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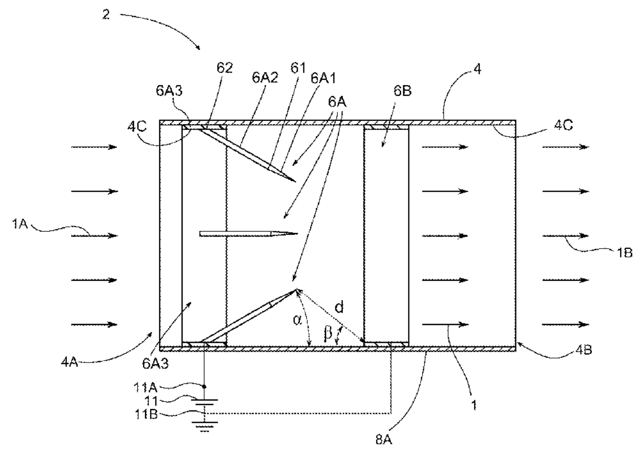

FIG. 1

(57) **Abstract**: The invention relates to a fluid displacement device (2) configured for generating a flow within a fluid. The fluid displacement device comprises an airflow duct (4) with an inner surface (4C) configured to accommodate a flow of fluid. A number of corona electrodes (6A) is disposed in the airflow duct wherein each of the corona electrodes comprises an elongated body (6A2) with a distal end (61) and a proximal end (62). The distal end is provided with a tip structure (6A1) configured to generate a corona discharge. A non-corona electrode (6B) is disposed downstream the corona electrodes, the tips (6A1) of the corona electrodes (6A) are positioned at a predefined distance (d) from the non-corona electrode (6B), and the proximal end joins the inner surface of the airflow duct (4) at a distance from the non-corona electrode which is longer than the predefined distance d.

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FLUID DISPLACEMENT DEVICE

TECHNICAL FIELD OF THE INVENTION

The invention relates to a fluid displacement device, in particular a device for displacement of room air, here meaning air in residential spaces, offices or industrial premises. The invention further relates to an air cleaning device for removing particulate material from a gas, in particular a device for cleaning of room air. Particulate material in the context of the present invention relates to any type of airborne particle including microorganisms and viruses. The invention further relates to a method of displacing air in a space.

BACKGROUND OF THE INVENTION

The physics of the ion-driven wind is reasonably well established. Although the first documentation of ion-driven wind occurred in 1709, the first in-depth analysis of the phenomenon was conducted almost 200 years later. There have been numerous studies concerning the use of ion-driven wind velocities for a variety of aerodynamic, heat transfer, and other applications, all of which would benefit from maximizing the gas velocities. An example of silent mass transfer in low flow (fan-less) electrostatic precipitators is disclosed in US4789801 (1988).

With the continuous growth of the world's population, technology and industry, increasingly larger numbers and multiple types of particulate material, also including pathogenic micro-organisms, are generated and released into the air. The number of diseases and the number of outbreaks thereof are increasing as a result. Examples hereof are, among others, the outbreak of the Ebola virus, Foot and Mouth disease and the SARS epidemic. Human contact with and exposure to such pathogenic particulate material in the air is increasing, which results in a further increase in the risk of infection and spread of diseases. The air quality is therefore of particular importance, particularly in environments where the chance of infection is high. An example of such an environment is an operating room, where patients, often with open wounds, are susceptible to aerogenic pathogenic particulate material.

The requirements for the air quality, i.e. the quantity of particulate material present in the air must lie below a determined maximum level, will increase further in the future.

One of the most sensitive market segments for aerogenic pathogenic particulate material and infections resulting therefrom are hospitals, where diseases and bacteria of all types converge and are concentrated at the same location. In order to achieve a high air purity, operating rooms are often connected to an air ventilation system which is equipped with air filters with a high efficiency, such as a 'High Efficiency Particulate Air (HEPA)' filter. Even such high-efficiency air filters have a limited efficiency and functional flexibility, and this affects their effectiveness under practical conditions. The efficiency of such HEPA filters thus depends on, among other factors, the flow rate, the pressure, flow speed and the heat or possibly present radiation.

