxide absorption device of claim 1, further comprising:
 - a control system operatively engaged to the power supply and the blower, wherein the control system operates the blower to generate a desired airflow rate.

4. The portable carbon dioxide absorption device of claim 3, further comprising:
a sensor disposed within or proximal to at least one of the inlet, the outlet, the exterior housing, the blower, the expansion manifold, or the carbon-dioxide absorbing apparatus; where the sensor is in communication with the control system to monitor an environmental concentration of CO₂ proximal to the sensor, wherein the control system receives data from the sensor to automatically operate the blower in such a manner to maintain the environmental CO₂ concentration below a desired threshold.
5. The portable carbon dioxide absorption device of claim 1, wherein the power supply includes a rechargeable battery.
6. The portable carbon dioxide absorption device of claim 5, wherein the outlet has an outlet width greater than an inlet width of the inlet.
7. The portable carbon dioxide absorption device of claim 5, wherein at least one of the inlet or the outlet comprises a screen or other vented covering.
8. The portable carbon dioxide absorption device of claim 1, wherein the carbon-dioxide absorbing apparatus further comprises a CO₂ absorbing material.
9. The portable carbon dioxide absorption device of claim 8, wherein the CO₂ absorbent comprises one or more derivatives of ammonia.
10. The portable carbon dioxide absorption device of claim 9, wherein the one or more derivatives of ammonia is monoethanolamine.
11. The portable carbon dioxide absorption device of claim 8, wherein the CO₂ absorbing material is provided as a solid, semi-solid, or liquid composition.
12. The portable carbon dioxide absorption device of claim 1, wherein the carbon dioxide absorption device operates at a flow rate in a range between 20 to 60 cubic feet per minute.

13. The portable carbon dioxide absorption device of claim 1, further comprising one or more displays, audio/visual indicators, or combinations thereof.
14. The portable carbon dioxide absorption device of claim 1, wherein the carbon-dioxide absorbing apparatus absorbs approximately seven liters of CO₂ per minute.
15. A portable carbon dioxide absorption device comprising:
 - an exterior housing defining an inlet and an outlet;
 - a blower in fluid communication with the outlet and with an expansion manifold, wherein the blower is disposed within the housing, pulls air from the expansion manifold, and pushes air from the exterior housing through the outlet;
 - the expansion manifold comprising a manifold housing defining an expansion chamber; the expansion chamber, disposed within the housing, filters and reduces a velocity of air pulled by the blower;
 - a carbon-dioxide absorbing apparatus disposed within the housing, the carbon-dioxide absorbing apparatus in fluid communication with the inlet and the expansion manifold, wherein the carbon-dioxide absorbing apparatus, absorbs carbon-dioxide from the air entering the inlet ; and,
 - a power supply also disposed within the housing, wherein the power supply is in electrical communication with the blower.
16. The portable carbon dioxide absorption device of claim 15, wherein the blower generates a negative pressure to draw air external to the exterior housing through the carbon-dioxide absorbing apparatus and the expansion manifold.
17. The portable carbon dioxide absorption device of claim 15, wherein the inlet has an inlet width greater than an outlet width of the outlet.

18. The portable carbon dioxide absorption device of claim 1, wherein the carbon-dioxide absorbing apparatus further comprises a CO₂ absorbing material.
19. A method for automatically reducing a concentration of carbon dioxide (CO₂) in an enclosed environment using a portable carbon dioxide absorption device, the method comprising:
 - providing the portable carbon dioxide absorption device in the enclosed environment;
 - continuously measuring an environmental concentration level of CO₂ in the enclosed environment using a sensor in communication with a control system of the portable carbon dioxide absorption device;
 - determining, at the control system if the environmental concentration level of CO₂ exceeds a threshold;
 - continuously or intermittently operating a blower of the portable carbon dioxide absorption device to draw environmental air into the portable carbon dioxide absorption device wherein the concentration of CO₂ emitted from the portable carbon dioxide absorption device is less than the environmental concentration level;
 - ceasing operation of the blower when the environmental concentration level falls below the threshold.
20. The method of claim 20 further comprising filtering the air entering the portable carbon dioxide absorption device to capture and remove dust or other particulates from the enclosed environment.

