

RESPIRATORY DEVICES

TECHNICAL FIELD

[0001] The present disclosure relates generally to respiratory devices. Embodiments of the disclosure are related to a respiratory device integrated with one or more micro high pressure piezoelectric air pumps to provide positive airflow within a mask.

BACKGROUND

[0002] Respirators are used to protect the wearer from inhaling harmful dusts, fumes, vapors, or gases. A wide range of types and sizes of respirators are used in various fields including without limitation, military, industry, and public. Respirators range from cheaper, single-use, disposable masks to reusable models with replaceable cartridges. In general, a respirator includes a mask sealed against the face of a user, an air inlet to permit air into the mask so that the user may breathe, a filter often being used to remove unwanted materials from the air to be inhaled and an outlet to exit the exhaled air into an ambient atmosphere.

[0003] Respirators can be of two types, an air-purifying respirator or an air-supplying respirator. The air-purifying respirator provides purified air to the user after filtering the air through a filter. The air-supplying respirator is provided with an alternate supply to deliver fresh air to the user. Each type of respirator utilizes different techniques to reduce or eliminate noxious airborne contents.

[0004] In accordance with a known art, a powered air purifying respirator (PAPR) is used that improves breathing experience of a user by reducing air resistance and supplying positive airflow. However, such active masks and respirators with air pumps mainly designed for industrial and medical usage, are heavy, cumbersome and expensive. Also, such devices are unsuitable for daily use by general public consumers against haze, virus and urban air pollutants.

[0005] In accordance with another art, a typical off-the-shelf non-powered air-purifying mask used by consumers such as the National Institute for Occupational Safety and Health (NIOSH) filters efficiency grade N95 series of filtered masks. Such masks are plagued by hygiene, moisture and dirt problems which results in increased breathing resistance, especially, with prolonged usage. The increased resistance reduces the exhalation efficacy thus, increasing heat and humidity trapped within the mask. Also, prolong usage of such masks may cause breathing difficulties and/or dizziness especially, to the elderly and young children. This issue may exacerbate for higher filter efficiency grade N99, N100 and HEPA filter masks where the lower filter porosity to provide higher filter efficiency is expected to significantly reduce air exchange rate.

[0006] A need, therefore, exists for an improved respiratory device that is compact, lightweight, low noise and consumes minimal power.

SUMMARY

[0007] The following summary is provided to facilitate an understanding of some of the innovative features unique to the disclosed embodiment and is not intended to be a full description. A full appreciation of the various aspects of the embodiments disclosed herein can be gained by taking into consideration the entire specification, claims, drawings, and abstract as a whole.

[0008] It is, therefore, one aim of the disclosed embodiments to provide a respiratory device including a mask to be positioned around the mouth and nose of a wearer to form a relatively closed area sealed from ambient air, one or more air exchange unit embedded in the mask such that the air exchange unit includes a first holding substrate having at least one air filter through which ambient air from outside the mask flows into the relatively closed area within the mask, one or more exhaust unit embedded in the mask such that the exhaust unit includes a second holding substrate including at least one high pressure piezoelectric micro-pump, and a first controller for controlling the high

pressure piezoelectric micro-pump, such that the high pressure piezoelectric micro-pump draws filtered air from the air filter into the relatively closed area and discharges expired air out of the relatively closed area of the mask thereby, maintaining positive filtered purified airflow into the mask.

[0009] It is another aim of the disclosed embodiments to provide a plurality of sensors in communication with the first controller such that the first controller triggers the high pressure piezoelectric micro-pump to regulate the air flow. The sensors may be one or more temperature and humidity sensors.

[0010] It is yet another aim of the disclosed embodiments to provide the air filter that includes one or more functional layers made of polypropylene felt and/or activated carbon fibers to hold back virus, particulate contaminants and odor.

[0011] It is yet another aim of the disclosed embodiments to provide an optional fan in the first holding substrate of the air exchange unit.

[0012] It is yet another aim of the disclosed embodiments that the mask is made of transparent silicone.

