(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 485 944 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
22.05.2019 Bulletin 2019/21

(21) Application number: **17202809.4**

(22) Date of filing: **21.11.2017**

(51) Int Cl.:
A62B 7/10 *(2006.01)*
A62B 18/00 *(2006.01)*
A62B 23/02 *(2006.01)*
A62B 7/08 *(2006.01)*
A62B 9/00 *(2006.01)*

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

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(54) **BREATHING MASK**

(57) A breathing mask having a CO_2 filter comprises one or more compounds which react exothermically with the CO_2 present in air exhaled by a user and exchanges the generated heat to air subsequently drawn in to the mask chamber. The mask allows a proportion of the exhaled air, which has passed through the CO_2 filter and has reduced CO_2 content, to be recycled without being drawn out of the mask chamber. The invention also provides a method of heating air drawn into the chamber of a breathing mask sealed to the face of a user.

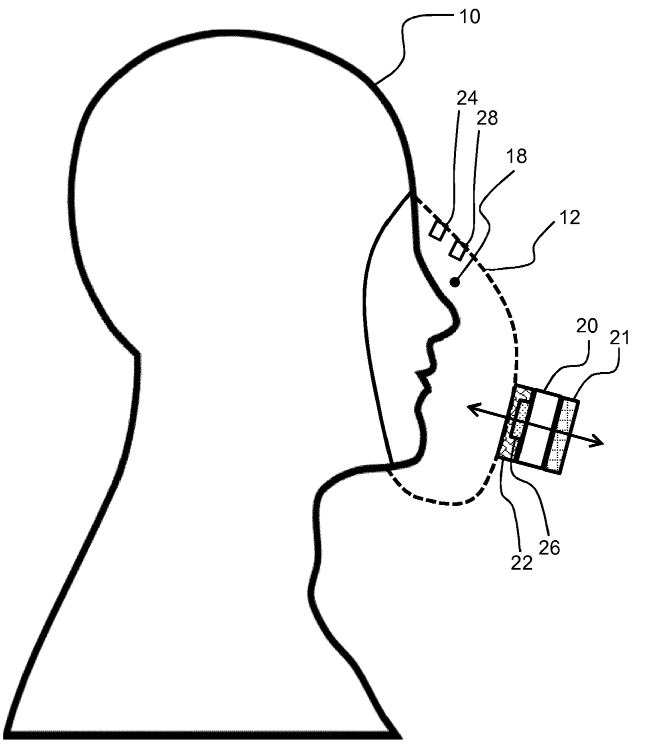

FIG. 1

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Description

FIELD OF THE INVENTION

[0001] This invention relates to breathing masks.

BACKGROUND OF THE INVENTION

[0002] Air pollution is a worldwide concern. The World Health Organization (WHO) estimates that 4 million people die from air pollution every year. Part of this problem is the outdoor air quality in cities. Nearly 300 smog-hit cities fail to meet national air quality standards.

[0003] Official outdoor air quality standards define particle matter concentration as mass concentration per unit volume (e.g. $\mu g/m^3$). A particular concern is pollution with particles having a diameter less than 2.5 μm (termed "PM2.5") as they are able to penetrate into the gas exchange regions of the lung (alveoli), and very small particles (<100 nm) may pass through the lungs to affect other organs.

[0004] Since this problem will not improve significantly on a short time scale, a common way to deal with this problem is to wear a mask which provides cleaner air by filtration and the market for masks in China and elsewhere has seen a great surge in recent years. For example, it is estimated that by 2019, there will be 4.2 billion masks in China.

[0005] However, during use, the temperature and relative humidity inside the mask increases and combined with the pressure difference inside the mask relative to the outside, makes breathing uncomfortable. To improve comfort and effectiveness, a fan can be added to the mask which draws in air through a filter. For efficiency and longevity reasons these are normally electrically commutated brushless DC fans.

[0006] The benefit to the wearer of using a powered mask is that the lungs are relieved of the slight strain caused by inhalation against the resistance of the filters in a conventional non-powered mask.

[0007] Furthermore, in a conventional non-powered mask, inhalation also causes a slight negative pressure within the mask which leads to leakage of the contaminants into the mask, which leakage could prove dangerous if these are toxic substances. A powered mask delivers a steady stream of air to the face and may for example provide a slight positive pressure, which may be determined by the resistance of an exhale valve, to ensure that any leakage is outward rather than inward.

[0008] Fan assisted masks thus may improve the wearing comfort by reducing the temperature, humidity and breathing resistance. Fan assisted masks may be provided with an inhale fan or an exhale fan or both. An inhale fan assists in drawing air through a filter and enables a positive mask pressure to be obtained to prevent contaminants leaking into the mask volume. An exhale fan assists in the mask ventilation and ensures the exhaled carbon dioxide is fully expelled.

[0009] However, in a cold weather, this active ventilation, particularly when use is made of an inhalation fan, will directly bring in air at the ambient temperature, which is rather low.

[0010] A first issue is that the humidity level inside the mask is typically relatively high due to the breathing of the user. The exhaled humid air (100% relative humidity at 37 degrees Celsius) in a cold mask will immediately cause the condensation of the water vapor inside the mask. This condensation may be uncomfortable or unpleasant for the user of the mask.

[0011] A second issue is that when breathing in air temperatures that are low, the coldness and dryness of the air can cause the muscles around the airway to tighten as the body attempts to restrict the flow of the cold air into the lungs. High CO_2 levels can exasperate difficulties breathing. This airway narrowing is sometimes referred to as exercise asthma, or cold air-induced asthma, and restricts the normal volume of air retrieved in an inhalation. If a person already has a lung disease, or a condition like asthma, the effect of the cold air on the lungs can further exacerbate breathing difficulties. This may lead to even more restricted airflow into the lungs. Direct recycling of warm, exhaled air within the mask is undesirable due to the high concentrations of toxic CO_2 (approximately 3% to 5%) in exhaled air.

[0012] There is therefore a need for a powered (fan assisted) mask design which avoids the problem of drawing in cold ambient air into the mask.

SUMMARY OF THE INVENTION

[0013] The invention is defined by the claims.

[0014] According to examples in accordance with an aspect of the invention, there is provided a breathing mask comprising:

- a mask body for covering the nose and/or mouth of a user thereby defining a mask chamber;
- an air pump for ventilating the mask chamber to the ambient surroundings;
- a particulate filter;
- one or more airflow regulators; and
- a carbon dioxide (CO_2) filter through which a proportion of the air drawn in to and out of the chamber is able to pass,

wherein the CO_2 filter comprises one or more compounds which react exothermically with carbon dioxide.

[0015] This mask design allows generation of heat when (CO_2-rich) air is exhaled by the user and passes through the CO_2 filter. The CO_2 in the exhaled air can react exothermically with the compound in the CO_2 filter, thereby generating heat within and around the CO_2 filter. This heat can subsequently be exchanged to air that passes into the mask chamber through the CO_2 filter when the user inhales. The heating of the inhaled air reduces condensation in the mask volume and also improves comfort for the user by preventing inhalation of cold ambient air. The heating relies on the exothermic reaction between the CO_2 and the compound in the CO_2 filter meaning no electrical energy is required for heating and a smaller, lighter battery can be used for the fan or the battery life of the mask can be extended.

[0016] The mask body is for example impermeable and has a sealable opening for the particulate filter and CO_2 filter. Thus, a proportion of air drawn in to the mask volume is thermally treated using heat exchanged from the CO_2 filter.

[0017] The breathing mask may comprise a controller which is adapted to control the air drawn in to and/or out of the mask chamber and the proportion of air drawn through the CO_2 filter. The controller can also allow a proportion of the exhaled air, which has passed through the CO_2 filter and has reduced CO_2 content, to be directly recycled into the mask chamber.