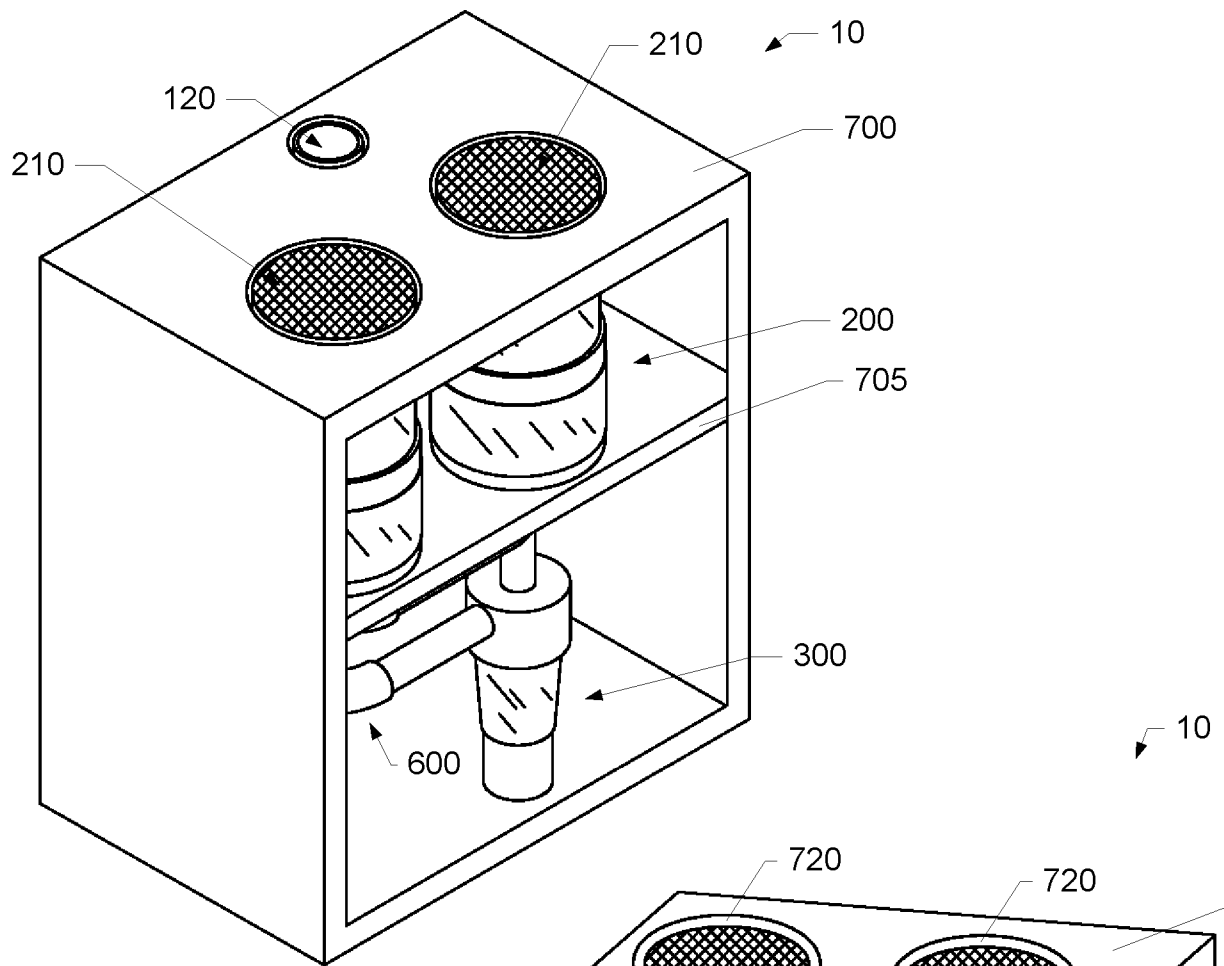


FIG. 1

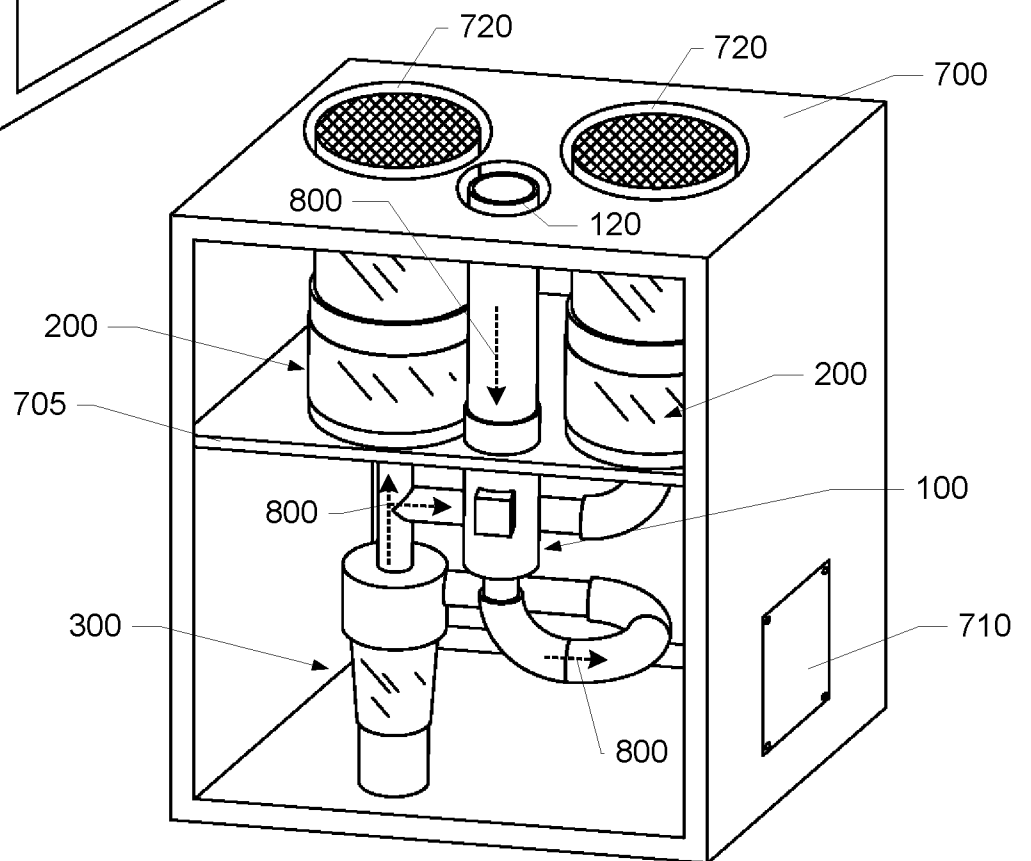


FIG. 2

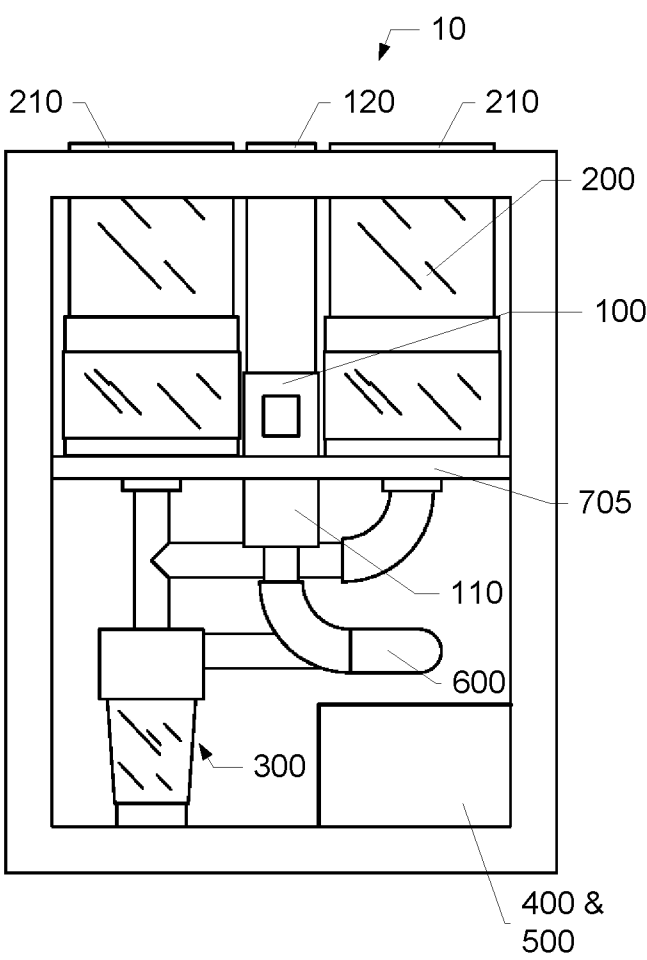


FIG. 3

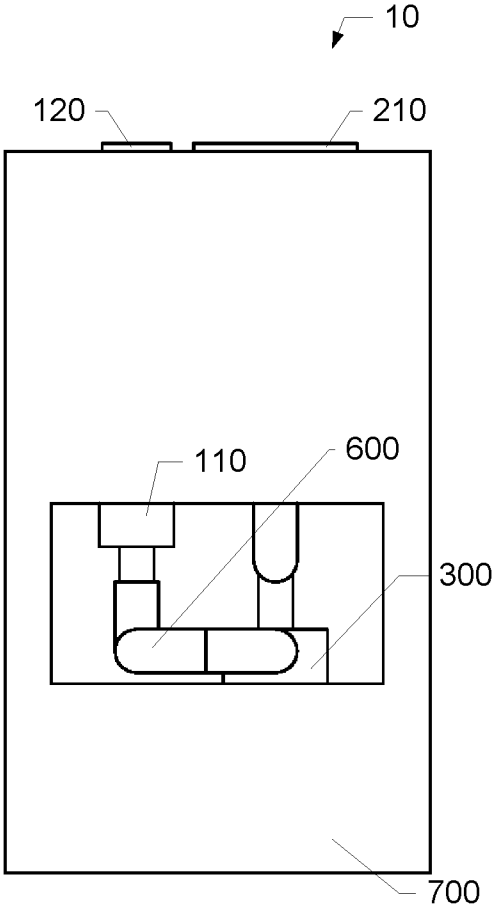