Research into the situation in the Netherlands in 2005 by the Nederlands Rijksinstituut voor Volksgezondheid en Milieu (RIVM, National Institute for Public Health and the Environment) has shown that 10% to 30% of patients admitted to a Dutch hospital have hospital-related infections, 30% to 40% of which are caused by aerogenic micro-organisms.

Furthermore, statistics show that, compared to other sectors, hospital staff have the highest illness-related absence, measured both in days and in frequency.

Similarly, there are regulations in some countries to control the infection in schools. A lot of infections are spread by air. An air cleaning device will help to reduce the risk of infections in buildings where a lot of humans come together.

US4689056A discloses an air cleaner using ionic wind which comprises the features of the preamble of claim 1. However, the embodiments comprising needle electrodes produce ozone. US4689056A teaches by means of some embodiments that the generation of ozone could be decreased by using discharge electrodes in the form of parallel wires and keeping the voltage at the discharge electrodes low.

US4231766A discloses a two stage electrostatic precipitator with electric field induced airflow. The device comprises ionizer wires to ionize the air. The document further teaches the variation of airflow, ozone production and ionizer current with ionizer wire placement with respect to the counter electrode. To preclude the possibility of arcing between the ionizer wire and accelerator plates, sufficient spacing must be maintained between these components.

In order to reduce the risk of infections, in particular in hospitals and schools, there is a need for an improved system which is able to remove particulate material, especially micro-organisms from air in a space and which does not generate ozone measured in part per million by volume of air circulation through the device that exceeds levels of regulations, i.e. wherein the generated background noise generated by the system is very low and the ozone concentration is below a predefined maximum allowable concentration value. For example, the maximum ozone concentration produced by electronic air cleaners and similar residential devices according to a proposed amendment of the Federal Food, Drug and Cosmetic Act is 0,050 ppm.

SUMMARY OF THE INVENTION

The object of the invention is to provide an improved fluid displacement device configured for generating a flow within a fluid, that could be used in an air cleaning device for removing particulate material from a gas, which overcomes at least one of the disadvantages mentioned before.

According to the invention, this object is achieved by a fluid displacement device, configured for generating a flow within a fluid, having the features of Claim 1. Advantageous embodiments and further ways of carrying out the invention may be attained by the measures mentioned in the dependent claims.

According to the invention, the fluid displacement device configured for generating a flow within a fluid comprises an airflow duct with an inner surface configured to accommodate a flow of fluid to flow from an inlet to an outlet of the fluid displacement device, a number of corona electrodes disposed in the airflow duct wherein each of the corona electrodes comprises an elongated body with distal end provided with a tip configured to generate a corona discharge and a proximal end. The device further comprises a non-corona electrode downstream the corona electrodes. The tips of the corona electrodes are positioned at a predefined distance from the non-corona electrode. The proximal end of the elongated body joins the inner surface of the airflow duct at a distance from the non-corona electrode which is longer than the predefined distance.

It has been found that in existing fluid displacement devices such as shown in CN101577397A a significant part of the energy of the flow is dissipated by the construction of the corona electrodes in the duct. Furthermore, mainly the air molecules between corona electrode and non-corona electrode are ionized, thus air molecules near the sidewalls of the duct and not the air molecules in the middle of the duct. As a result, the velocity of the air flow near the sidewalls is much higher than the velocity of the air flow in the middle of the duct. Therefore, multiple stages are needed to obtain a desired flow capacity through the duct. The features of the present invention provide a construction of the corona electrodes with reduced aerodynamic drag or air resistance in the airflow duct.

This enables to provide a fluid displacement device which needs only one pair of corona electrodes/non-corona electrode to generate a sufficient high flow output through a duct with reduced length as only one stage is needed.

In an embodiment of the invention, the elongated body is rod-shaped. In an advantageous embodiment the elongated body has a straight body axis.