[0013] It is yet another aim of the disclosed embodiments to provide a respiratory device including a mask positioned around the mouth and nose of a wearer to form a relatively closed area sealed from ambient air, one or more air exchange unit comprising of an air filter, a first holding substrate with a first fastener and a first cover, a fan and a first controller for driving the fan to draw ambient air from outside the mask to flow through the air filter into the relatively closed area within the mask, and one or more exhaust unit comprising a second holding substrate with a plurality of sensors, a second fastener and a second cover, a high pressure piezoelectric micro-pump, a power source for driving the high pressure piezoelectric micro-pump, and a second controller for controlling the high pressure piezoelectric micro-pump through suitable control signals

whereby filtered air is drawn into the relatively closed area and expired air is discharged out of the relatively closed area of the mask, thereby drawing positive filtered purified air into the mask.

[0014] It is yet another aim of the disclosed embodiments to utilize the plurality of sensors for regulating the air flow through the exhaust unit and out of the mask based on temperature and humidity levels in the relatively closed area.

[0015] It is another aim of the disclosed embodiments to make the mask of transparent silicone.

[0016] It is another aim of the disclosed embodiments that the air filter includes one or more functional layers made of polypropylene felt and/or activated carbon fibers to hold back virus, particulate contaminants and odor.

[0017] Other aspects and advantages of the invention will become apparent from the following detail description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0001] The summary above, as well as the following detailed description of illustrative embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the present disclosure, exemplary constructions of the disclosure are shown in the drawings. However, the disclosure is not limited to specific methods and instrumentalities disclosed herein. Moreover, those in the art will understand that the drawings are not to scale. Wherever possible, like elements have been indicated by identical numbers.

[0002] **FIG. 1** is an illustration of a schematic front view of a mask of a respiratory device, in accordance with the disclosed embodiments;

[0003] **FIG. 2A** is an illustration of a schematic side view of the mask depicted in **FIG. 1** on a wearers' face with an exhaust unit, in accordance with the disclosed embodiments;

[0004] **FIG. 2B** is an illustration of a schematic side view of the mask depicted in **FIG. 1** on a wearers' face with an air exchange unit, in accordance with the disclosed embodiments;

[0005] **FIG. 3** is an illustration of an exploded assembly view of the air exchange unit depicted in **FIG. 2B**, in accordance with the disclosed embodiments;

[0006] **FIG. 4** is an illustration of a cross-sectional view of the integrated structure of the air exchange unit depicted in **FIG. 3**, in accordance with the disclosed embodiments;

[0007] **FIG. 5** is an illustration of an exploded assembly view of the exhaust unit depicted in **FIG. 2A**, in accordance with the disclosed embodiments;

[0008] **FIG. 6** is an illustration of a cross-sectional view of the integrated structure of the exhaust unit depicted in **FIG. 5**, in accordance with the disclosed embodiments; and

[0009] **FIG 7 (7a-7d)** illustrate the operation of the mask **101** in accordance with the disclosed embodiments.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0010] The particular values and configurations discussed in these non-limiting examples can be varied and are cited merely to illustrate at least one embodiment and are not intended to limit the scope thereof.

[0011] The present disclosure provides a respiratory device having an air exchange unit and exhaust unit integrated or embedded in a respiratory mask. The air exchange unit provides filtered air to the user and also allows the expended air to exit. The exhaust unit vents the mask as heat and humidity build up within the mask. An air pump in the exhaust unit draws filtered air into the relatively closed area between a wearers' face and the mask through the air exchange unit, and pumps out expired air of the relatively closed area through the exhaust unit. The speed and amount of air flow may be regulated by controlling the air pump through suitable control signals. The air exchange unit and exhaust unit may work jointly or independently to provide purified air and regulate the temperature and humidity within the mask.

[0012] **FIG. 1** is a front schematic view of one embodiment of a respiratory device including a mask **101**. The mask **101** includes an air exchange unit **102** and exhaust unit **103**. The air exchange unit **102** and exhaust unit **103** are integrated or embedded in the mask **101**. In an embodiment, the air exchange unit **102** and exhaust unit **103** are located on the mask **101** such that once the mask **101** is worn, the air exchange unit **102** and exhaust unit **103** are placed near the nostrils and mouth area of the wearers' face. Also, this strategic positioning of the air exchange unit **102** and exhaust unit **103** allows a continuous stream of purified air to be drawn across very near to the face nostrils and mouth area for better breathing experience. Alternatively, the air exchange unit **102** and exhaust unit **103** may be located on one side of the mask **101**. Such variations are within the scope of the present invention.