FIG. 4

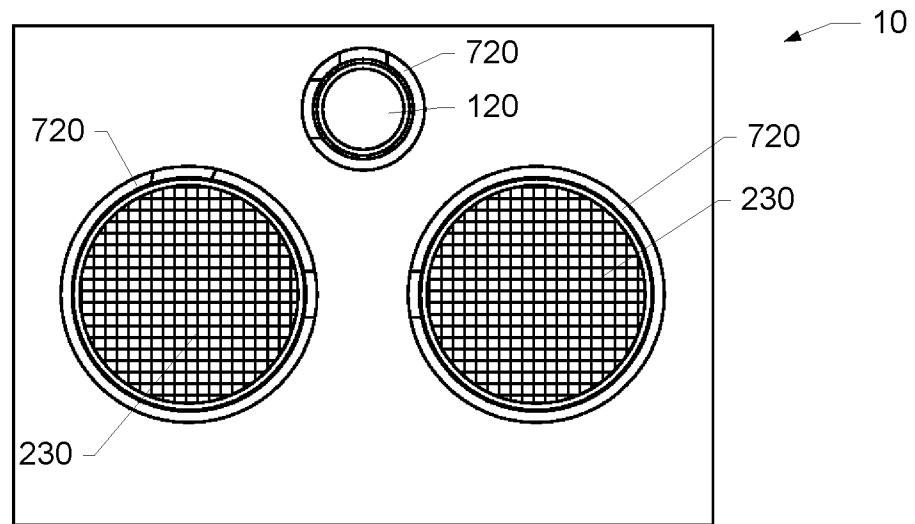


FIG. 5

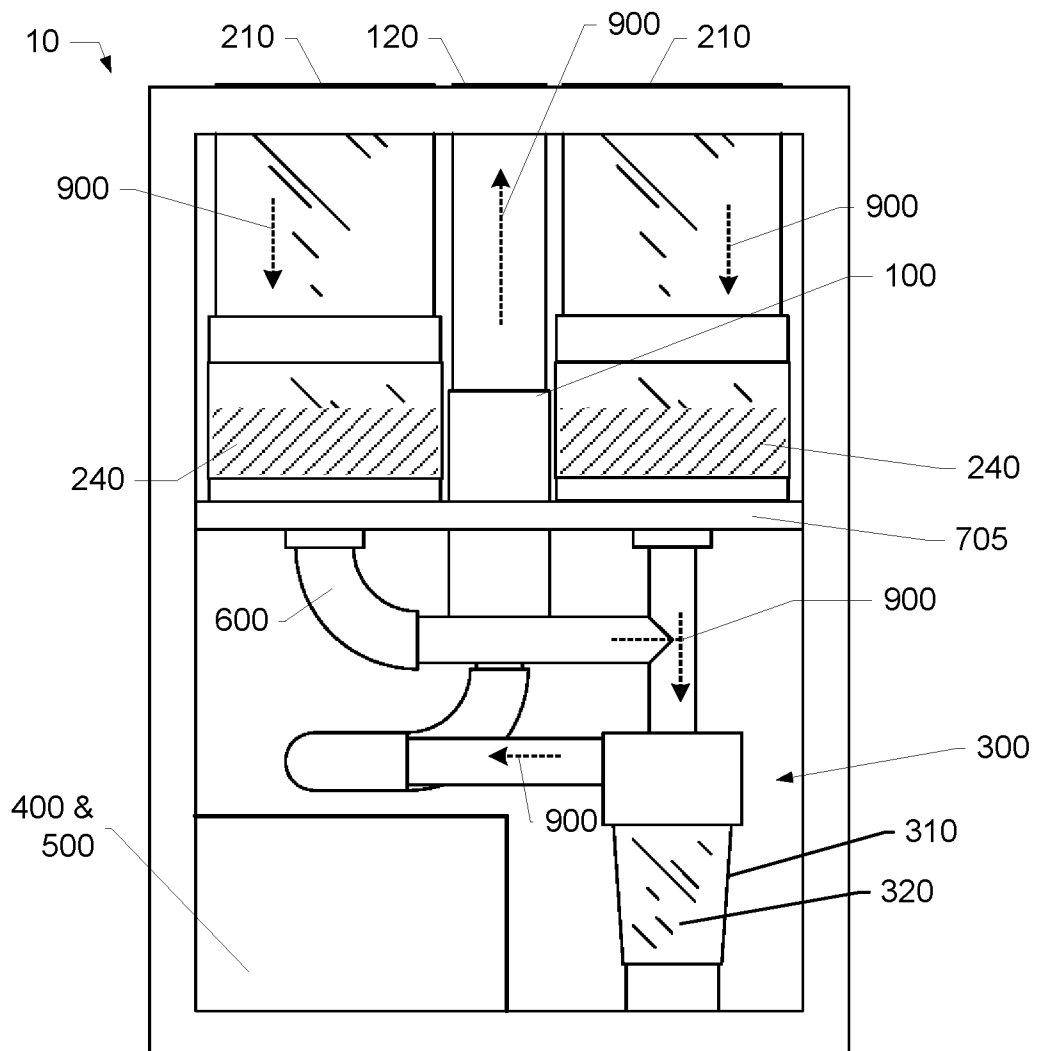


FIG. 6

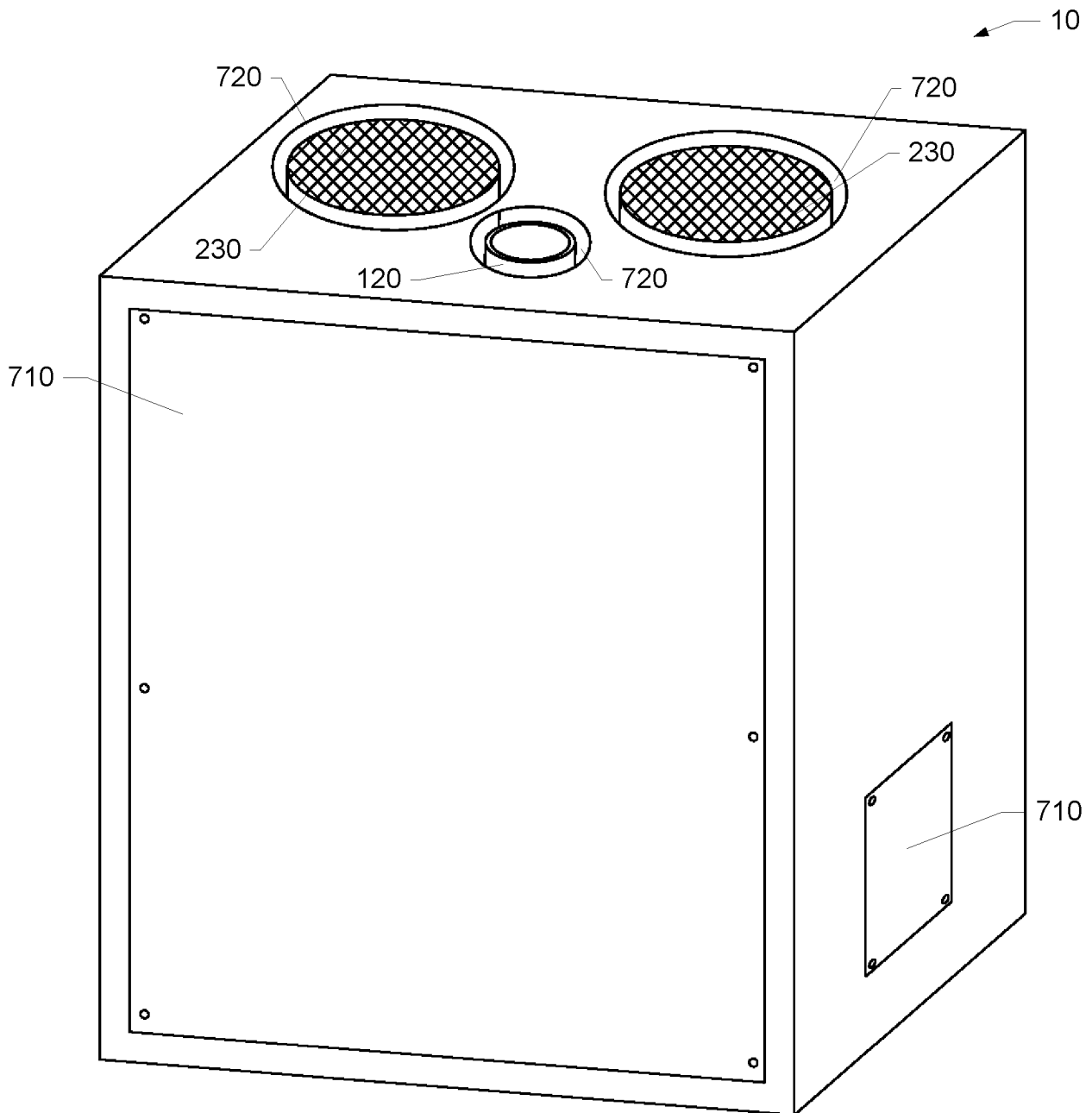
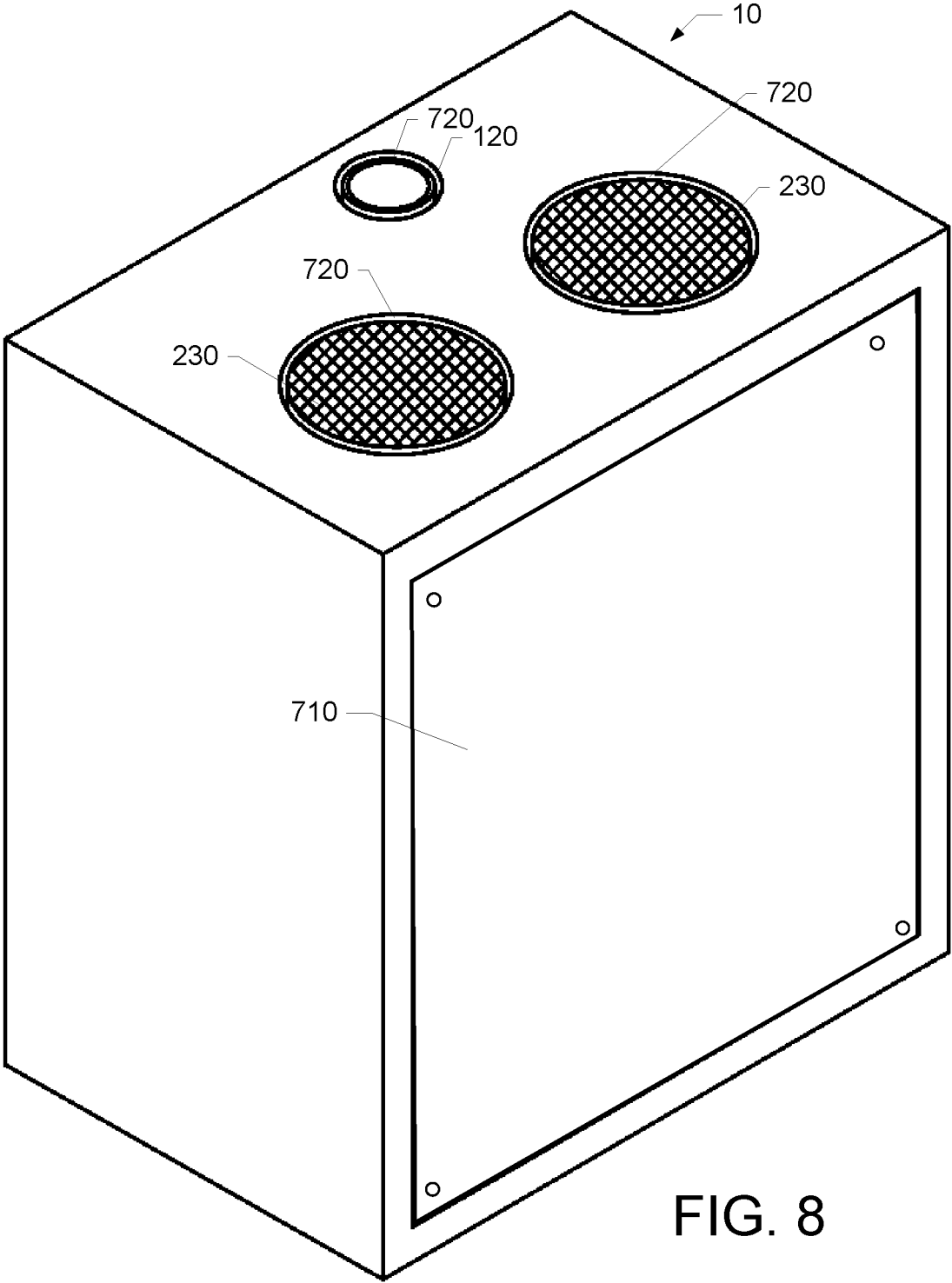