[0018] The controller may be a manual controller physically coupled to the airflow regulator and directly controlled by the user. Such a controller allows the user to manually regulate the temperature of the air drawn in to the mask at a comfortable level.

[0019] In an alternative arrangement, the controller may be an electronic controller electronically coupled to the airflow regulator and/or the air pump, and controlled by the user. Such a controller allows the user to regulate the temperature of the air drawn in to the mask at a comfortable level by selecting a desired temperature level.

[0020] In an alternative arrangement, there may be a sensor arrangement for providing feedback control of an electronic controller wherein the sensor arrangement comprises one or more of:

a breathing rate sensor;
an activity monitor;
an air flow sensor;
a CO_2 sensor within the mask chamber;
an O_2 sensor within the mask chamber;
one or more pressure sensors inside and/or outside the mask chamber;
and/or one or more temperature sensors inside and/or outside the mask chamber.

[0021] There may be a wireless interface to receive sensor signals wirelessly. In one example, the controller is an electronic controller electronically coupled to the airflow regulator and/or the air pump, and controlled by a feedback sensor arrangement of at least one or more temperature sensors inside and/or outside the mask chamber. Such a controller allows the temperature of the air drawn in to the mask to be regulated using direct feedback from the temperatures of the ambient surroundings or mask chamber.

[0022] The air pump may comprise:

an inhalation air pump; or
an exhalation air pump; or
an inhalation and an exhalation air pump.

[0023] An inhalation air pump enables a positive pressure to be maintained in the mask volume and provides assistance in breathing in through the filter. An exhalation air pump provides effective ventilation of the mask volume. When both are provided, the timing of operation of the two air pumps may be synchronized with the breathing cycle of the user. A pressure sensor may be provided for sensing the pressure inside the mask, or the differential pressure between the inside and outside, to enable the breathing cycle timing to be obtained.

[0024] The airflow regulator may comprise:

an inhalation airflow regulator; or
an exhalation airflow regulator; or
an inhalation and an exhalation airflow regulator.

[0025] An exhalation airflow regulator controls the proportion of air drawn out of the chamber through the CO_2 filter, thereby controlling how much CO_2 can react and how much heat is produced; it therefore controls how much heat can exchange when air is subsequently drawn in to the CO_2 filter. An inhalation airflow regulator controls the proportion of air drawn in to the chamber through the CO_2 filter and thereby controls the proportion of air heated and the total amount of heat exchanged to air passing into the mask chamber.

[0026] Combination of an inhalation and an exhalation airflow regulator allows maximum control of the temperature of the air being drawn in to the mask and within the mask chamber.

[0027] The airflow regulators for example may comprise a valve.

[0028] The CO_2 filter can be a replaceable air permeable pad or cartridge, preferably a disposable or refillable air permeable cartridge. The CO_2 filter may include an in-built dust filter to prevent fine particles of the compound being inhaled by the user. The compound within the CO_2 filter can weigh only a few grams (1 to 10 g). The cartridge may have a lifetime of about 1 hour or greater, preferably 1 to 8 hours. When the expended compound is harmless, the expended cartridge may be recharged with fresh compound. Such a replaceable CO_2 filter reduces the environmental impact of the mask and extends the lifespan of the mask if the mask is used for longer than the lifetime of the CO_2 filter. It also allows users to select different CO_2 filters depending on the temperature, humidity and composition of the ambient air.

The lifetime of the CO_2 filter can be monitored using a timer (to directly detect the use time), an airflow sensor (to calculate how much air has passed through), a CO_2 sensor (to detect when the concentration of CO_2 in the air passed through starts to increase), a temperature sensor (to detect when the heat generated by the air passed through starts to decrease), or other methods known to those skilled in the art. The user can then be alerted to the imminent expiration of the CO_2 filter by for example a display on the mask, or by a message on a connected smart device or computer.

[0029] When the CO_2 filter can remove particulate matter from the proportion of air passed through, it may be unnecessary to also filter this proportion of air through the particulate filter. In such a situation, it is preferable that only the proportion of air not passing through the CO_2 filter is passed through particulate the filter. Such a configuration minimizes the resistance on the air drawn in to and out of the mask.

[0030] The compound which reacts exothermically with carbon dioxide can do so to form a carbonate or hydrogencarbonate. The reaction can be a single-step or multi-step reaction where the final product is a carbonate or hydrogencarbonate. The exothermic reaction is a chemical reaction, not just absorption or adsorption on to a surface, such as activated carbons or zeolites. The exothermic reaction may release greater than 20 $kJmol^{-1}$ of heat, preferably greater than 50 $kJmol^{-1}$ of heat, more preferably greater than 100 $kJmol^{-1}$ of heat.

[0031] The compound can be an oxide, hydroxide or peroxide of the alkali or alkali earth metals. Preferably the compound can be selected from the group consisting of LiOH, Na_2O_2, NaOH, KOH, $Mg(OH)_2$, $Ca(OH)_2$ and CaO. Most preferably the compound is $Ca(OH)_2$. Such compounds are well known to react exothermically with CO_2 and can provide a strong heating effect. Such compounds are also hydroscopic so can reduce the humidity of the air passing through the CO_2 filter. Then reaction of the compounds in the CO_2 filter with water may also advantageously produce extra heat.

[0032] Where the compound comprises Na_2O_2, Na_2O_2 can react with CO_2 to produce O_2 and $NaCO_3$, or react with H_2O to form O_2 and NaOH. Such a compound can be used to increase the O_2 content in the recycled exhaled air and improve respiration of the user. When Na_2O_2 is present, it is preferably present in an amount of 50 weight% or greater, relative to the total amount of compound which reacts exothermically with carbon dioxide.

[0033] Where the compound comprises CaO, CaO will first react with water vapor in the air to produce $Ca(OH)_2$ and then react with CO_2 to produce $CaCO_3$. Such a compound could be used to reduce the humidity of the exhaled air and increase the comfort to the user. The use of CaO also has the potential to increase the total heat produced by the compound in the CO_2 filter, because heat is first produced during the exothermic reaction between CaO and water vapor, then when $Ca(OH)_2$ reacts with CO_2 to produce $CaCO_3$. When CaO is present, it is preferably present in an amount of 30 weight% or less, relative to the total amount of compound which reacts exothermically with carbon dioxide.

[0034] The compound can be in the form of a solid, a solvate or a liquid; preferably in the form of a solid pellet, a bead, a granule, a flake, a crystal, or porous solid state compounds, more preferably in the form of a bead or a porous solid state compound. Such solid forms allow air to pass efficiently through the CO_2 filter, maximize the surface area of the compound available for reaction and minimize the presence of particles that could be inhaled by the user. Such solid forms can also be easily and cleanly replaced by the user. The free gas volume of the CO_2 filter can be equal or less than 10% of the exhaled air passing through the filter. Such a free gas volume maximizes interaction between the CO_2 in the air and the compound in the CO_2 filter, but also minimizes airflow resistance through the CO_2 filter.

[0035] The CO_2 filter may comprise two or more compounds which react exothermically with carbon dioxide and each may be present in the amount of 1 weight% to 99 weight%, relative to the total amount of compound which reacts exothermically with carbon dioxide. Such combinations of compounds allow the modulation of the amount of heat produced by the exothermic reaction as well as the amounts of CO_2 and H_2O extracted and/or O_2 produced when air passes through the CO_2 filter.

[0036] One preferred combination of compounds comprises 1 weight% to 99 weight% $Ca(OH)_2$ and 1 weight% to 30 weight% CaO, relative to the total amount of compound which reacts exothermically with carbon dioxide. Another preferred combination of compounds comprises 1 weight% to 50 weight% NaOH and 50 weight% to 99 weight% Na_2O_2, relative to the total amount of compound which reacts exothermically with carbon dioxide.

[0037] The CO_2 filter can further comprise additives such as anti-caking agents, stabilizers, binders, desiccants, zeolites, and/or activated charcoals. The identity of suitable additives is known to those skilled in the art and must be compatible for use with the compound which reacts exothermically with carbon dioxide.