In an embodiment of the invention, a line through the tip and proximal end of the elongated body forms an angle α with the inner surface, wherein $15° < \alpha < 90°$. An angle in this range has been found optimal with respect to the minimal length of the duct.

In an embodiment of the invention, a tip of a corona electrode has a tip pointing to the middle of the air flow duct downstream the tip. This feature improves the ionization of the air molecules in the middle of the air flow duct, as a result of this the velocity of the air flow in the middle of the air flow duct is increased. This makes that the speed difference between the air flow in the middle and the air flow near the side walls is reduced, allowing reducing the maximum flow speed while the capacity of the flow though the device is not decreased.

In an embodiment of the invention, the distal end comprises a coupling structure to attach a tip structure to the elongated body. It is known in the art that when metallic ion emitters are subjected to corona discharges in room air, they show signs of deterioration and/or oxidation within a few hours and the generation of fine particles. This problem is prevalent with needle electrodes formed of copper, stainless steel, aluminium, and titanium. Corrosion is found in areas under the discharge or subjected to the active gaseous species O_3 and NO_X. NO_3 ions are found on all the above materials, whether the emitters had positive or negative polarity. The corona electrodes could be made of an anticorrosive metal such as tungsten or platinum. However, such electrodes when manufactured from one piece are expensive and difficult to process into electrodes having an elongated body with the desired shape. The features of this embodiment enable to provide corona electrodes with elongated body with reduced costs and excellent anticorrosive characteristics. The elongated body could be made from an inexpensive electrically conductive material, whereas the relative small tip of the electrode could be made from an anticorrosive material. The coupling structure provides the required conductivity between the elongated body and the tip. This feature further allows having corona electrodes of which the tip and elongated body are made from different conductive materials.

In an embodiment of the invention, the airflow duct comprises a conductive ring-shaped element which forms a part of the inner surface of the airflow duct and the proximal ends of the corona electrodes are attached to the ring-shaped element. These features allows to produce one structure comprising all corona electrodes attached, which could be placed in one go in the airflow duct and which needs only one terminal to connect all corona electrodes to a high-voltage source. This reduces the manufacturing costs significantly.

In a further embodiment, the conductive ring-shaped element has an electrical resistivity ρ, wherein 0,001 ohm·metre < ρ < 1000 ohm·metre. A conductive element of high resistivity material readily conducts a corona current. However, the material provides a voltage drop along current paths through the element. The material thereby damps or limits an incipient sparking event. The conductive ring-shaped element may be a coating applied to the inner surface of the airflow duct. Examples of such relatively high resistance materials include polymers filled with carbon or other additives that increase conductivity, intrinsically conductive polymers, silicon, gallium arsenide, indium phosphide and silicon carbide.

In an embodiment of the invention, the tips of the corona electrodes are placed circularly around a central axis of the airflow duct. In an advantageous embodiment, the tips are radially equidistant from each other. These features provide a well-conditioned airflow through the airflow duct.

In an embodiment of the invention, the non-corona electrode is a ring-shaped element which forms a part of the inner surface of the airflow duct. A ring-shaped non-corona electrode has a lower air resistance than a grid-shaped non-corona electrode and thus provides a better airflow through the device. The non-corona electrode may be in the form of a coating annularly applied to the inner surface of the airflow duct.

In an embodiment, the fluid displacement device further comprises a ionizing structure disposed in the airflow duct, the ionizing structure comprising a cylindrical non-corona electrode which forms a part of the inner surface of the airflow duct, and a central corona electrode having a tip, wherein the tip is positioned in the airflow duct upstream the cylindrical non-corona electrode at a cylinder axis of the cylindrical-shaped non-corona electrode. It has been found that the corona electrodes with elongated body ionize up to 95% of the particles in the airflow without generating ozone. In combination with an electrostatic filter, which is positioned downstream, the device will capture utmost 95% of the particles. An air cleaning device suitable for use in a hospital needs to capture more than 95% of the particles from the airflow. The features of this embodiment enable to increase the ionization of particles up to 99,99% and thus the cleaning efficiency. This ionizing structure has almost no negative influence on the airflow through the device.