FIG. 7



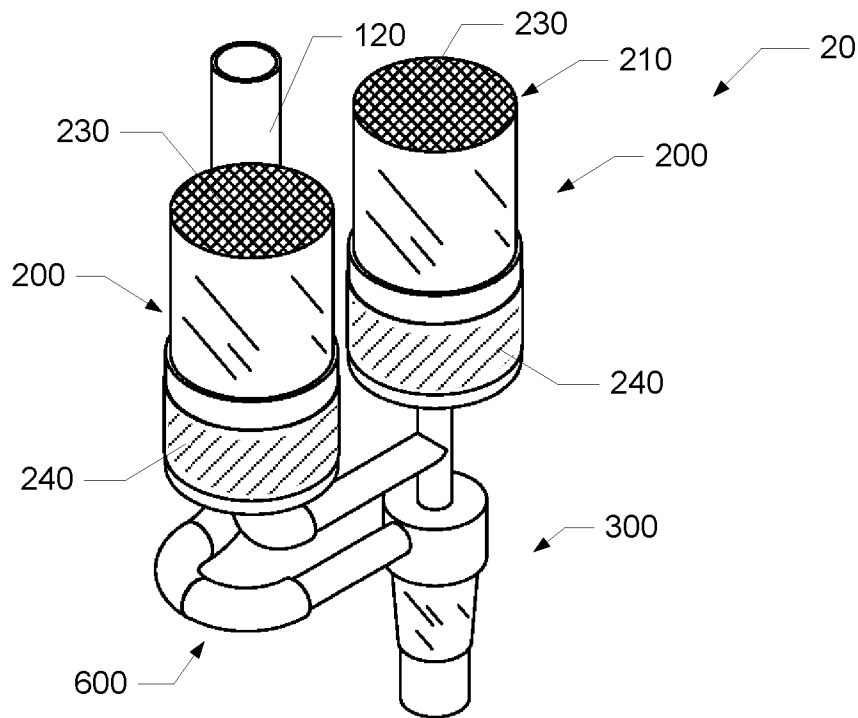


FIG. 9

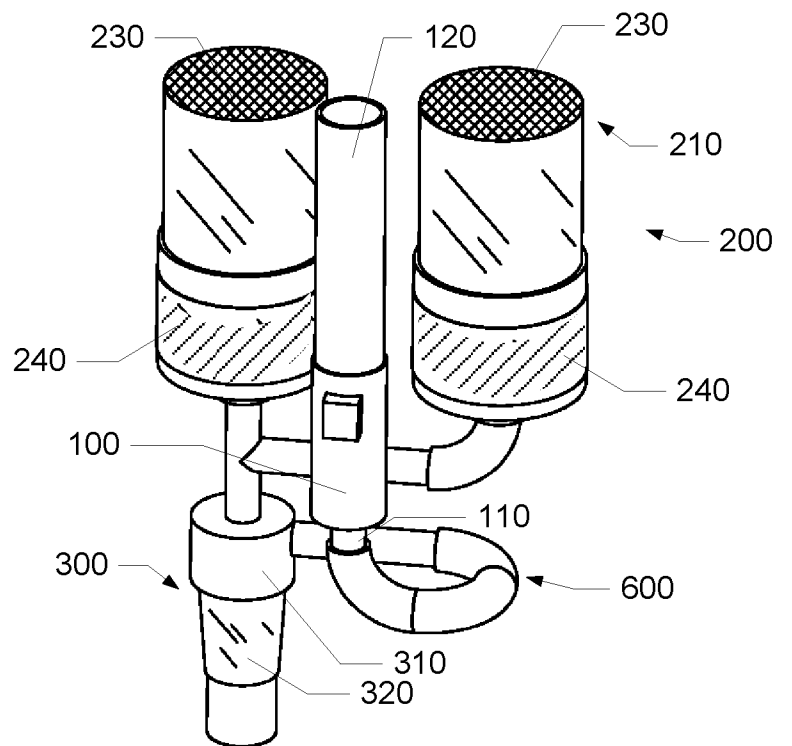


FIG. 10

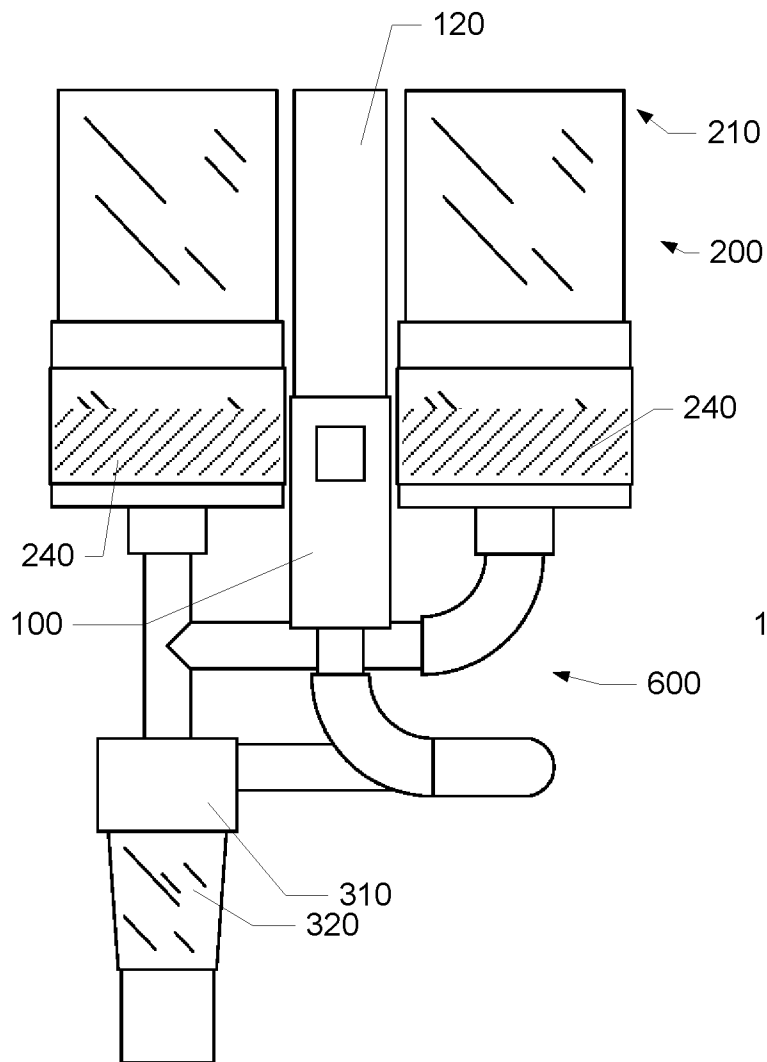


FIG. 11

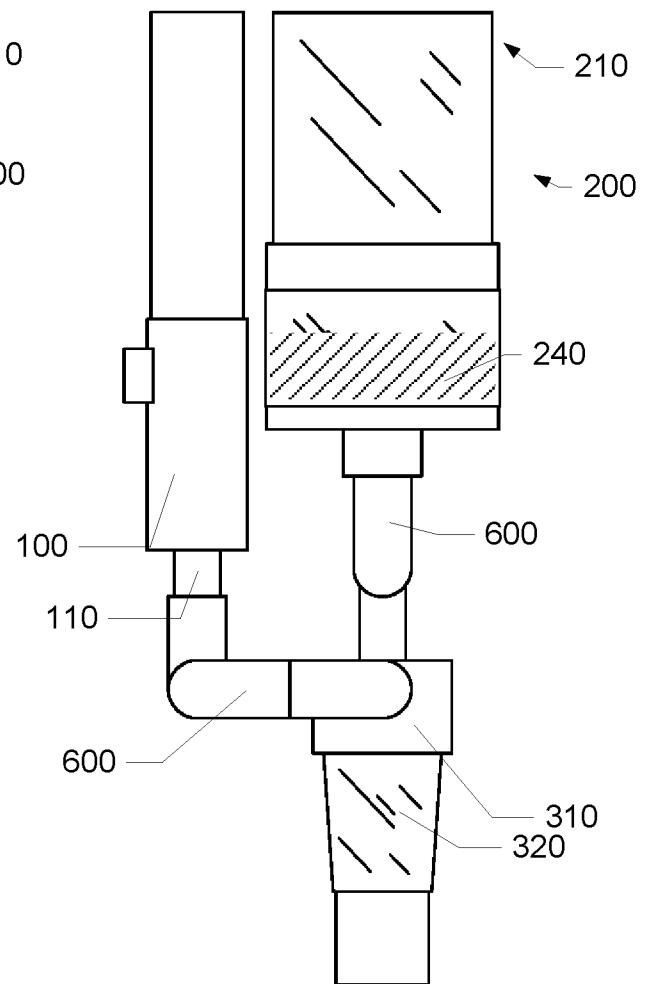


FIG. 12