[0038] Furthermore, the invention discloses a method of heating air drawn into the chamber of a breathing mask sealed to the face of a user comprising:

drawing a proportion of air exhaled by a user through a carbon dioxide filter; and
drawing a proportion of air subsequently inhaled by the user through the carbon dioxide filter,
wherein the CO_2 filter comprises one or more compounds, which react exothermically with carbon dioxide.

[0039] Preferably, the mask used in the method described above further comprises:

an air pump for ventilating the mask chamber to the ambient surroundings;
a particulate filter; and
one or more airflow regulators.

[0040] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041] Examples of the invention will now be described in detail with reference to the accompanying drawings, in which:

- Figure 1 shows in schematic form a mask in accordance with one example of the invention where the particulate filter is in contact with the ambient air and is designed to filter particulates from the air before it is drawn in to the mask chamber;
- Figure 2a shows an alternative air pump arrangement in the form of a honeycomb array of pump channels;
- Figure 2b shows alternative micropump channel configurations for inflow and outflow of air;
- Figure 3 a shows one example of the mask design in more detail when the user is exhaling and a proportion of the air passes through the CO_2 filter and a proportion is recycled into the mask chamber;
- Figure 3b shows one example of the mask design in more detail when the user is inhaling and a proportion of the air passes through the CO_2 filter;
- Figure 4 shows an example of a schematic layout of the pumps, the airflow regulators, the CO_2 filter and the mask chamber;
- Figure 5 shows an alternative example of a schematic layout of the pumps, the airflow regulators, the CO_2 filter and the mask chamber;
- Figure 6 shows another example of a schematic layout of the pumps, the airflow regulators, the CO_2 filter and the mask chamber; and
- Figure 7 shows one example of the mask design from an alternative perspective.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0042] The invention will be described with reference to the Figures.

[0043] It should be understood that the detailed description and specific examples, while indicating exemplary embodiments of the apparatus, systems and methods, are intended for purposes of illustration only and are not intended to limit the scope of the invention. These and other features, aspects, and advantages of the apparatus, systems and methods of the present invention will become better understood from the following description, appended claims, and accompanying drawings. It should be understood that the Figures are merely schematic and are not drawn to scale. It should also be understood that the same reference numerals are used throughout the Figures to indicate the same or similar parts.

[0044] The invention provides a breathing mask having a CO_2 filter which comprises one or more compounds which react exothermically with the CO_2 present in air exhaled by a user and exchange the generated heat to air subsequently drawn in to the mask chamber. The mask optionally also allows a proportion of the exhaled air, which has passed through the CO_2 filter and has reduced CO_2 content, to be recycled without being drawn out of the mask chamber. The invention also provides a method of heating air drawn into the chamber of a breathing mask sealed to the face of a user.

[0045] Figure 1 shows a schematic of the sagittal plane of a user 10 wearing a face mask 12 which covers the nose and mouth of the user. The purpose of the mask is to filter air before it is inhaled by the user and to provide active control of the flow of air into an air chamber 18 (i.e. the mask volume) and/or out of the air chamber. An air pump arrangement 20 provides active flow control and a particulate filter 21 provides filtering of at least the air drawn in to the mask. A CO_2 filter 26 reacts exothermically with the CO_2 present in air exhaled by a user and exchanges the generated heat to air subsequently drawn in.

[0046] The particulate filter 21 is provided in series with the air pump arrangement 20. The particulate filter 21 can be for use in filtering and/or deactivating particulates, preferably bacteria, viruses, spores, pollen, allergens, dust, smoke, smog, soot and other particulate pollutants from the ambient environment. The air pump arrangement 20 and particulate filter 21 maybe in the opposite order.

[0047] The body of the mask 12 is preferably impermeable (to air) so that all outside air is drawn through the filter.

[0048] Air is drawn in to the air chamber 18 by inhalation, and with assistance provided by the air pump arrangement 20.

[0049] During exhalation, air is expelled from the air chamber 18. In this schematic example, exhalation is through the same air pump arrangement and hence also through the particulate filter 21 (even though the expelled air does may need to be filtered).

[0050] An air flow regulator 22 controls the flow of inhalation and exhalation air through the CO_2 filter 26. As will become apparent from the examples below, this function may be part of the functionality of the air pump arrangement or it may be a separate function, for example implemented by a valve arrangement.

[0051] In a most basic implementation, the amount of air passing through the CO_2 filter as a fraction of the overall air flow is fixed. For example, all air flow may pass through the CO_2 filter or else a fixed proportion of the flow area passes through the CO_2 filter in both directions. This provides the desired heating but does not enable control of the user comfort.

[0052] For the most basic implementations, the flow into the mask may be generated by the air pump arrangement 20 or it may be induced by the breathing in of the user. Similarly, the flow out of the mask may be generated by the pump arrangement 20 or it may be induced by the breathing out of the user. In all cases, at least a part of the area of the flow can be made incident on the CO_2 filter 26 in both flow directions.

[0053] Preferred examples enable dynamic control of the amount of air flow through the CO_2 filter 26 in one or both flow directions. This enables control of the comfort level for the user, and enables the user to set the mask to operate in a manner which suits their needs or preferences.

[0054] This controllability may be achieved by providing a manual adjustment of the flow amount directed to the CO_2 filter 26. However, an electronic control of the air flow conditions is preferred either under the control of the user or automatically using feedback control.

[0055] The ambient air temperature or conditions detected inside the mask chamber 18 can be used to calculate the proportion of air to be drawn through the CO_2 filter 26 and the proportion of air recycled. Ambient temperature or the temperature inside the mask can be measured directly by a temperature sensor (such as a thermo-resistor) in the sensor 28 of the mask. Conditions detected inside the mask chamber 18, such as breathing rate, air flow, CO_2 levels or O_2 levels, can be detected by sensor 28 and used to calculate the proportion of air to be drawn through the CO_2 filter 26. In such cases, the proportion of air to be drawn through the CO_2 filter 26 can be determined by wireless connection of the controller 24 to a smart device (such as a mobile phone), a wearable monitor (such as an Actiwatch) or computer (such as a cloud computer), which can determine the proportion of air to be drawn through the CO_2 filter 26 based on the measured data. These calculations may be based parameters general to the population or specific to the user. Wireless devices can also be used to determine the location of the mask and estimate the ambient temperature predicted by online weather forecast information.

[0056] There are two main examples of how to enable this dynamic flow control. A first is to provide the air pump arrangement as an array of individually controllable pump channels. The pump channels can then be activated to control the flow amount and the locations where flow takes place. The second is to provide a valve arrangement so that the flow through the CO_2 filter can be controlled. This latter approach enables the air pump arrangement 20 to be a more basic fan arrangement (of one or multiple fans). Examples of these two approaches are presented below.

[0057] In a first example, the pump 20 depicted schematically in Figure 1 is a bi-directional pump that is composed of an array of pump channels which function as micropumps and the CO_2 filter 26 is fluidically coupled to a portion of the area of the array facing the mask body. The portion of the channels which draws air through the CO_2 filter 26 can be varied either by changing the size of the CO_2 filter 26, or by only drawing air through a subset of the channels fluidically coupled to the CO_2 filter 26.

[0058] The CO_2 filter 26 comprises one or more compounds which react exothermically with the CO_2 present in air exhaled by a user and exchanges the generated heat to air subsequently drawn in to the mask chamber. The example of a micropump provides a more compact air pump than a fan arrangement. The CO_2 filter 26 is fluidically coupled to at least a proportion of the flow into the mask and to a proportion of the flow out of the mask.

[0059] In this example, the proportion of air passing through the CO_2 filter 26 is controlled by controller 24 which determines which flow channels are activated.