[0013] The air exchange unit **102** provides filtered regulated purified positive air to ensure smooth inhalation and exhalation. The exhaust unit **103** draws out expired/dead air from the mask. Details of the air exchange unit **102** and exhaust unit **103** are provided in **FIGS. 3** and **5** respectively. The mask **101** may be made of a transparent and easily moldable material for example, transparent silicone, to minimize visual obstruction and offer a comfortable, conforming fit to the wearer's face.

[0014] **FIGS. 2A** and **2B** depict exemplary placement of the mask **101** on a wearer's

face **104**. In this embodiment, the mask **101** covers the central part of the wearer's face **104** around the nose and mouth to form a relatively closed space **105** catering to filtered purified air for inhalation. Alternatively, the mask **101** can be designed to cover the entire face **104** including the eyes as a full facial mask piece.

[0015] As shown, the air exchange unit **102** and exhaust unit **103** are placed near the nostrils of the wearer. Alternatively, the exhaust unit **103** can also be located near the lower part of the mask **101** between the mouth and chin area of the face **104** to effectively discharge exhaust expired air, which is carbon dioxide and moisture rich and therefore relatively heavier. Mask **101** may also have more than one air exchange unit **102** and exhaust unit **103** to provide stronger air flow and exchange.

[0016] The air exchange unit **102** provides filtered regulated purified positive air into the relatively closed space **105** located near the nose while the exhaust unit **103** draws the expired/dead air from the relatively closed space **105** near the nose to the ambience outside the mask **101**. The structure and method of integrating and embedding the air exchange unit **102** and exhaust unit **103** are illustrated in accompanying **FIGS. 3-6**.

[0017] **FIGS. 3** and **4** show an exploded view and cross-sectional view respectively of the air exchange unit **102**. The air exchange unit **102** includes a first holding substrate **121**, a fan **122**, an air filter **123**, a first gasket **124** and a first cover **125**. As shown in **FIG. 3**, all of the components of the air exchange unit **102** are stacked in sequence and integrated or embedded onto the mask **101**. Depending upon requirements, it is possible to include plurality of the above components, for example, air filter **122** or gasket **124**, etc. The first holding substrate **121** may be designed to allow integration of the air exchange unit **102** onto the mask **101**. For example, the first holding substrate **121** has a circular cross-section and is slightly curved to fit into the mask **101**. The first holding substrate **121** includes one or more suitably sized perforations **129** for easy air passage. The first holding substrate **121** can be made of, for example, acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polypropylene (PP), polyvinyl chloride (PVC).

[0018] The air filter **123** is used to supply filtered purified air continuously into the space **105** for breathing. In the depicted embodiment, the air filter **123** is circular in shape and is of such dimensions that it can be placed within the first holding substrate **121**. The air filter **123** may contain one or more functional layers, such as polypropylene felt and/or activated carbon to hold back virus, particulate pollutants and odor. The air filter **123** may be of disposable or replaceable type, in which case, the air exchange unit **102** may be modular to facilitate convenient access and replacement of the air filter **123**. The air filter **123** may be designed to be of appropriate size and type such that even when an air pump **132** of the exhaust unit **103** and/or fan **122** is/are not working, air flow into and out of the mask **101** through the air filter **123** is sufficient.

[0019] The fan **122** is mounted on the substrate **121** to draw air through the air filter **123** into the mask **101** thereby, increasing the air flow into the mask **101**. For example, as shown in **FIGS. 2A** and **2B**, once the mask **101** is worn, the fan **122** of the air exchange unit **102** serves to improve the drawing of ambient air from outside the mask **101** through the filter **123** into the relatively closed space **105** within the mask **101** to further improve breathing experience of the mask wearer. The fan **122** is optional, but advisable to be used with the air exchange unit **102**. The fan **122** may be a micro fan. By controlling the speed of the fan **122**, air flow through the air exchange unit **102** into the mask **101** can be regulated. The fan **122** is connected to a first controller (not shown) for power and control signals. The first controller can be carried in the wearer's pocket, strap onto the wearer head, ear, neck or limbs. Alternatively, the first controller can be miniaturized and contained in the first cover **125** of the air exchange unit **102**. The connecting wires may be integrated within the mask **101** to provide safety to the wearer and for aesthetic reason. It should be noted that even when the fan **122** is not working, the air flow through the air filter **123** into and out of the air exchange unit **102** is not obstructed.