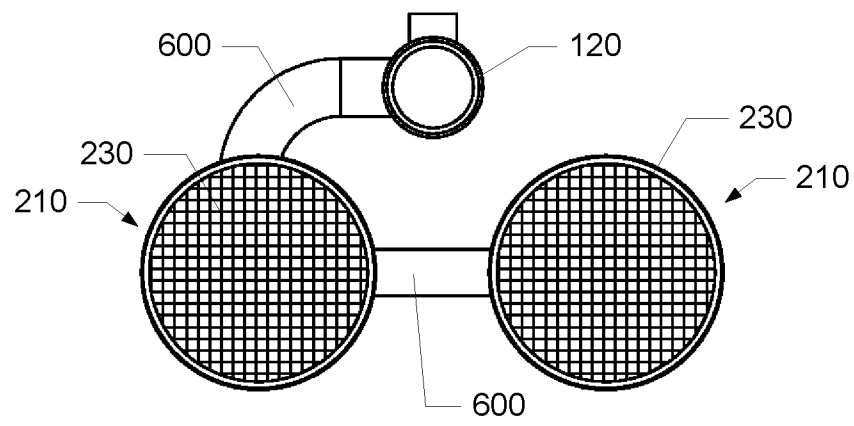


FIG. 13

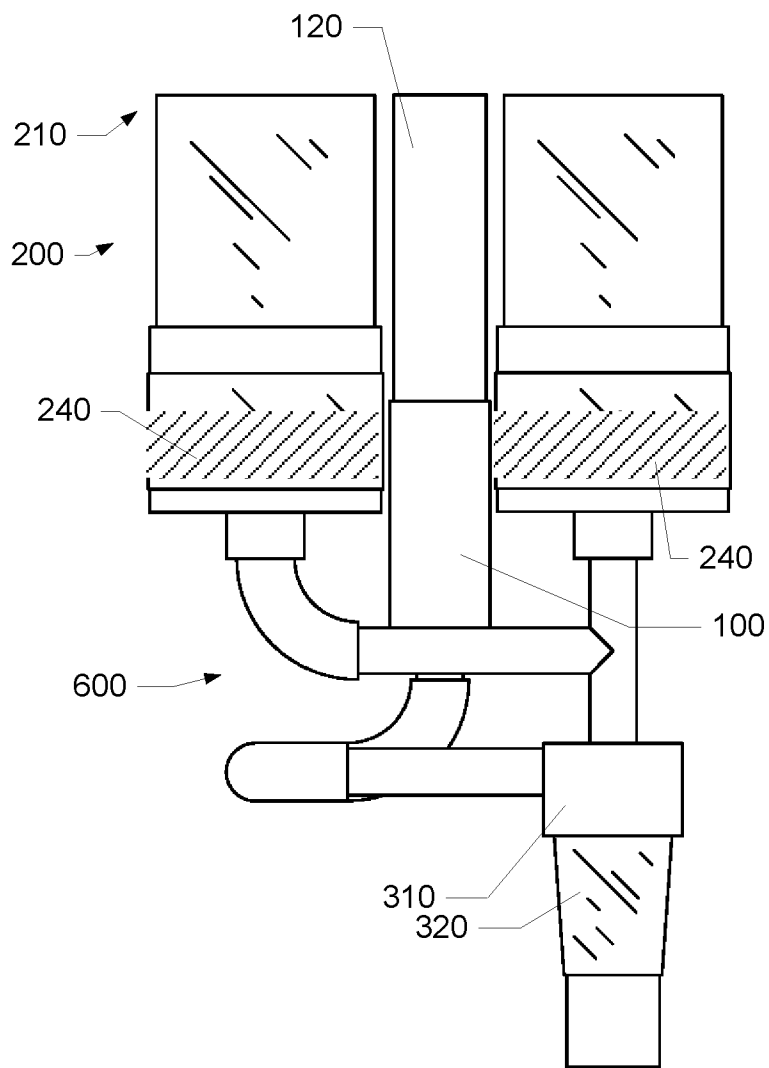


FIG. 14

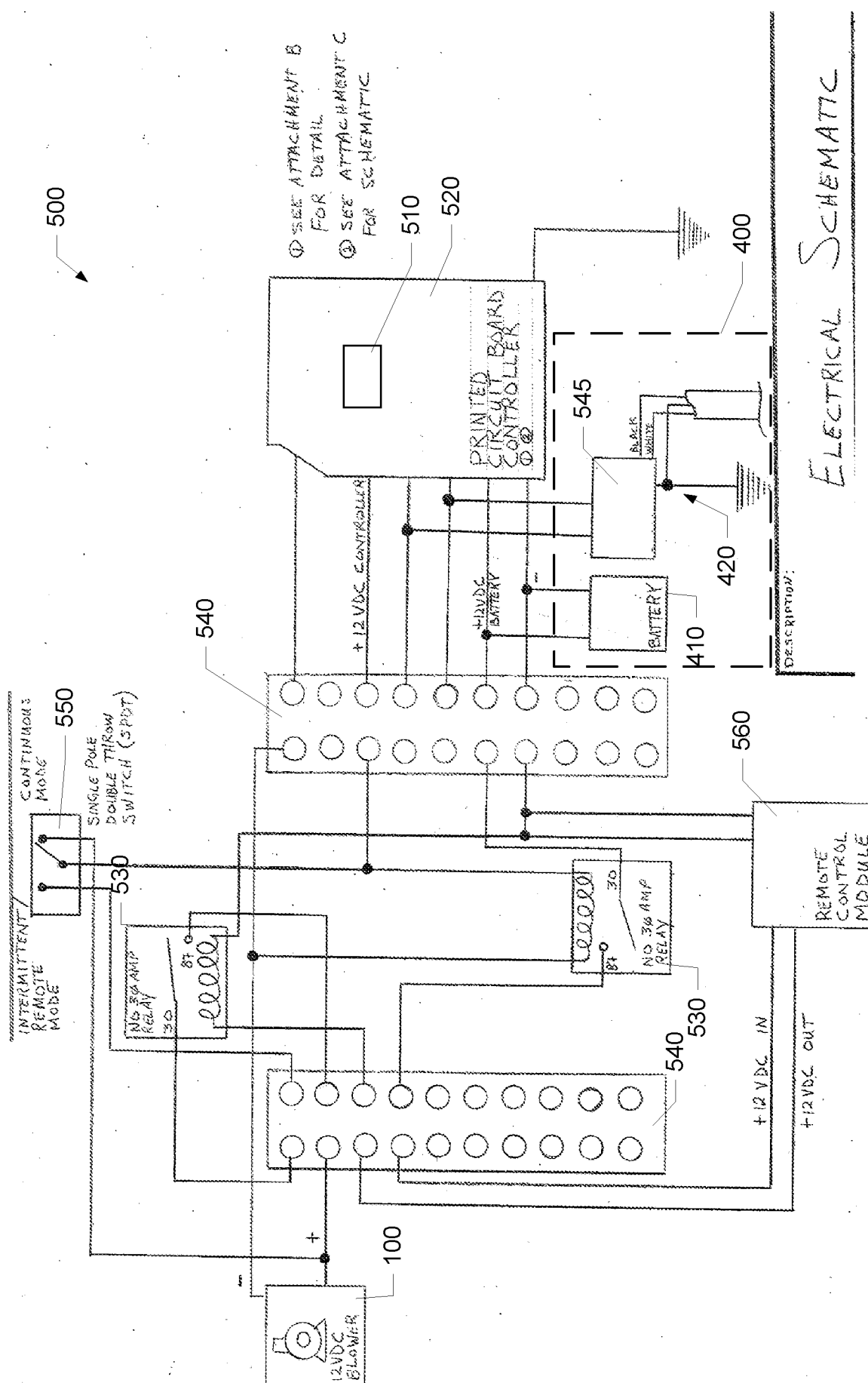


FIG. 15

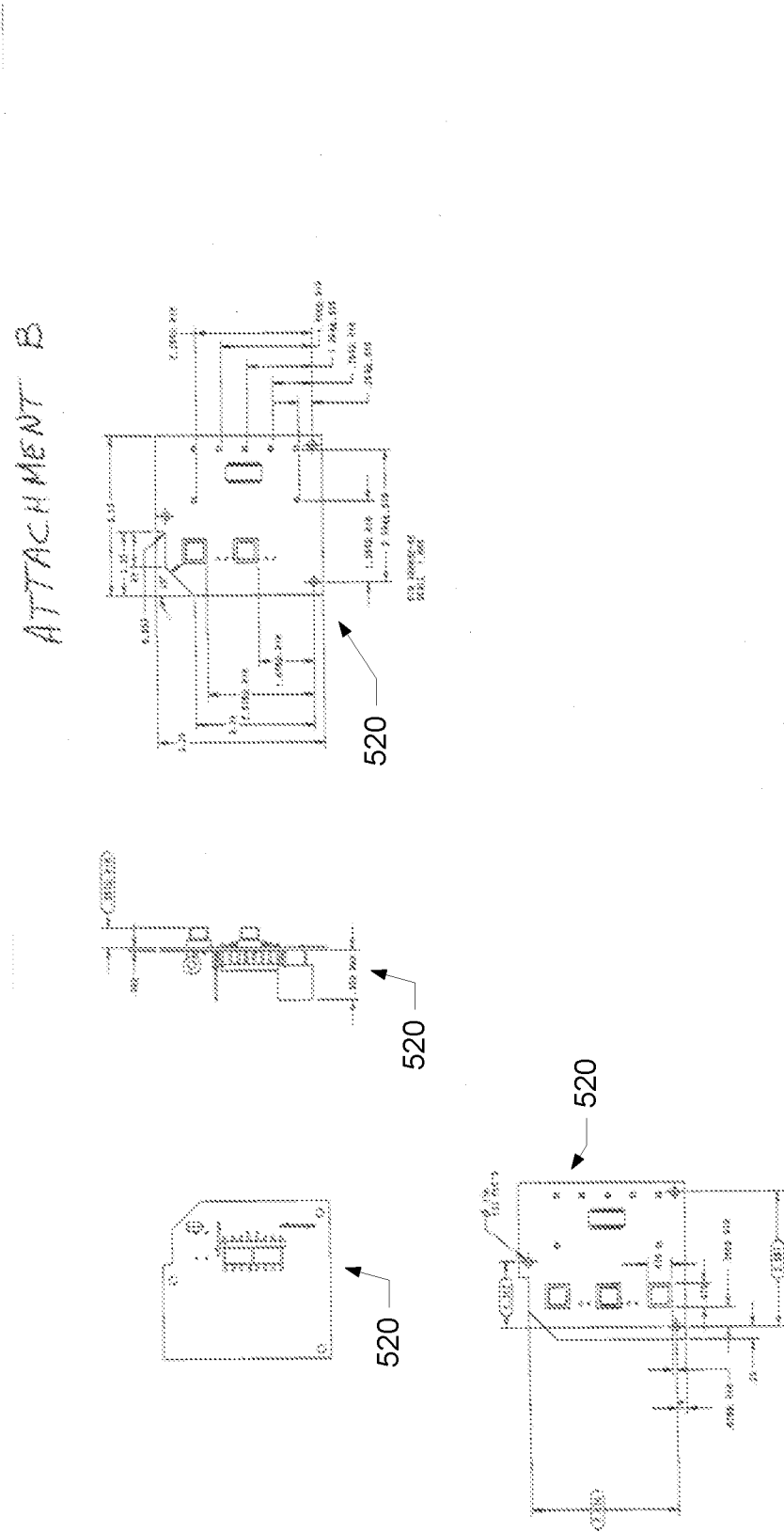
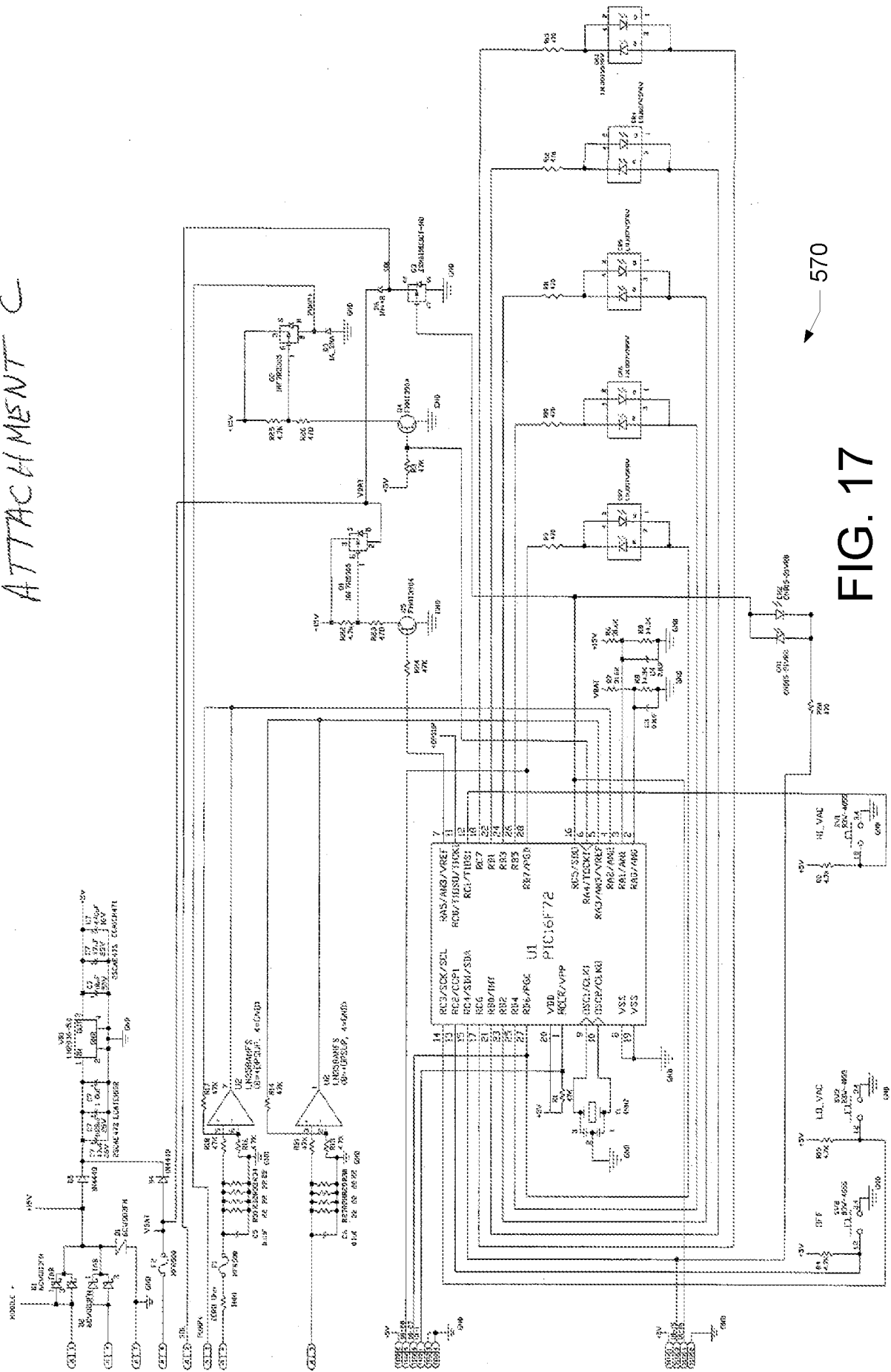