[0060] By selecting which pump channels are activated, the flow rate can be controlled as well as the area over which flow takes place. Thus, the flow channels that align with the CO_2 filter 26 may be activated to provide flow through the filter or only the other channels may be activated so that the CO_2 filter 26 is not used.

[0061] The pump channel setting may be the same during inhalation as exhalation. However, the control of the pump channels may also involve detecting the breathing cycle of the user, for example using a differential pressure sensor 28. The operation of the air pump arrangement is then also timed with the breathing cycle of the user.

[0062] In this way, the flow area and hence proportion of the air that passes through the CO_2 filter 26 during inhalation and during exhalation may be controlled independently. For example, a greater proportion of the pump channels may be used for pumping air into the mask chamber through the CO_2 filter compared to the pump channels used for pumping air out of the mask chamber through the CO_2 filter.

[0063] The controller 24 can control the individual pump channels to provide a pump channel flow in a selectable direction. A single micropump design may then function both as an inhalation fan and an exhalation fan. Figure 2 shows a possible implementation of the air pump arrangement 20 in the form of a honeycomb array of pump channels 30. This provides a compact micropump arrangement. The pump channels 30 may be independently controllable or controlled in groups. The channels 30 are shown as parallel and they may be grouped into rows and columns. A single micropump channel has a very small dimension (e.g. 50 μm), and an array of several hundreds or thousands of single micropump channels may be used to provide enough air flow for human breath. The single micropump channels 30 may be formed into any pattern and can alternate between two directions of air flow by switching the pumping directions.

[0064] Thus, the single pump channel arrangement functions both as an inhale (inlet) and exhale (exhaust) pump. There may be only pump channels controlled to provide outward flow during exhalation (as determined by the controller) and only pump channels controlled to provide inward flow during inhalation, but there could also be inward and outward flow at the same time at different flow channels.

[0065] As shown schematically in Figure 2a, every cell of the honeycomb comprises an individual pump cell and they may be controlled separately or connected in groups for a simple implementation. A proportion of the channels are coupled fluidically to the CO_2 filter 26. One simple example is that the control terminals for the cells are connected together in each row, and different rows are separately controlled. For example, rows 1,2,3 and 4 could be controlled at the same time to make these rows act as intake units, whereas rows 5, 6, 7, and 8 could be controlled at the same time as discharge units. Each row will have several lines connected (for example 3) to a controller.

[0066] Typically, one terminal is connected to a positive voltage, another terminal is connected to a negative voltage, and a third terminal is connected to a control voltage that could be positive or negative.

[0067] By switching the third terminal, a diaphragm film of each single cell moves towards the first or second terminal by electrostatic attraction and repulsion. This generates the desired micro flow. By controlling the sequence of signals applied to the third terminal, the flow rate is controlled, and by switching the first and second terminals the direction of flow also can be controlled.

[0068] For a full implementation there could be more than three terminals for each cell for better performance. There are insulation layers between each channel.

[0069] By way of example, each cell is hexagonal with the first and second terminals on opposite faces, and the third terminal arranged to move between them.

[0070] The pump channels are all parallel in this example, but there could instead be pump channels with different directions.

[0071] The number of flow channels 30 drawing air through the CO_2 filter 26 can be controlled. This allows modulation of the proportion of inhaled air which is heated. To maximize efficient heat exchange, the inhaled air should be drawn through the same portions of the CO_2 filter 26 as the exhaled air, thereby providing direct contact between the heated portions of the CO_2 filter 26 and the inhaled air. This can be achieved by either drawing air in to and out of the CO_2 filter 26 through the same bidirectional channels, or by drawing air out through a matrix of channels then drawing air in through juxtaposed channels; Figure 2b shows two exemplary layouts where air inflow channels 30a (white hexagons) are juxtaposed with air outflow channels 30b (black hexagons). The proportion of air drawn in to and out of the CO_2 filter 26 may be varied. For example, about 10% of exhaled air may be drawn out through the CO_2 filter 26 and about 50% of inhaled air may be drawn in through the CO_2 filter 26. Figure 3a shows a schematic of the sagittal plane of a user 10 exhaling air (dotted arrows 31, 32 and 33) whilst wearing a face mask 12. When the ambient air temperature is high, the CO_2 filter can be bypassed during exhalation and only non-CO_2-filtered air 31 can be drawn out of the mask. In this case, no heat is generated in the CO_2 filter 26.

[0072] When the ambient air temperature is low, a proportion of the exhaled air is passed through the CO_2 filter 26 and the CO_2-filtered air 32 can also be drawn out of the mask. As the exhaled air passes through the CO_2 filter, it undergoes an exothermic chemical reaction with the compound in the CO_2 filter 26 and generates heat. This heat can be transferred to air subsequently drawn in to the mask chamber.

[0073] Furthermore, a proportion of the CO_2-filtered air 32 can be recycled without being drawn out of the mask chamber under the control of regulator 22. The recycled air 33, depleted of CO_2 and heated by the exothermic reaction in the CO_2 filter 26, therefore allows heated, breathable air to be retained within the mask chamber.

[0074] The proportion of the exhaled air passed through the CO_2 filter 26 can be 0% to 50%, preferably 1% to 30% and more preferably 2% to 20% of the total exhaled air. The proportion of recycled air 33 can be 0% to 50% and preferably 1% to 20%, more preferably 5% to 10% of the total exhaled air. These proportions can be controlled by controller 24 using airflow regulator 22.

[0075] Figure 3b shows a schematic of the sagittal plane of a user 10 inhaling air (dashed arrows 34 and 35) whilst wearing a face mask 12. When the ambient air temperature is high, the CO_2 filter can be bypassed during inhalation and only non-CO_2-filtered air 34 can be drawn in the mask. In this case, no heat can be transferred to the air drawn in to the mask chamber.

[0076] When the ambient air temperature is low, a proportion of the inhaled air is also passed through the CO_2 filter 26 and the CO_2-filtered air 35 can be drawn in to the mask. Heat previously generated in the CO_2 filter 26 by the CO_2-filtered air 32 and recycled air 33 can be exchanged to the CO_2-filtered air 35.

[0077] The proportion of air drawn in to the mask chamber can therefore consist of any combination of recycled air 33, non-CO_2-filtered air 34 and CO_2-filtered air 35. Preferably, the air drawn in to the mask chamber comprises 0% to 50% of recycled air 33, 30% to 100% non-CO_2-filtered air 34 and 0% to 50% CO_2-filtered air 35. These proportions can be controlled by controller 24 using airflow regulator 22.

[0078] Figure 4 shows an example of a schematic layout of the pumps 20, the airflow regulator 22 when implemented by valves, the CO_2 filter 26 and the mask chamber 18. For simplicity, no particulate filter 21 is shown. A first pump or ventilator 20a can support inhalation and a second pump or ventilator 20b can support exhalation. A CO_2 filter 26 is connected to pump 20a via tubing (dashed arrows) and optionally one or more in-valves 22a. The CO_2 filter 26 is also connected to pump 20b via tubing (dotted arrows) and at least one out-valve 22b. When the ambient air is warm, the regulator valves 22a and 22b are closed and no air passes through the CO_2 filter 26. Only when the ambient air temperature is low are the regulator valves 22a and 22b opened and air allowed to flow through the CO_2 filter 26. The regulator valves 22a and 22b regulate the proportion of air which passes through the CO_2 filter 26 rather than regulating the total amount of air able to enter or leave the mask chamber. The CO_2 filter 26 can be positioned in, on or close to the mask or close to one pump.

At low ambient air temperature the out-valve 22b can be opened. A proportion of the exhaled air is drawn through the CO_2 filter 26 and the CO_2 present in the CO_2-filtered air 32 (approximately 3% to 5%) reacts exothermically with the compound in the CO_2 filter 26. Optionally, a proportion of the CO_2-filtered air 32 (preferably about 10% of the total exhaled air) can be recycled into the mask chamber 18 as recycled air 33 by opening recycling valve 22c. CO_2 filtering generates heat that can exchange to the air passing through the filter as well as to the compound and the CO_2 filter 26, but also (significantly) reduces the amount of gaseous CO_2 in the CO_2-filtered air 32 and recycled air 33.