In an embodiment, the cylindrical non-corona electrode of the ionizing structure and the non-corona electrode of the airflow generation structure are the same element. This feature enables to reduce the length of the duct.

In an embodiment, the number of corona electrodes of the airflow generation structure and the central corona electrode of the ionizing structure are electrically coupled and the tip of the central corona electrode is positioned in the airflow duct downstream the number corona electrodes and has a distance from the non-corona electrode which is at least the predefined distance.

In an embodiment, a tip of the corona electrodes comprises a multitude of conductive wires forming a broom. This type of corona electrodes is expected to have better characteristics with respect to corrosion than the type of corona electrode having only one sharp pointed distal end.

It is a further object of the invention to provide an improved method of fluid displacement and/or cleaning air in a space. The method comprises providing a fluid displacement device comprising the essential features of the invention in a space of a building and turning on the air cleaning device.

It will be clear that the various aspects mentioned in this patent application may be combined and may each be considered separately for a divisional patent application. Other features and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings which illustrate, by way of example, various features of preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE FIGURES

These and other aspects, properties and advantages of the invention will be explained hereinafter based on the following description with reference to the drawings, wherein like reference numerals denote like or comparable parts, and in which:

Figure 1 shows schematically a sectional view of a first embodiment of the invention;

Figure 2 shows schematically a side view of the first embodiment;

Figure 3 shows schematically a side view of a second embodiment;

Figure 4 shows schematically a sectional view of a third embodiment;

Figure 5 shows schematically a sectional view of an embodiment of a corona electrode;

Figure 6 shows schematically a sectional view of another embodiment of a corona electrode;

Figure 7 shows schematically a sectional view of a fourth embodiment;

Figure 8 shows schematically a sectional view of a fifth embodiment;

Figure 9 shows schematically a side view of the fourth and fifth embodiment;

Figure 10 shows schematically a sectional view of a first embodiment of an air cleaning device comprising fluid displacement devices according to the invention;

Figure 11 shows schematically a side view of the embodiment shown in figure 10; and,

Figure 12 shows schematically a sectional view of a second embodiment of an air cleaning device comprising fluid displacement devices according to the invention.

DESCRIPTION OF EMBODIMENTS

In this patent the term 'contaminated gas flow' is understood to mean the gas flow with particulate material admitted into the housing through the inlet opening of the housing. The term "purified gas flow' refers to the gas flow leaving the outlet opening of the housing. The term "particulate material' is understood in this patent to mean all the particulate material or airborne particles present in a gas, including micro-organisms, bacteria and viruses, but for instance also dust particles. The term “fluid” refers to any gaseous substance.

Fig. 1 shows schematically a sectional view of a first embodiment of a fluid displacement device 2 according to the invention. The fluid displacement device 2 comprises a housing which forms an airflow duct 4 of the fluid displacement device. The airflow duct 4 is configured to accommodate a gas flow 1 to flow from an inlet 4A to an outlet 4B of the fluid displacement device 2. The gas flow flowing to the inlet 4A is indicated with reference 1A. Reference 1 indicates the gas flow through the airflow duct 4 and reference 1B indicates the gas flow coming out of the airflow duct 4.

The fluid displacement device 2 comprises a number of corona electrodes 6A and a non-corona electrode 6B disposed in the housing 4. The corona electrodes 6A comprises a structure having a rod shaped elongated body 6A2 with a distal end 61 and a proximal end 62 and a tip structure 6A1. The tip structure is provided at the distal end 61. The tip structure 6A1 has a sharp pointed end configured to generate a corona discharge. A ring-shaped conductive element 6A3 is provided in the housing 4 and forms a part of the inner surface 4C of the channel through the housing 4. The proximal end 62 of the elongated body 6A2 is coupled to the ring-shaped conductive element 6A3. This could be by means of clamping, welding or soldering. The ring-shaped conductive element 6A3 could comprise openings in which the proximal ends 62 are clamped.