FIG. 16

ATTACHMENT C



570

FIG. 17

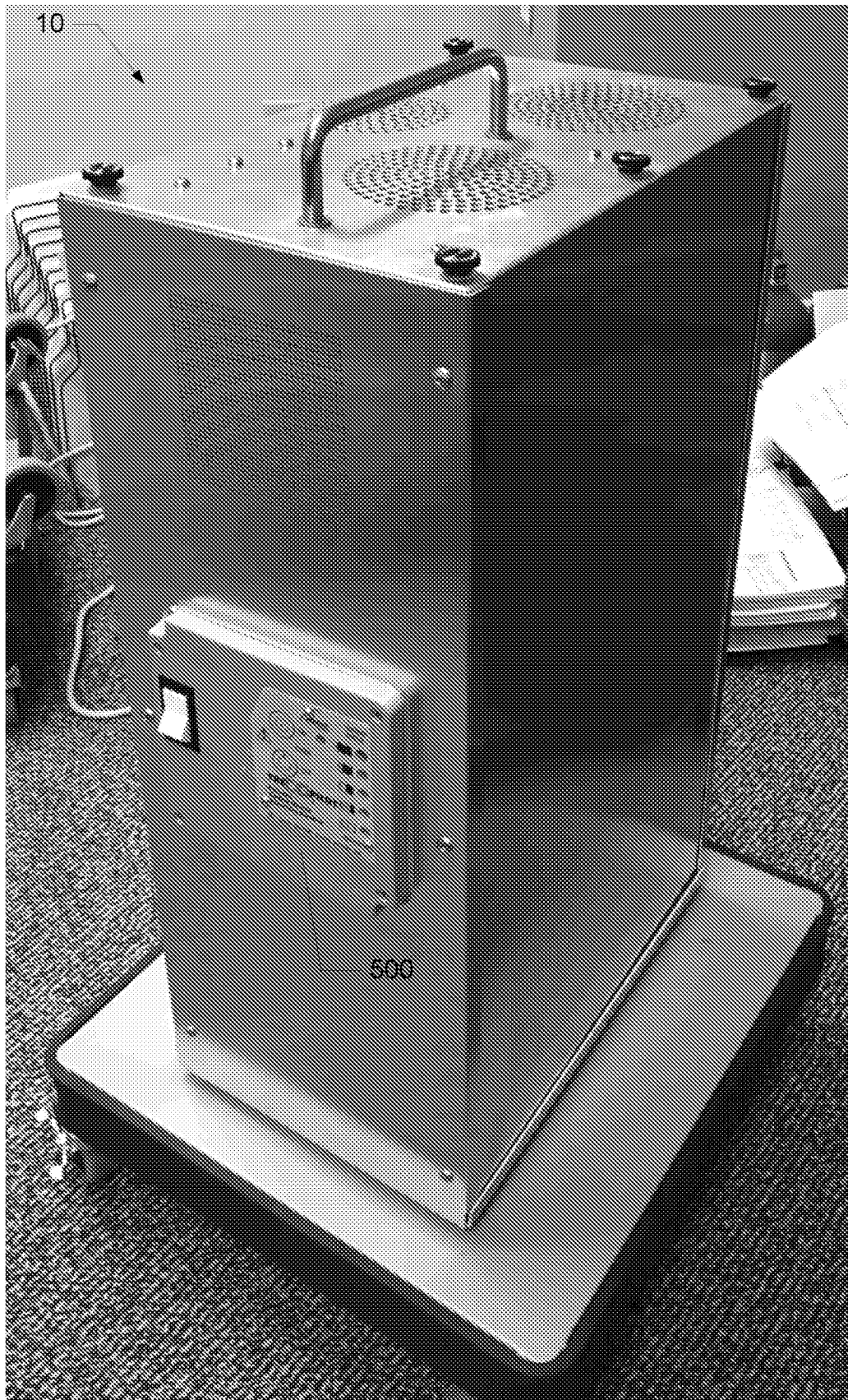


FIG. 18



FIG. 19



FIG. 20



FIG. 21

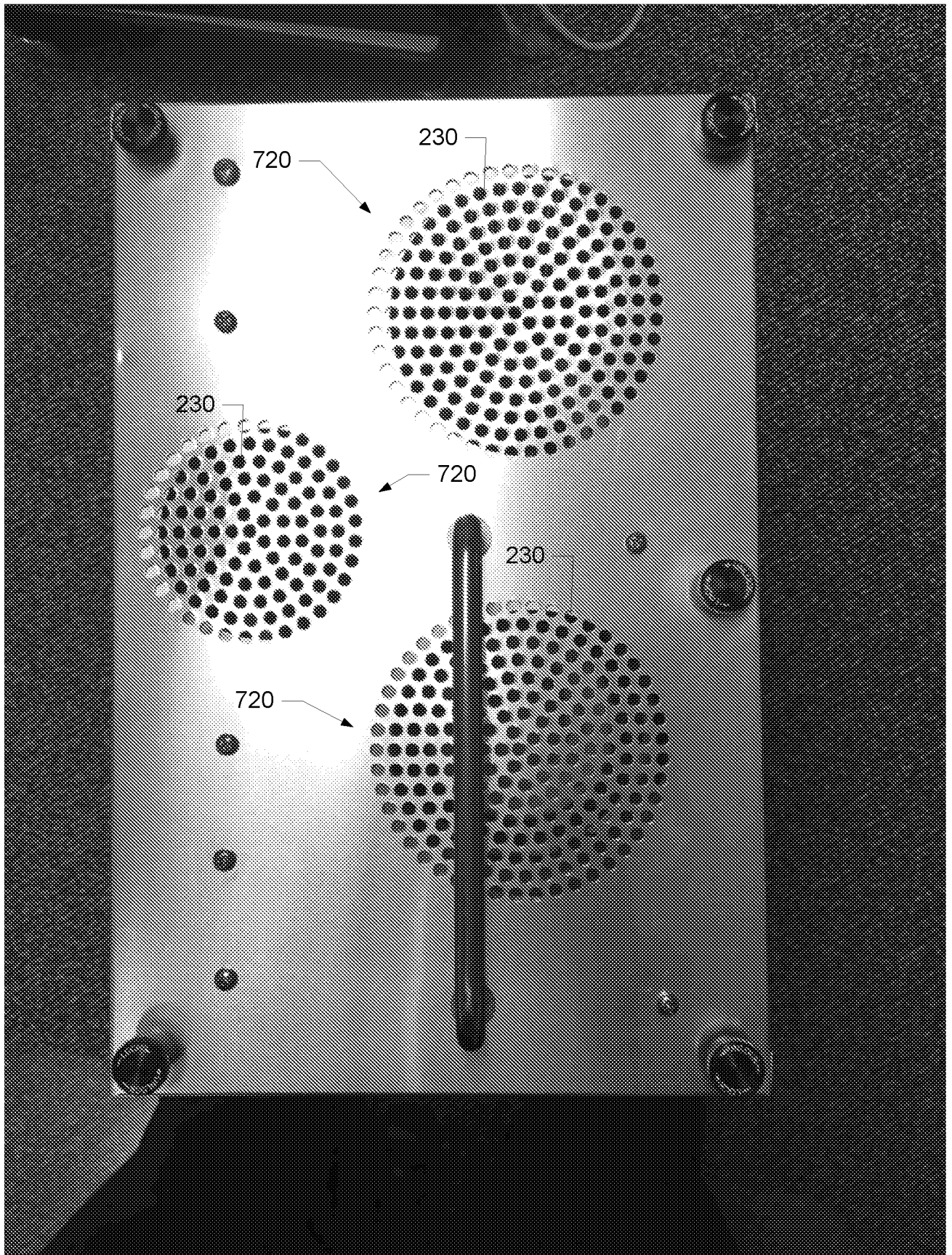


FIG. 22

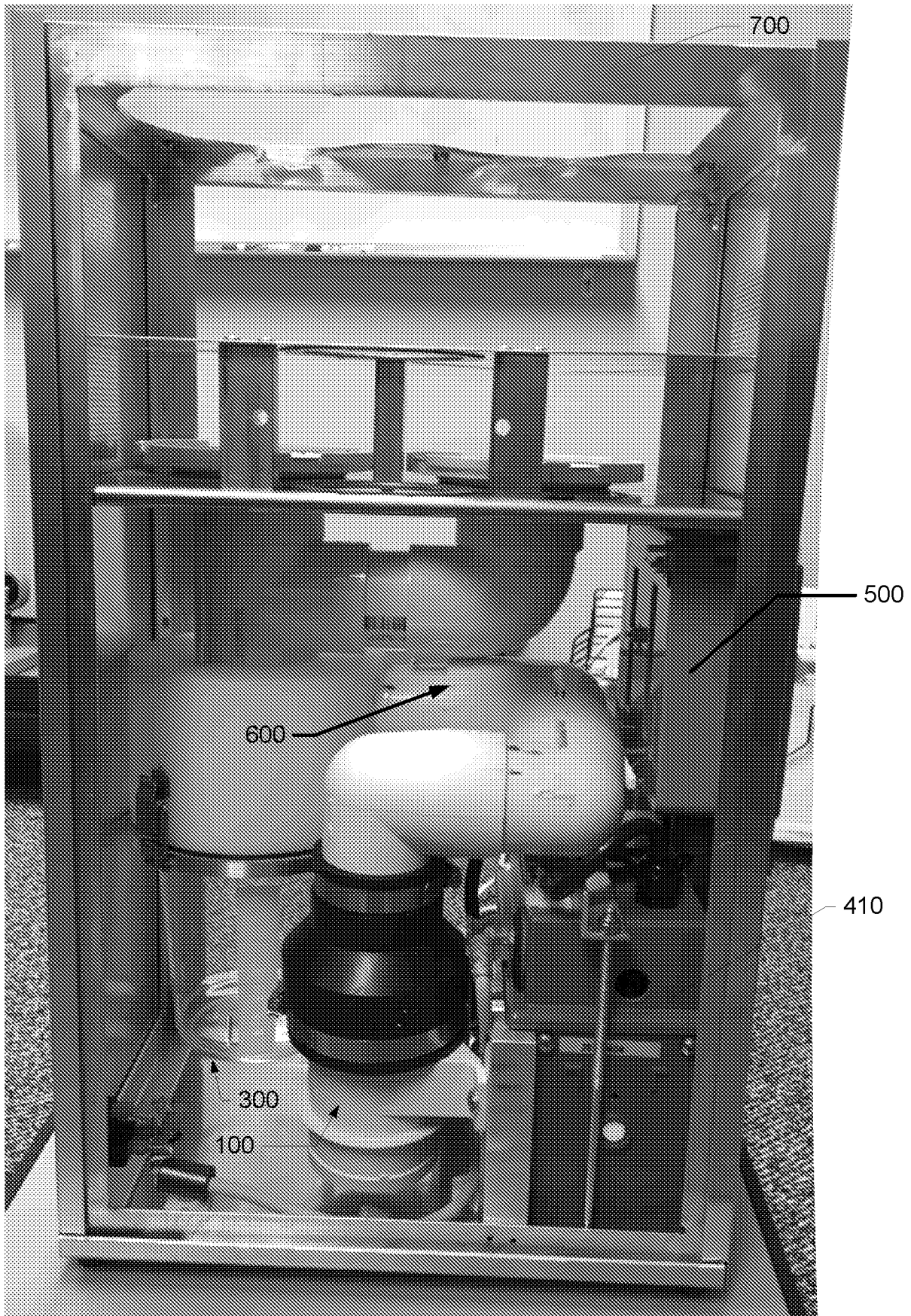


FIG. 23



FIG. 24

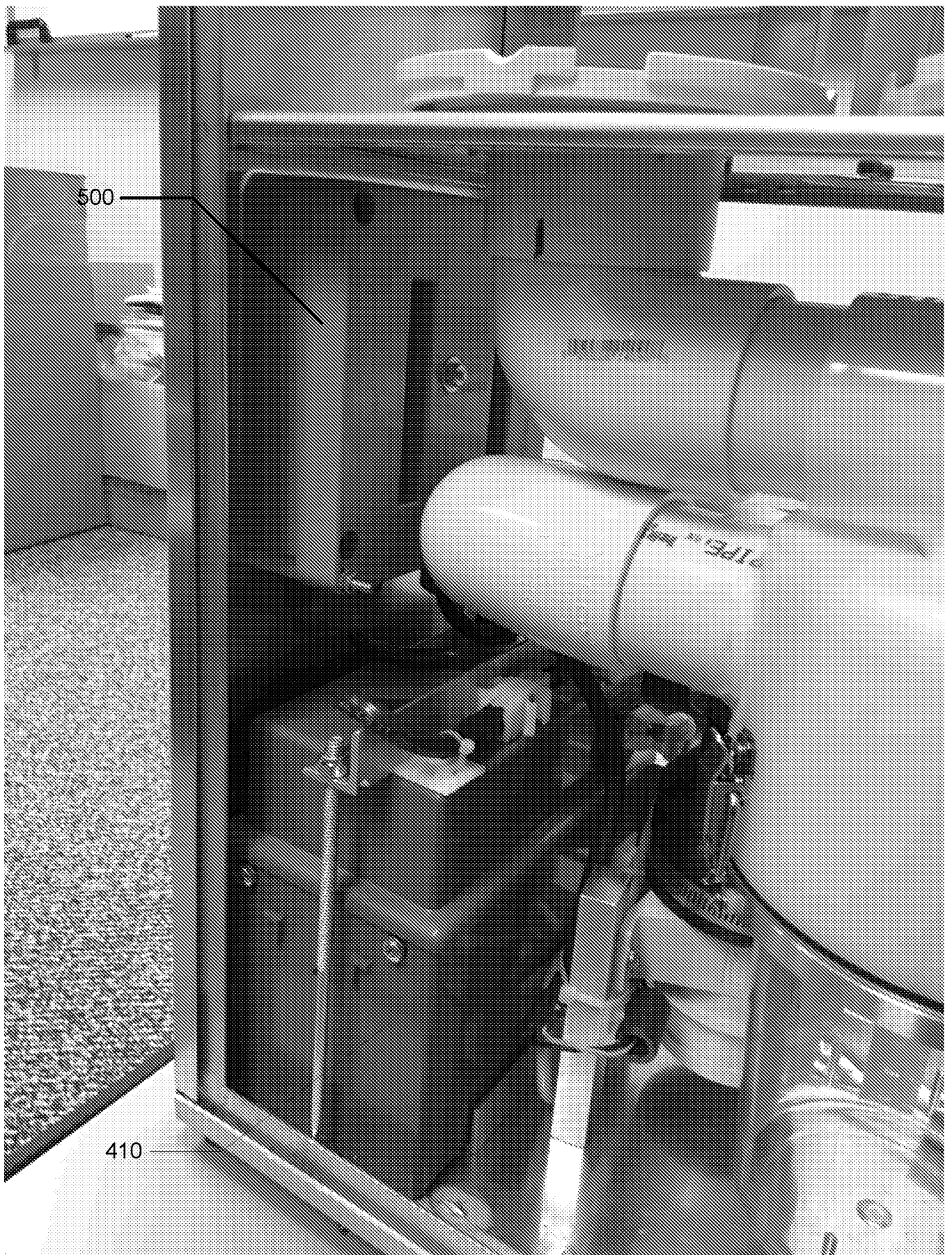


FIG. 25



FIG. 26



FIG. 27

410



FIG. 28



FIG. 29



FIG. 30



FIG. 31

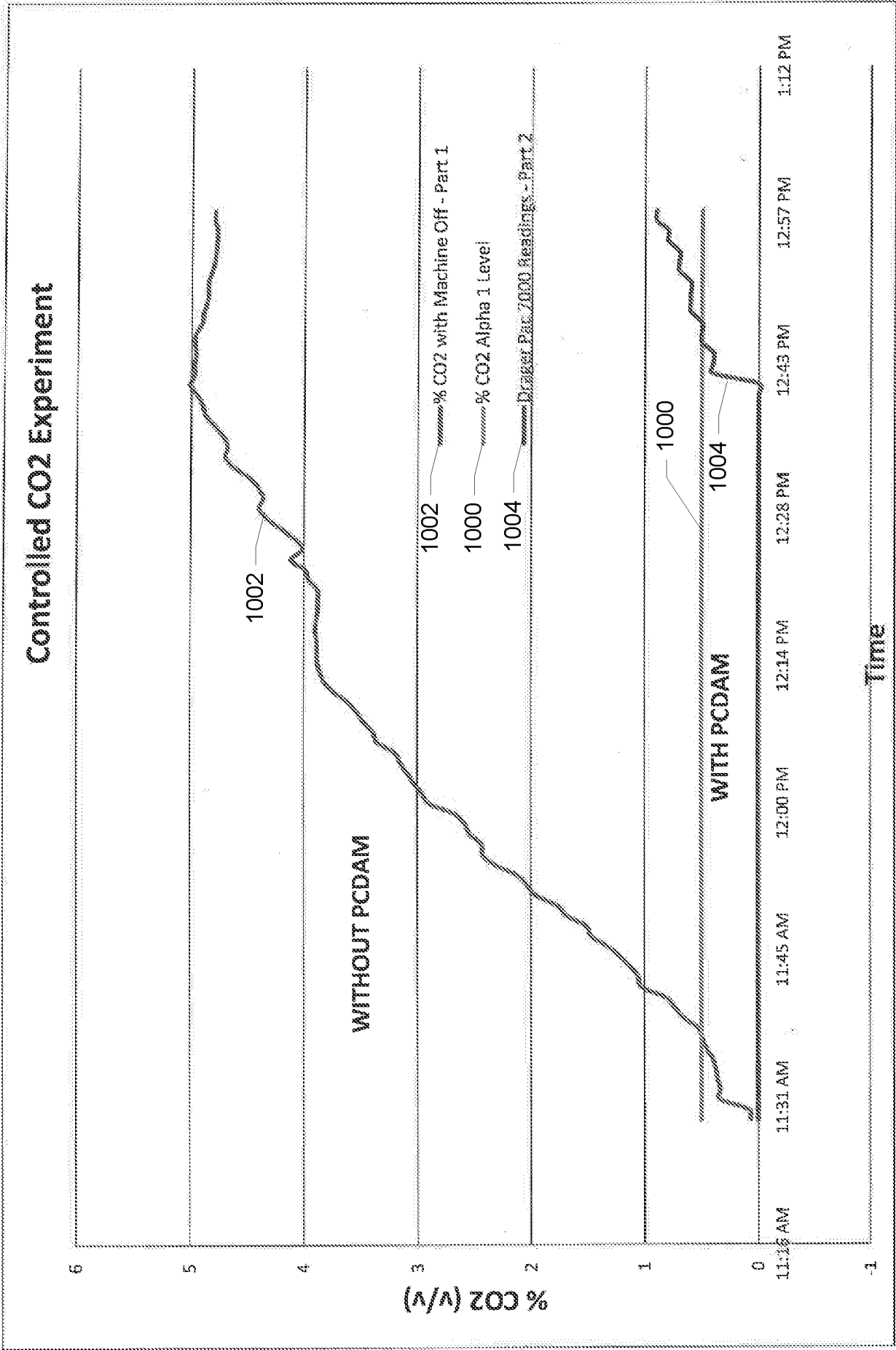


FIG. 32

Time	% CO ₂ Alpha 1 Level	% CO ₂ with Machine Off - Part 1	Drager Pac 7000 Readings Part 2	Time	% CO ₂ Alpha 1 Level	% CO ₂ with Machine Off - Part 1	Drager Pac 7000 Readings Part 2
11:29 AM	0.5	0.067	0.0	12:14 PM	0.5	3.884	0.0
11:30 AM	0.5	0.088	0.0	12:15 PM	0.5	3.885	0.0
11:31 AM	0.5	0.338	0.0	12:16 PM	0.5	3.827	0.0
11:32 AM	0.5	0.333	0.0	12:17 PM	0.5	3.901	0.0
11:33 AM	0.5	0.356	0.0	12:18 PM	0.5	3.893	0.0
11:34 AM	0.5	0.373	0.0	12:19 PM	0.5	3.880	0.0
11:35 AM	0.5	0.400	0.0	12:20 PM	0.5	3.878	0.0
11:36 AM	0.5	0.458	0.0	12:21 PM	0.5	3.880	0.0
11:37 AM	0.5	0.493	0.0	12:22 PM	0.5	3.959	0.0
11:38 AM	0.5	0.530	0.0	12:23 PM	0.5	3.992	0.0
11:39 AM	0.5	0.660	0.0	12:24 PM	0.5	4.117	0.0
11:40 AM	0.5	0.733	0.0	12:25 PM	0.5	4.012	0.0
11:41 AM	0.5	0.816	0.0	12:26 PM	0.5	4.086	0.0
11:42 AM	0.5	1.026	0.0	12:27 PM	0.5	4.209	0.0
11:43 AM	0.5	1.054	0.0	12:28 PM	0.5	4.332	0.0
11:44 AM	0.5	1.119	0.0	12:29 PM	0.5	4.402	0.0
11:45 AM	0.5	1.210	0.0	12:30 PM	0.5	4.364	0.0
11:46 AM	0.5	1.326	0.0	12:31 PM	0.5	4.409	0.0
11:47 AM	0.5	1.466	0.0	12:32 PM	0.5	4.493	0.0
11:48 AM	0.5	1.513	0.0	12:33 PM	0.5	4.624	0.0
11:49 AM	0.5	1.686	0.0	12:34 PM	0.5	4.697	0.0
11:50 AM	0.5	1.770	0.0	12:35 PM	0.5	4.677	0.0
11:51 AM	0.5	1.960	0.0	12:36 PM	0.5	4.711	0.0
11:52 AM	0.5	2.033	0.0	12:37 PM	0.5	4.788	0.0
11:53 AM	0.5	2.126	0.0	12:38 PM	0.5	4.869	0.0
11:54 AM	0.5	2.325	0.0	12:39 PM	0.5	4.896	0.0
11:55 AM	0.5	2.428	0.0	12:40 PM	0.5	4.944	0.0
11:56 AM	0.5	2.436	0.0	12:41 PM	0.5	5.009	0.0
11:57 AM	0.5	2.540	0.0	12:42 PM	0.5	4.971	0.4
11:58 AM	0.5	2.581	0.0	12:43 PM	0.5	4.975	0.4
11:59 AM	0.5	2.678	0.0	12:44 PM	0.5	4.959	0.4
12:00 PM	0.5	2.898	0.0	12:45 PM	0.5	4.968	0.5
12:01 PM	0.5	2.963	0.0	12:46 PM	0.5	4.964	0.5
12:02 PM	0.5	3.030	0.0	12:47 PM	0.5	4.908	0.5
12:03 PM	0.5	3.091	0.0	12:48 PM	0.5	4.894	0.6
12:04 PM	0.5	3.151	0.0	12:49 PM	0.5	4.869	0.6
12:05 PM	0.5	3.199	0.0	12:50 PM	0.5	4.851	0.6
12:06 PM	0.5	3.353	0.0	12:51 PM	0.5	4.854	0.6
12:07 PM	0.5	3.395	0.0	12:52 PM	0.5	4.826	0.7
12:08 PM	0.5	3.473	0.0	12:53 PM	0.5	4.801	0.7
12:09 PM	0.5	3.535	0.0	12:54 PM	0.5	4.787	0.7