During inhalation, in-valve 22a can be opened and a proportion (preferably about half) of the ambient air is fed through the CO_2 filter 26 by pump 20a to produce CO_2-filtered air 35, which can be significantly heated by heat exchange in the CO_2 filter 26. CO_2-filtered air 35 together with recycled air 33 is mixed with non-CO_2-filtered air 34 (preferably about 40%) to form inhaled air at a comfortable temperature. Over the lifetime of the mask and as the compound in the CO_2 filter 26 expires, it maybe preferable to increase the proportion of CO_2-filtered air 35 that is recycled into the mask chamber 18 as recycled air 33, such that up to all of the CO_2-filtered air 35 is recycled. This allows heat to be retained in the mask chamber 18 even when the efficiency of the CO_2 filter 26 is reduced. The lifetime of the CO_2 filter, and therefore the proportion of CO_2-filtered air 35 recycled, can be monitored using a timer, a sensor, or other methods known to those skilled in the art.

[0079] Another option is to provide a desired ratio of CO_2-filtered air sent to the outside and recycled air by time sequencing. In the first phase of exhalation the CO_2-filtered air may be (mainly) provided to the outside and in the second phase the recycled air is (mainly) led back.

Figure 5 shows a variation of the example in Figure 4 where a pump 20a is only used to support inhalation. The preferred proportions of recycled air 33, non-CO_2-filtered air 34, and CO_2-filtered air 35 are the same as in the example of Figure 4. In this example, an air pump 20a is used to draw air into the mask chamber 18 and exhaled air leaves the mask via air outlet 50. Exhalation airflow out is regulated by out-valve 22b. Optionally, inhalation airflow into the CO_2 filter 26 is regulated by in-valve 22a and the proportion of recycled air 33 is regulated by valve 22c. When the ambient air is warm, the regulator valves 22a and 22b close the paths to the CO_2 filter (i.e. the valve 22b allowing exhaled air to pass but not recycling any to the CO_2 filter 26) and no air passes through the CO_2 filter 26. Only when the ambient air temperature is low are the regulator valves 22a and 22b opened and air allowed to flow through the CO_2 filter 26. The regulator valves 22a, 22b and 22c regulate the proportion of air which passes through the CO_2 filter 26 rather than regulating the total amount of air able to enter or leave the mask chamber. The regulator valve 22b thus regulates the amount of exhaled air flowing through the CO_2 filter.

Figure 6 shows another variation of the example in Figure 4 where a pump 20b is only used to support exhalation. The preferred proportions of recycled air 33, non-CO_2-filtered air 34, and CO_2-filtered air 35 are the same as in the example of Figure 4. In this example, only an air pump 20b is used to draw air out of the mask chamber 18. Inhaled air enters the mask through air inlet 30. Optionally, the proportion of recycled air 33 is regulated by valve 22c. When the ambient air is warm, the regulator 22d and regulator valve 22b are closed and no air passes through the CO_2 filter 26. Only when the ambient air temperature is low are regulator 22d and regulator valve 22b opened and air allowed to flow through the CO_2 filter 26. The regulator valves 22d, 22b and 22c regulate the proportion of air which passes through the CO_2 filter 26 rather than regulating the total amount of air able to enter or leave the mask chamber. Regulator 22d actively distributes the air that goes directly into the mask chamber and that which first passes through the CO_2 filter 26.

[0080] Figures 1 and 3 show the pumps, filters and regulators on the face of the mask body in contact with ambient air. This preferred configuration ensures these components do not come into contact with the users face and allows the user to change filters without removing the mask. However, it is within the scope of the invention that some or all of these components are housed within the mask chamber.

[0081] Figures 4 to 6 show valves in positions which illustrate the functions they perform. The actual physical locations of the valves may vary as a function of the actual design. Figure 7 shows the user 10 and mask body 12 through the transverse plan. The design shown in Figure 7 avoids a direct airflow into the face of the user. The inlet air will always be directed from a side or from above or from below to the nose, which also improves the wearing comfort.

[0082] Figure 7 also shows a strap 54 for holding the mask and a mask seal 56.

[0083] The Figures show the CO_2 filter in direct contact with the mask body and separating the pump from the mask body. However, it is within the scope of the invention that the pump is in direct contact with the mask body and separating the CO_2 filter from the mask body.

[0084] Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

Claims

1. A breathing mask comprising:

   a mask body (12) for covering the nose and/or mouth of a user thereby defining a mask chamber (18);
   an air pump (20) for ventilating the mask chamber to the ambient surroundings;
   a particulate filter (21);
   one or more airflow regulators (22); and
   a CO_2 filter (26) through which a proportion of the air drawn in to and out of the chamber is able to pass,
   wherein the CO_2 filter comprises one or more compounds, which react exothermically with carbon dioxide.

2. A breathing mask as claimed in claim 1, wherein the mask body is impermeable and has an opening for the CO_2 filter and the particulate filter.

3. A breathing mask as claimed in claim 1 or 2, further comprising a controller (24) which is adapted to control the proportion of air drawn in to and/or out of the chamber through the CO_2 filter, wherein the controller is:

   a manual controller physically coupled to the airflow regulator, or
   an electronic controller electronically coupled to the airflow regulator and/or the air pump, and controlled by the user.

4. A breathing mask as claimed in claim 3, comprising a sensor arrangement for providing feedback control of an electronic controller, wherein the sensor arrangement comprises one or more of:

   a breathing rate sensor;
   an activity monitor;

   an air flow sensor;

   a CO_2 sensor within the mask chamber;
   an O_2 sensor within the mask chamber;
   one or more pressure sensors inside and/or outside the mask chamber;
   and/or one or more temperature sensors inside and/or outside the mask chamber.

5. A breathing mask as claimed in any preceding claim, wherein the air pump comprises:

   an inhalation air pump; or
   an exhalation air pump; or
   an inhalation and an exhalation air pump.

6. A breathing mask as claimed in any preceding claim, wherein the airflow regulator comprises:

   an inhalation airflow regulator; or
   an exhalation airflow regulator; or
   an inhalation and an exhalation airflow regulator.

7. A breathing mask as claimed in any preceding claim, wherein the CO_2 filter is a replaceable air permeable cartridge.

8. A breathing mask as claimed in any preceding claim, wherein the compound is an oxide, hydroxide or peroxide of the alkali or alkali earth metals.

9. A breathing mask as claimed in claim 8, wherein the compound is one or more selected from the group consisting of LiOH, Na_2O_2, NaOH, KOH, $Mg(OH)_2$, $Ca(OH)_2$ and CaO.

10. A breathing mask as claimed in any preceding claim, wherein the compound is in the form of a solid, a solvate or a liquid.

11. A breathing mask as claimed in claim 10, wherein the compound is in the form of a solid pellet, a bead, a granule, a flake, a crystal, or a porous solid state compound.

12. A breathing mask as claimed in any preceding claim, wherein the CO_2 filter comprises two or more compounds which react exothermically with carbon dioxide and each is present in the amount of 1 weight% to 99 weight%, relative to the total amount of compound which reacts exothermically with carbon dioxide.

13. A breathing mask as claimed in claim 12, wherein the CO_2 filter comprises 1 weight% to 99 weight% $Ca(OH)_2$ and 1 weight% to 30 weight% CaO, relative to the total amount of compound which reacts exothermically with carbon dioxide.

14. A breathing mask as claimed in claim 12, wherein the CO_2 filter comprises 1 weight% to 50 weight% NaOH and 50 weight% to 99 weight% Na_2O_2, relative to the total amount of compound which reacts exothermically with carbon dioxide.