The non-corona electrode 6B is in the form of a ring-shaped element which forms a part of the inner surface 4C of the airflow duct 4.

The ring-shaped element 6A3 is coupled to a high voltage pole 11A of a first high voltage source 11. The ring-shaped non-corona electrode 6B is coupled to a reference voltage pole 11B of the first high voltage source 11. In the present embodiment, the reference pole 11A is coupled to ground. The potential difference between the high voltage pole 11A and the reference voltage pole 11B of the first high voltage source 11 is in the range of 8 – 25 kV, preferably in the range of 14 – 18 kV. The reference voltage pole 11B is coupled to electrical ground.

The elongated body 6A2 shown in Fig. 1 has a straight body axis. A line through the tip 6A1 and the location where the proximal end 62 joins the inner surface of the airflow duct has an angle α with the inner surface. The angle α could be in a range between 15° and 90°. The tips 6A1, i.e. the end of the corona electrode configured to generate a corona discharge, are positioned at a predefined distance d from the non-corona electrode. This distance corresponds to the shortest distance between a surface of the corona electrode and non-corona electrode. The distance between the tips of the corona electrodes and the non-corona electrodes is in the range of 1 – 5cm. A line defined by the shortest distance between the corona electrode and the non-corona electrode has an angle β with respect to the inner surface of the duct. The relation between angle α and angle β is defined by the following equation $\alpha < 90° - \beta/2$.

If corona electrodes with a straight body axis are used, the proximal ends 62 of the corona electrodes are clamped in the openings through the ring-shaped conductive element 6A3, wherein the openings are at an angle α with respect to the inner surface in the direction of the fluid flow. However, if corona electrodes with a curved body axis are used, the openings could be perpendicular to the inner surface.

A tip structure 6A1 of a corona electrodes has a longitudinal body axis. The longitudinal body axis is oblique to the gas flow and pointing to a center of the air of the air flow duct downstream the tip of the corona electrode. In other words, a tip of a corona electrode not located at the center of the air flow duct has a tip pointing to the middle of the air flow duct downstream the tip. In the first embodiment the pointing direction of the tip corresponds to the angle α of the straight body axis of the elongated body 6A2. Experiments have shown that a tip pointing in the direction of the center of the air flow duct 4 improves the ionization of air molecules in the center of the air flow duct. As a consequence, the speed of the air flow through the middle part of the air flow is increased and the difference between the speed of the air flow part along the inner surface 4C of the air flow duct 4 and the speed of the air flow in the middle part of the air flow is reduced. This enables reducing the highest speed in the air flow without decreasing the throughput or rate of flow through the air flow duct 4. If the longitudinal axis of the tip structures are parallel to the air flow, less ion will be generated in the middle part or the air flow duct. Consequently, the air in the middle part of the duct will be accelerated less.

Fig. 2 shows a side view of the embodiment shown in Fig. 1 wherein Fig. 1 is a cross section along the line I-I in Fig. 2. The device is seen from the inlet side in a direction parallel to the airflow through the device. The embodiment comprises four needle-like corona electrodes 6A positioned in a circular duct 4 with an inner surface 4C. The four needle-like corona electrodes 6A are placed circularly around a central axis of the duct. The distal ends of electrodes have the same radial distance from the center of the circular duct 4. Preferably, the tips of the corona electrodes 6A are radially equidistant from each other and radially equally distributed along a cross section of the duct, i.e. around the centre of the airflow duct 4. Fig. 3 shows an embodiment of a device having eight circularly placed needle-like corona electrodes 6A. The number of electrodes depends on the dimensions of the duct.

It should be noted that in the embodiments described above the elongated bodies of the corona electrodes are attached to the inner surface 4C of a ring-shaped conductive element 6A3 which is positioned in the housing 4, wherein the inner surface 4C of the element 6A3 forms at the same time the inner surface of the duct. However, it might also be possible that the housing 4 comprises opening for passing the elongated body of the electrodes from the inner side of the housing 4 to the outer side of the housing. The proximal ends of the elongated bodies are in said latter case electrically coupled to the high voltage source outside the housing 4.