12:10 PM	0.5	3.616	0.0	12:55 PM	0.5	4.782	0.8
12:11 PM	0.5	3.741	0.0	12:56 PM	0.5	4.774	0.8
12:12 PM	0.5	3.823	0.0	12:57 PM	0.5	4.794	0.9
12:13 PM	0.5	3.860	0.0	12:58 PM	0.5	4.794	0.9

FIG. 33

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 18/16966

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B01D 53/14, B01D 53/18, B01D 53/62, B01D 53/74 (2018.01)

CPC - B01D 53/145, B01D 53/18, B01D 53/14, B01D 53/1475, B01D 53/62, B01D 53/74, B01D 53/75, B01D 2257/504; Y02C 10/06

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 --- Y	US 5,595,949 A (Goldstein et al.) 21 January 1997 (21.01.1997), Fig. 1, col. 5, ln. 56 - col. 6, ln. 47	1-2, 5-6, 8, 11-15 and 18 --- 3-4, 7, 9-10 and 16-17
Y	US 2003/0209140 A1 (Kutt et al.) 13 November 2003 (13.11.2003), Fig. 6, para [0103]	3-4
Y	US 2008/0216653 A1 (Paton-Ash et al.) 11 September 2008 (11.09.2008), Figs. 1-5, para [0031]	7
Y	US 3,469,934 A (Bocard et al.) 30 September 1969 (30.09.1969), col. 4, ln. 15-18	9-10
Y	US 5,186,903 A (Cornwell) 16 February 1993 (16.02.1993), Fig. 1, col. 8, ln. 46 - col. 9, ln. 14	16
Y	US 2011/0318231 A1 (Hago et al.) 29 December 2011 (29.12.2011), Fig. 2, para [0023]	17
A	US 3,178,269 A (McConnaughey) 13 April 1965 (13.04.1965), Figs. 1-3, col. 2, ln. 15 - col. 3, ln. 20	1-18

☐ 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

"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

16 May 2018

Date of mailing of the international search report

11 JUN 2018

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-8300

Authorized officer:

Lee W. Young

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 18/16966

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 ---

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.:
1-18

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/US 18/16966

Continuation of 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 1-18, directed to a portable carbon dioxide absorption device.

Group II: Claims 19-20, directed to a method for automatically reducing a concentration of carbon dioxide in an enclosed environment.

The inventions listed as Groups I-II do not relate to a single inventive concept under PCT Rule 13.1 because under PCT Rule 13.2 they lack the same or corresponding technical features for the following reasons:

Special Technical Features