[0020] The first gasket **124** provides an air tight seal between the first cover **125** and the air filter **123**. This ensures that there is no air leakage. Other mechanisms that serve

the same function as that of gasket can be used with the present invention.

[0021] The first cover **125** is provided on the top of the assembly of the fan **122**, air filter **123** and first gasket **124** and is attached onto the first holding substrate **121** securely by a suitable fastening mechanism. For example, the fastening mechanism for the first cover **125** may be screw threads while for the first holding substrate **121** may be corresponding nut threads. The entire air exchange unit **102** when fully assembled onto the mask **101** may be sealed and fully isolate the relatively closed space **105** within the mask **101** from the ambience outside the mask **101**. The first cover **125** may be designed to have enough empty space exposed to allow ambient air outside mask **101** to pass through and reach the filter **123** easily. The first cover may be made of, for example, acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polypropylene (PP), polyvinyl chloride (PVC).

[0022] **FIGS. 5** and **6** show an exploded view and a corresponding cross-sectional view of the exhaust unit **103** respectively. The exhaust unit **103** includes a second holding substrate **131** with one or more embedded sensors, an air pump **132**, a second gasket **133**, a second cover **134** and a battery module **135**. As shown in **FIG. 5**, all of the components of the exhaust unit **103** are stacked in sequence and integrated or embedded onto the mask **101**. Depending upon requirements, it is possible to include a plurality of the above components, for example, air pump **132** or gasket **133**, etc. The second holding substrate **131** includes a suitably sized first perforation **137** to release air from inside the mask **101** when the air is being sucked by the air pump **132**. The second holding substrate may be made of, for example, acrylonitrile butadiene styrene (ABS), polycarbonate (PC), polypropylene (PP), polyvinyl chloride (PVC). The second holding substrate **131** may be designed to allow integration of the exhaust unit **103** onto the mask **101**. For example, the second holding substrate **131** has a circular cross-section and is slightly curved to fit into the mask **101**.

[0023] The air pump **132** may draw filtered air into the mask **101** through the air filter **123** of the air exchange unit **102** and pump out expired air from within the mask **101** into

the ambience through the first perforation **137** and a second perforation **136** on the second cover **134** of the exhaust unit **103** when power is supplied to it by the battery module **135**. The pressure of the air pump **132** is sufficiently high to prevent external ambient air from flowing into the mask, even when the user inhales. The air pump **132** can be attached directly to the mask **101** by mounting it on the second holding substrate **131** without any tubes and draws its power from the battery module **135**. The air pump **132** can be for example, a micro-electro-mechanical systems (MEMS) like a high pressure piezoelectric micro-pump which has the advantages of ultra-low power consumption, small and slim dimensions, light weight and operation quietness. In addition, the air pump **132** may have a very low flow rate which can be adjusted using a second controller. The exemplary piezoelectric micro-pump is driven by an alternating current (AC) power and control signals to draw filtered air into the relatively closed area of the mask **101** through the air exchange unit **102** and pump out expired air of the relatively closed area of the mask **101** through the exhaust unit **103**. The regulated air pump **132** creates forced ventilation through the air filter **123** to provide positive airflow within the respiratory device. The sensor driven MEMS/micro air pumps are energy saving and consume significantly less power than conventional systems. In addition, the MEMS/micro air pump that provides positive airflow is lightweight, compact and portable. The air pump may be turned on all the time, throughout the breathing cycle.