Fig. 4 shows schematically a sectional view of a third embodiment. This embodiment differs from the first embodiment in that the elongated body is not a body with a straight body axis but a body with a curved body axis. In Fig. 4 the line through the tip 6A1 and the location where the proximal end 62 joins the inner surface of the airflow duct is indicated with reference 63. It should be noted that the body axis of the elongated body could have any curvature as long as the tip of the electrode has the shortest distance to the non-corona electrode 6B. In the third embodiment, the body axis at the proximal end 62 is perpendicular to the housing 4 of the duct. This allows to use openings through the housing which are perpendicular and to pass the proximal end 62 of the elongated body through the opening and to connect the elongated body outside the housing to a high voltage source 11. In the first embodiment a slanted hole has to be provided to pass the straight elongated body.

The corona electrodes could be made from one piece. In that case the distal end 61 is the cross section along the body axis of the electrode where the elongated body 6A2 passes into the tip structure. Fig. 5 shows schematically a sectional view of an embodiment of a corona electrode wherein the corona electrode is made from to two parts, the elongated body part 6A2 and the tip part 6A1. In this case two different types of conductive materials could be used to assemble the corona electrode. The elongated body part could be made from a cheap and easy to manufacture and handle material, for example a metal, alloy or conductive plastic. The tip part could be made from a harsh anticorrosive material such as tungsten or could comprise a core of corrosive material, for example iron, which is covered with a coating of platinum or any other material that is resistant to a corona discharge environment. To couple the tip part 6A1 to the elongated body part 6A2, the distal end of the elongated body and the tip part comprises a mutually compatible coupling structure. Fig. 5 shows a hole in the distal end of the elongated body 6A2. An extension of the tip part is inserted and clamped in the hole. A person skilled in the art knows other usable coupling structures. In Fig. 5 the tip part 6A1 has a needle like structure. In Fig. 6 the tip part 6A1' is composed of bundled carbon fibers forming a broom. JP2008112714 discloses the use of bundled carbon fibers to form a tip of a corona electrode used in an ion wind generator.

Figure 7 shows schematically a sectional view of a fourth embodiment of a fluid displacement device. The fluid displacement devices described before have a charging efficiency in the range of 60 – 80%. This means that 60 – 80% of the particles in the flow are charged and 40% - 20 % of the particles are not charged. This means that when the fluid displacement device is used in front of an electrostatic filter, 20 – 40% of the particles in the airflow will not be captured by the electrostatic filter. The fourth embodiment has improved charging efficiency wherein up to 99,9% of the particles in the fluid flow are charged. The fourth embodiment comprises a flow generation section 6 and an ionizing section 7 both disposed in the housing 4. The flow generation section 6 comprises the corona electrodes 61 and ring shaped non-corona electrode 6B is described in the first embodiment. The ionizing section 7 is disposed in the housing 4 downstream the flow generation section. The ionizing section 7 comprises a central corona electrode 7A and a cylindrical or ring-shaped non-corona electrode 7B. The inner surface of the cylindrical non-corona electrode 7B forms a part of the inner surface 4C of the airflow duct. The tip of the central corona electrode 7A is positioned on the cylinder axis of the ring-shaped non-corona electrode 7B. The central corona electrode 7A is coupled to a high voltage pole 12A of a second high voltage source 12. The ring-shaped non-corona electrode 7B is coupled to a reference voltage pole 12B of the second high voltage source 12. In the present embodiment, the reference pole 12A is coupled to ground. The potential difference between the high voltage pole 12A and the reference voltage pole 12B of the second high voltage source 12 is in the range of 8 – 25 kV, preferably in the range of 14 – 18 kV. The reference voltage pole 12B is coupled to electrical ground.