15. A method of heating air drawn into the chamber (18) of a breathing mask sealed to the face of a user (10) comprising:

   drawing a proportion of air exhaled by a user through a carbon dioxide filter (26),
   drawing a proportion of air subsequently inhaled by the user through the carbon dioxide filter,

wherein the CO_2 filter comprises one or more compounds, which react exothermically with carbon dioxide.

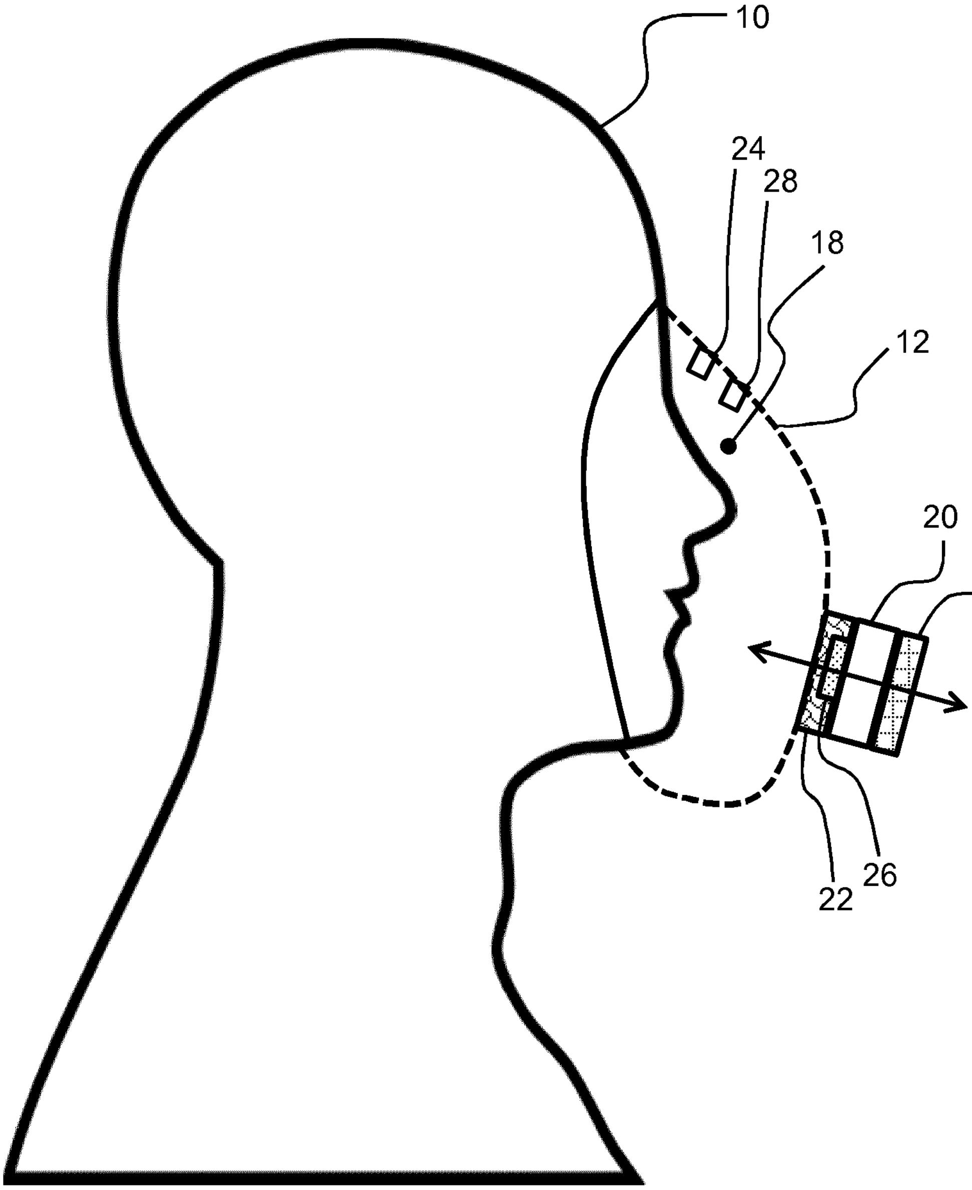

FIG. 1

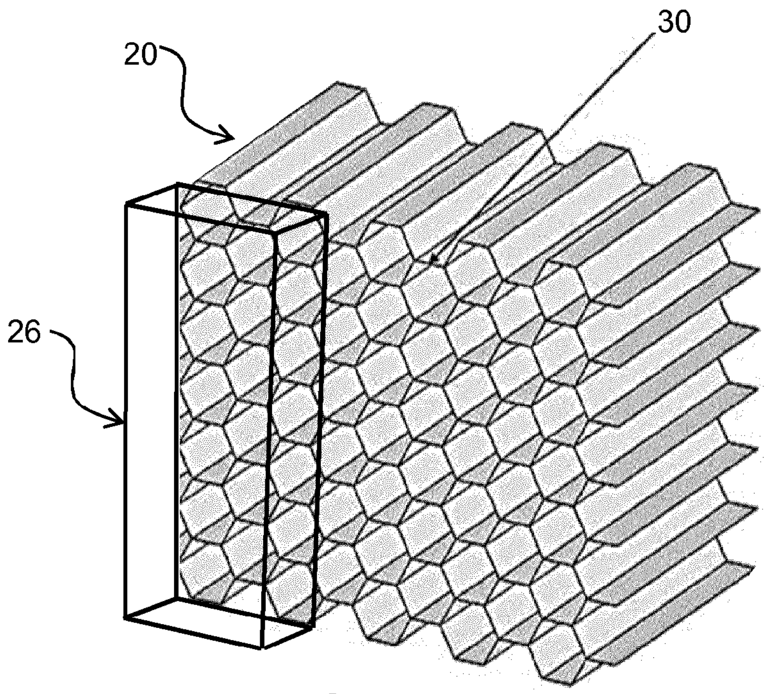

FIG. 2a

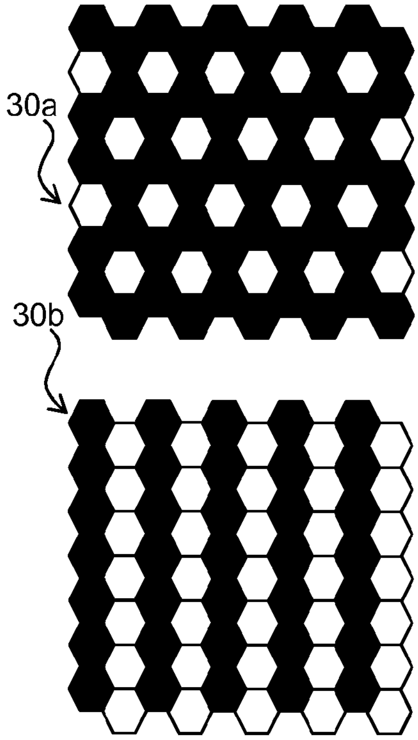

FIG. 2b

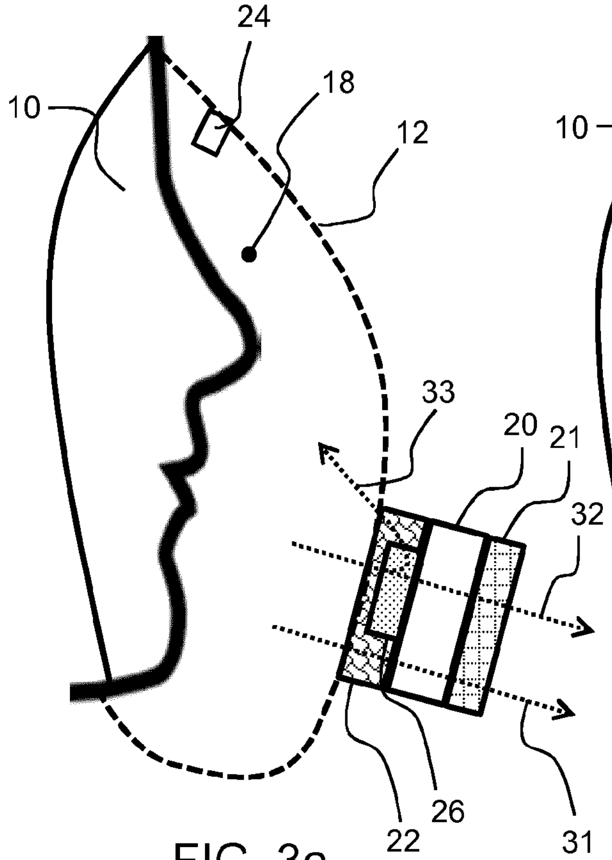

FIG. 3a

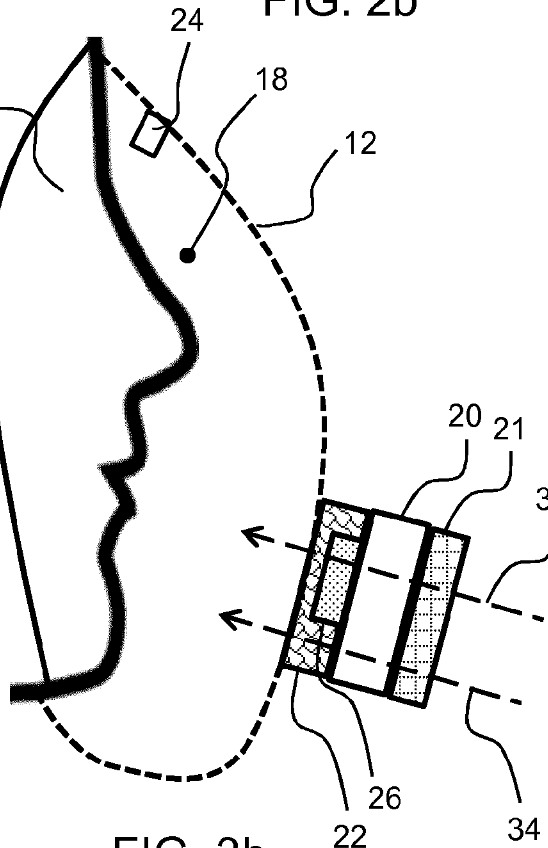

FIG. 3b

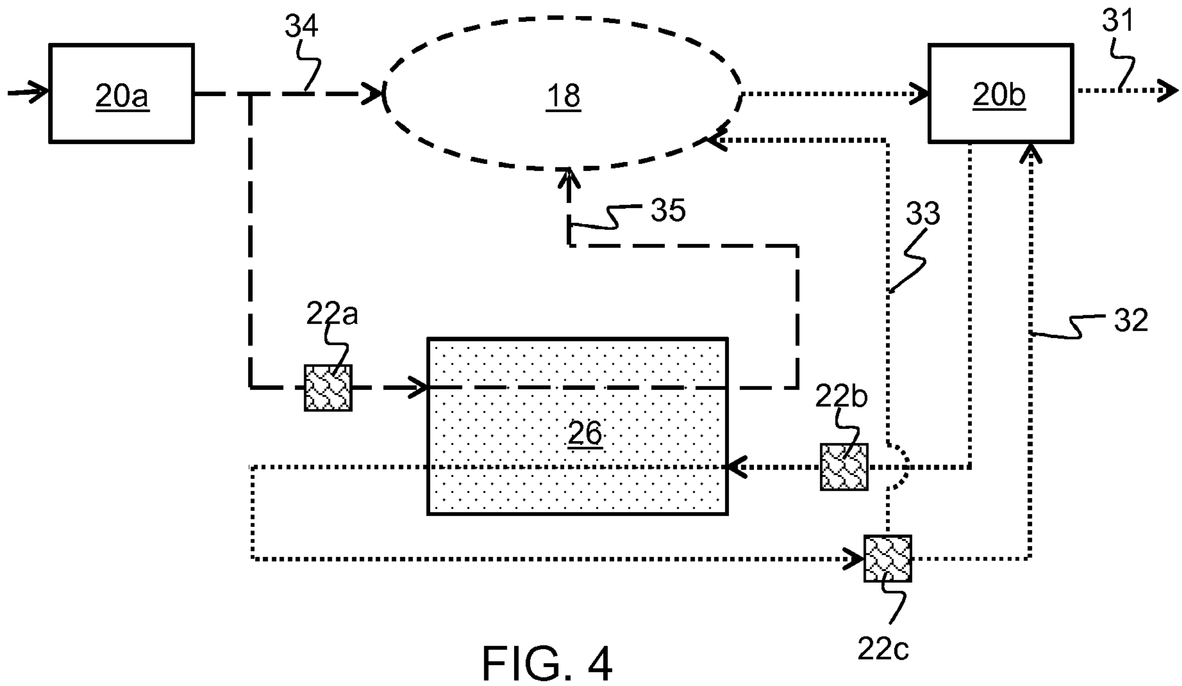
34
31
20a
18
20b
35
33
32
22a
26
22b
22c