[0024] The number of air pumps **132** or exhaust unit **103** may be increased to increase overall air flow throughput to further improve a mask wearers' breathing experience. A second controller (not shown) is required to drive the air pump **132** for power and control signals. The second controller can be the same as the first controller of the air exchange unit **102** or a different controller which provides power and control signals to the fan **122** of the air exchange unit **102**. The connecting wires are integrated within the mask **101** for safety and aesthetic reason. The second controller can be carried in the wearer's pocket, strap onto the wearer head, ear, neck or limbs. The second controller can also be miniaturized and contained in the second cover **134** of the exhaust unit **103**. The second controller controls the sensors and the air pump **132** such that on sensing heat and humidity beyond a predefined limit, it triggers the air pump to exhaust the

expended air build up within the mask **101**.

[0025] The second gasket **133** provides an air tight seal between the second cover **134** and the air pump **132**. The second cover **134** caps the air pump **132**, the second gasket **133** and the battery **135** and attaches itself onto the second holding substrate **131** securely by a suitable fastening mechanism. The fastening mechanism can be for example, screw threads on the second cover **134** and corresponding nut threads on the second holding substrate **131**. The second cover **134** may have one or more second perforations **136** for the air pump **132** to extract the expired air from within the mask **101** and expel it to the ambience outside the mask **101** without allowing outside ambient air from entering the mask **101** through the exhaust unit **103** even when the air pump **132** is not working. The entire exhaust unit **103** when fully assembled onto mask **101** is sealed and fully isolates the relatively closed space **105** within the mask **101** from the ambience outside the mask **101**. It should be noted that the **FIGS. 1-6** utilize gaskets **124** and **133** as fasteners, other fasteners can be utilized without limitation.

[0026] **FIG 7 (7a-7d)** illustrate the operation of the mask **101**. The air exchange unit **102** and exhaust unit **103** may work jointly or independently to provide purified air and regulate the temperature and humidity within the mask **101**. **FIG 7a** depicts a graph **202** showing a breathing cycle. The abscissa depicts time component while the ordinate depicts the volume of air inhaled/exhaled. In each breathing cycle, air is inhaled as shown by **204**, exhaled shown by **206** and a short period during which there is a pause **208** before the next breathing cycle. During **204**, air is inhaled therefore the volume of air in the lungs increases while in **206**, due to exhalation, volume of air in the lungs decreases.

[0027] **FIG 7b** depicts the air flow during the inhalation phase **204**. During this phase, the ambient air flows into the air exchange unit **102** through the air filter **123**. The arrow depicts the direction of air inflow in the mask **101**. The second controller may trigger the air pump **132** to draw the filtered air into the relatively closed area of the mask **101** through the air exchange unit **102**. In case the fan **122** is present, the first controller may

control the speed of the fan for drawing the required quantum of air.

[0028] In the exhalation phase **206** depicted in **FIG 7c**, the expired air from inside the mask **101** is sucked and discharged outside the mask **101**. The air exchange unit **102**, in addition to the air pump **132**, allows the expended air to exit at the exhalation phase **206**. This means, that the exhaled air does not only exit through the air pump **132** but also through the air filter **123** in the air exchange unit **102**. The air pump **132** pumps out the expired air from within the mask **101** into the ambience through the second perforation **136** on the second cover **134** of the exhaust unit **103**. In an alternate embodiment, only one of the two, namely the air exchange unit **102** or the exhaust unit **103**, may discharge the air within the mask **101** outside. In this way, a positive continuous air flow is built up within the mask **101**. The air flow through the exhaust unit **103** and out of mask **101** is regulated by embedded sensors according to the temperature and humidity levels.

[0029] In one embodiment, the sensor may be one or more temperature sensors that are able to detect the increase in temperature during the exhalation phase **206** and the decrease in temperature during the inhalation phase **204**. The temperature sensor(s) detect the temperature increase during the exhalation phase **206** and feed it to the second controller which in turn may trigger one or more control signals to turn on the air pump **132** during exhalation. Conversely, upon sensing temperature decrease during inhalation **204**, control signals may sent to turn off the air pump **132**. This serves to conserve power.

[0030] In a second embodiment, the temperature sensors may activate the pump if a set first threshold temperature of, for example, 33degC is reached. Once the temperature drops below a second threshold temperature of for example 32.5decC, the air pump **132** may be turned off.

[0031] In a third embodiment, instead of using temperature sensors, one or more humidity sensors may be used that can detect relative humidity within the mask **101**.