It has been found that an ionizing section 7 described above has a charging efficiency of 99,9%, whereas a fluid displacement section 6 described above has optimal flow generation characteristics. By applying the flow generation section 6 and ionizing section 7 in the same duct, a fluid displacement device is obtained with optimal flow characteristic and a charging efficiency which makes the fluid displacement device suitable for use in an air cleaning device. It should be noted that the order of flow generation section 6 and ionizing section 7 has almost no effect on the charging efficiency and generated flow. It should further be noted that the first and second high voltage source might be the same voltage source. The corona electrodes 6A of the flow generation section and the central corona electrode 7A of the ionization section are then coupled to the same high voltage pole.

Figure 8 shows schematically a sectional view of a fifth embodiment, wherein the flow generation section and ionizing section are combined in to one section. This enables to reduce the length of the duct. In this embodiment, the central corona electrode 7A of the ionization section is coupled to the ring shaped element 6A3 to which the corona electrodes 6A of the flow generation section are coupled. Furthermore, the cylindrical non-corona electrode 7B of the ionizing section and the non-corona electrode 6B of the flow generation section are the same element. The tip of the central corona electrode 7A of the ionization section is positioned in the duct at a distance Δ downstream the tips of the corona electrodes 6A of the flow generation section. The corona electrode of the ionizing section has at least the distance d to the common non-corona electrode 6B, 7B. The position on the central axis 13 of the duct 4 which has a distance d to the non-corona electrode 6B, 7B is Δmax downstream the tips of the corona electrodes 6A of the flow generation section. It has been found that when the distance between the tip of the corona electrode of the ionizing section and the common non-corona electrode is larger than the distance d between the tips of the corona electrodes of the flow generation section and the common non-corona electrode, the production of ozone can be reduced further without reducing the charging efficiency. Fig 9 shows schematically a side view of the fourth and fifth embodiment wherein Fig. 8 is a cross section along the line VII-VII in Fig. 9. The device is seen from the inlet side in a direction parallel to the airflow through the device. The tip of the central corona electrode is positioned on the central axis 13 of the tubular duct.

It should further be noted that in the fifth embodiment, the tubular housing 4 of the airflow duct is composed of three parts. The first part 41 is the ring-shaped conductive element 6A3 to which the corona electrodes 6A are coupled. The second part 42 is the ring-shaped conductive element 6B, 7B forming the common non-corona electrode. The third part 43 is a ring-shaped element of non-conductive material.

The ring-shaped conductive elements 6A3 and 6B may be made from any type of conductive material, including metal and alloys. However, the conductive ring-shaped elements may have an electrical resistivity ρ, wherein 0,001 ohm·metre < ρ < 1000 ohm·metre. An advantage of a conductive element of high resistivity material is that it readily conducts a corona current without a large voltage drop along the current path. However, the material provides a large voltage drop along current paths through the element due to a spark. The material thereby damps or limits an incipient sparking event. An example of a relative high resistance material is a polymer filled with carbon, for example carbon filled polycarbonate. An advantage of a carbon filled plastic is that it allows one to produce the conductive elements by an injection moulding process or pultrusion process. Both the ring-shaped conductive element 6A3 and the ring-shaped non-corona electrode 6B could have identical dimensions. This enables us to produce elements with the same mould. By boring through holes in a ring-shaped conductive element the openings are created to clamp the proximal end of the elongated body of the corona electrodes and to provide an electrical connection between the electrode and the ring-shaped element.

The conductive ring-shaped elements 6A3 and 6B may also be in the form of a conductive coating applied to the inner surface of the airflow duct. The conductive coating may be any type of conductive coating, however a coating having a relative high electrical resistivity ρ in the range of 0,001 ohm·metre - 1000 ohm·metre have the advantage described above. Examples of such relatively high resistance materials include polymers filled with carbon or other additives that increase conductivity, intrinsically conductive polymers, silicon, gallium arsenide, indium phosphide and silicon carbide.