Group I includes the special technical features of an exterior housing defining an inlet and an outlet; a blower in fluid communication with an expansion manifold; wherein the blower is disposed within the housing; the expansion manifold comprising a manifold housing defining an expansion chamber; the expansion chamber, disposed within the housing, filters and reduces a velocity of air received from the blower; a carbon-dioxide absorbing apparatus disposed within the housing, the carbon-dioxide absorbing apparatus in fluid communication with the expansion manifold; where the carbon dioxide absorbing apparatus, absorbs carbon-dioxide; a power supply also disposed within the housing, and wherein the power supply is in electrical communication with the blower that are not required by Group II.

Group II includes the special technical features of providing the portable carbon dioxide absorption device in the enclosed environment; continuously measuring an environmental concentration level of CO₂ in the enclosed environment using a sensor in communication with a control system of the portable carbon dioxide absorption device; determining, at the control system if the environmental concentration level of CO₂ exceeds a threshold; continuously or intermittently operating a blower of the portable carbon dioxide absorption device to draw environmental air into the portable carbon dioxide absorption device wherein the concentration of CO₂ emitted from the portable carbon dioxide absorption device is less than the environmental concentration level and ceasing operation of the blower when the environmental concentration level falls below the threshold that are not required by Group I.

Shared Technical Features

Groups I-II share the common technical features of a portable carbon dioxide absorption device and a blower. However, these shared technical features do not represent a contribution over prior art as being anticipated by US 2017/0087963 A1 to Sharp Kabushiki Kaisha (hereinafter 'Sharp') which discloses a portable carbon dioxide absorption device (Figs. 1-2; para [0022], 'portable-type carbon dioxide concentration control device 10...controlled by... carbon dioxide absorbent 16') and a blower (para [0024], 'device 10 may be provided with a pump and a fan so as to take the air into the detecting unit 12 and the carbon dioxide absorbent 16').

Therefore, Groups I-II lack unity under PCT Rule 13 because they do not share a same or corresponding technical feature.

NOTE: Claim 20 depends from claim 20. For purposes of this opinion, claim 20 is treated as depending from claim 19.