High humidity levels are not desired as high moisture levels reduce permeability and effectiveness of the air filter **123**, hence making it more difficult for hot, humid exhalation to escape outside the mask **101**. The second controller may trigger one or more control signals to turn on the air pump **132** once a humidity threshold is reached. The hot and humid air within the mask **101** is then let out. It may be noted that a combination of temperature and humidity sensors can be used and are within the teachings of the present invention.

[0032] FIG 7d illustrates that in the pause stage **208**, the air pump **132** may still be in the on state to remove humidity from the relatively closed area **105**. Due to very little air in the relatively closed area, there may be no air flow through the air exchange unit **102**.

[0033] Through the above description, one can understand that this respiratory device with integrated or embedded air exchange unit **102** and exhaust unit **103** provides the wearer with an improved breathing experience by drawing fresh filtered purified air, removing expired air within the relatively closed space **105** of mask **101** and vents the mask **101** in every breathing cycle. This technique is highly efficient, low power consumption and compact.

[0034] The invention may be preferable for users who need to stay in hostile environment with air pollution or contamination for a prolonged period of time. The invention can be used for normal respiration, and does not provide any supplied/pressurized air for breathing per se, due to low air flow from the air pump.

[0035] It will be appreciated that variations of the above disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. Also, that various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the following claims.

[0036] Although embodiments of the current disclosure have been described comprehensively, in considerable detail to cover the possible aspects, those skilled in the art would recognize that other versions of the disclosure are also possible.

CLAIMS

What is claimed is:

1. A respiratory device comprising:

a mask to be positioned around the mouth and nose of a wearer to form a relatively closed area sealed from ambient air;

at least one air exchange unit embedded in the mask, wherein the at least one air exchange unit comprises a first holding substrate having at least one air filter through which ambient air from outside the mask flows into the relatively closed area within the mask;

at least one exhaust unit embedded in the mask, wherein the at least one exhaust unit comprises a second holding substrate including at least one high pressure piezoelectric micro-pump; and

a first controller for controlling the high pressure piezoelectric micro-pump, wherein the high pressure piezoelectric micro-pump draws filtered air from the air filter into the relatively closed area and discharges expired air out of the relatively closed area of the mask thereby, maintaining positive filtered purified airflow into the mask.

2. The respiratory device of claim 1, wherein the exhaust unit comprises a plurality of sensors in communication with the first controller, wherein the first controller triggers the high pressure piezoelectric micro-pump to regulate the air flow.

3. The respiratory device of claim 2, wherein the sensors comprises one or more temperature and humidity sensors.

4. The respiratory device of claim 1, wherein the air filter comprises one or more functional layers made of polypropylene felt and/or activated carbon fibers to hold back virus, particulate contaminants and odor.

5. The respiratory device of claim 1, wherein the air exchange unit further comprises a fan mounted on the first holding substrate.
6. The respiratory device of claim 1, wherein the mask is made of transparent silicone.
7. A respiratory device, comprising:
 - a mask positioned around the mouth and nose of a wearer to form a relatively closed area sealed from ambient air;
 - at least one air exchange unit comprising of an air filter, a first holding substrate with a first fastener and a first cover, a fan and a first controller for driving the fan to draw ambient air from outside the mask to flow through the air filter into the relatively closed area within the mask; and
 - at least one exhaust unit comprising a second holding substrate with a plurality of sensors, a second fastener and a second cover, a high pressure piezoelectric micro-pump, a power source for driving the high pressure piezoelectric micro-pump, and a second controller for controlling the high pressure piezoelectric micro-pump through suitable control signals whereby filtered air is drawn into the relatively closed area and expired air is discharged out of the relatively closed area of the mask, thereby drawing positive filtered purified air into the mask.
8. The respiratory device of claim 7, wherein the plurality of sensors are utilized for regulating the air flow through the exhaust unit and out of the mask based on temperature and humidity levels in the relatively closed area.
9. The respiratory device of claim 7, wherein the mask is made of transparent silicone.
10. The respiratory device of claim 7, wherein the air filter comprises one or more functional layers made of polypropylene felt and/or activated carbon fibers to hold back virus, particulate contaminants and odor.