FIG. 4

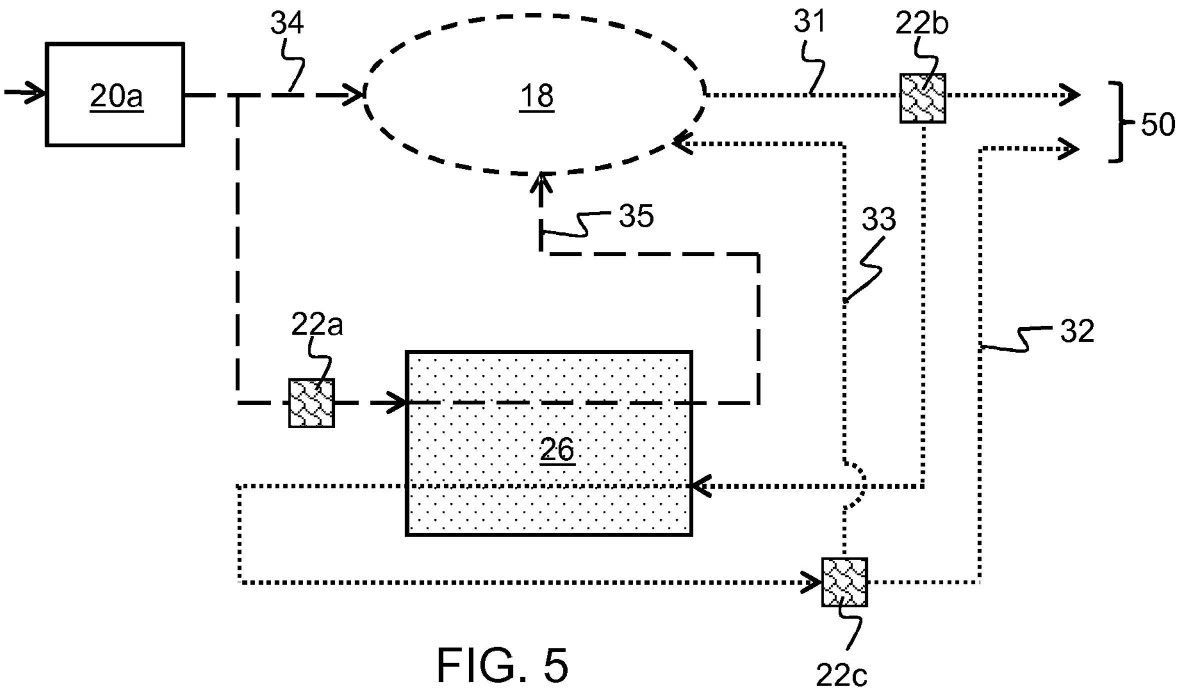
34
31
22b
20a
18
50
35
33
32
22a
26
22c

FIG. 5

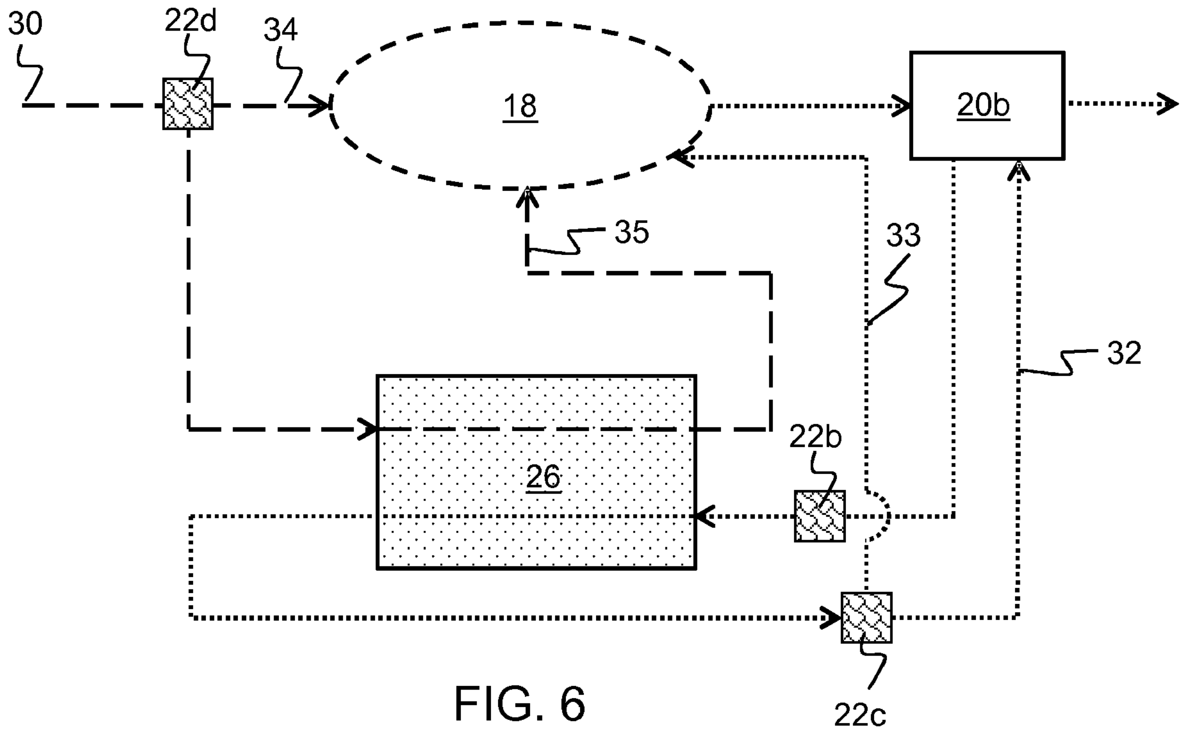

FIG. 6

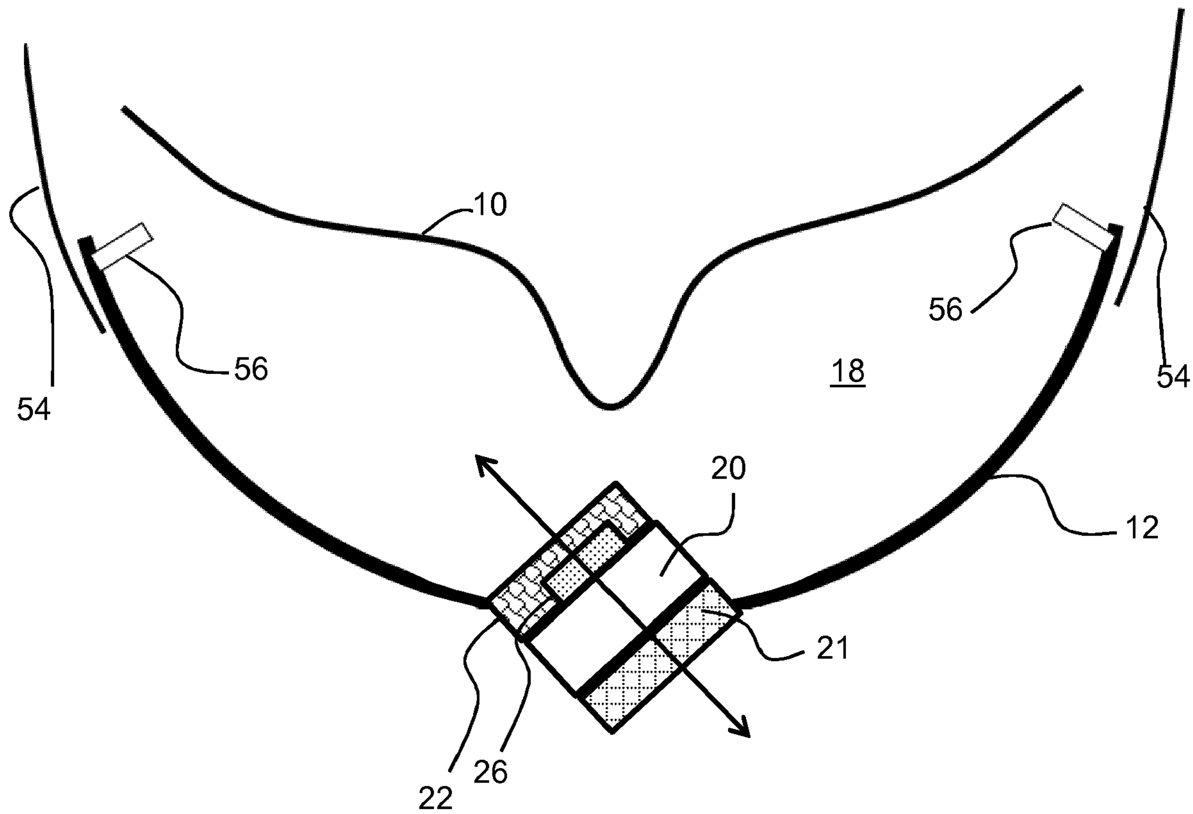

FIG. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 17 20 2809

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 2015/114389 A1 (SERNFÄLT MATS ULRIK [SE] ET AL) 30 April 2015 (2015-04-30) * paragraphs [0001], [0017] - [0018]; figures 1-5 * -----	1-15	INV. A62B7/10 A62B18/00 A62B23/02 A62B7/08 A62B9/00
A	US 2017/143933 A1 (PASADILLA PATRICK DEE [US] ET AL) 25 May 2017 (2017-05-25) * paragraphs [0006], [0024] - [0046]; figures 1-8 * -----	1-15	
A	US 5 040 528 A (O'NEILL WILBUR J [US]) 20 August 1991 (1991-08-20) * column 1, line 5 - column 5, line 11; figures 1-11 * -----	1-15	
A	GB 2 234 440 A (SABRE SAFETY LTD [GB]) 6 February 1991 (1991-02-06) * the whole document * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			A62B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	23 April 2018	Horrix, Doerte

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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23-04-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015114389 A1	30-04-2015	AU 2014340355 B2	13-07-2017
		CA 2926397 A1	30-04-2015
		CN 105636631 A	01-06-2016
		EP 3060284 A1	31-08-2016
		KR 20160077112 A	01-07-2016
		RU 2016113766 A	29-11-2017
		US 2015114389 A1	30-04-2015
		WO 2015061186 A1	30-04-2015
US 2017143933 A1	25-05-2017	NONE	
US 5040528 A	20-08-1991	NONE	
GB 2234440 A	06-02-1991	DE 4023013 A1	31-01-1991
		FR 2649897 A1	25-01-1991
		GB 2234440 A	06-02-1991

EPO FORM P0459

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