Figs 10 and 11 show schematically a sectional view and side view of a first embodiment of an air cleaning device comprising fluid displacement devices according to the invention. The air cleaning device 21 comprises an ionization stage 67 and collecting stage 8 disposed in a common housing 14. The housing 14 has an inlet 14A and an outlet 14B. The ionizing stage 67 comprises a multitude of fluid displacement devices as shown in Fig. 8. The collecting part 8 is in the form of an electrostatic filter. In principle any type of electrostatic filter could be used to trap the ionized particles which are ionized in the ionization stage 67. In the embodiments shown the collecting part 8 comprises a stack 8A of metal plates with a space between each of the metal plates. The spaces between the metal plates form a passage to pass the gas flow through the stack of plates along the surface of plates. The plates of the stack of plates 8A are alternately connected to a high voltage pole 10A and a reference pole 10B of a high voltage source 10. The plates coupled to the high voltage pole 10A are referred to as high voltage plates and the plates coupled to the reference pole 10A are referred to as reference voltage plates. The reference pole 10B is in the embodiment connected to ground. The potential difference between the high voltage pole 10A and the reference pole 10B is in the range of 4 – 20 kV, preferably in the range of 4 – 10 kV, more preferable in the range of 4 – 8 kV. The distance between two neighbouring plates forming the space depends on the application of the air cleaning device and is in the range of 4 – 20mm. The minimal length of the space in the direction of the airflow has a relationship with the used potential difference, the speed of the airflow and the distance between two neighbouring plates.

The stack of plates 8A could be in the form a detachable or removable unit comprising the stack of plates. The unit (not shown) comprises further a high voltage terminal to couple the high voltage plates to the high voltage pole 10A and a reference voltage terminal to couple the reference plates to the reference pole 10B. A detachable unit allows one to clean the stack of plates periodically, for example washing by hand under a tap or in a dishwashing machine.

In an embodiment, the surfaces of the plates are provided with an antimicrobial coating to kill the micro-organisms that are trapped on the surface of the plates. In another embodiment, the surfaces of the plates are provided with a dirt repellent coating, to facilitate cleaning of the stack of plates 8A. The coating could be both an antimicrobial coating and dirt repellent coating.

The air cleaning device comprising a fluid displacement device according to the inventions functions as follows. Contaminated gas is present in the space of the ionizing part 67. A potential difference is applied between the corona electrodes 6A, 7A and the non-corona electrode 6B. When the potential difference between two adjacent electrodes is high enough, a corona discharge will occur around the tips of the corona electrodes 6A, 7A. Ionization of the nearby molecules results in generation of ionized air molecules having the same polarity as that of the charged tip. Subsequently, the tip repels the like-charged ion cloud, and the ion cloud immediately expands due to the repulsion between the ions themselves. Under the influence of the applied electric field the ions are accelerated, from the corona electrodes 6A in the direction of the non-corona electrode 6B. During the movement of the ions collisions will occur between the ions and neutral gas molecules, which causes transfer of kinetic energy between ions and molecules. In this way, the gas in the ionizing part is forced to move from the corona electrodes 6A in the direction of the non-corona electrode 6B. This is the so-called corona wind, which causes a gas flow through the airflow duct 4 and consequently from the inlet opening 14A to outlet opening 14B of the common housing 14. Furthermore, the ionized particles attach to particulate material in the intake air and charge the particulates. The charged particulates will move along the electric field in the direction of the non-corona electrode 6B. The gas flow depends on the potential difference applied by the high-voltage source 11. The gas flow with ionized particles will flow through the ring-shaped non-corona electrode 6B and only a small part of the ionized particles in the gas flow will be trapped by the non-corona electrode 6B. Subsequently, the airflow with ionized particles flows through the space between the plates of the stack of plates 8A. The ionized particles which have generally a positive charge are repelled by the plates connected to the voltage pole 10A of the high voltage source having the highest potential and attracted by the plates connected to the pole 10B of the voltage source having the lowest potential. While flowing through the space between two plates, the positively charged particles move to the plate with the lowest potential and will finally be trapped by said plate. Similarly, air-born particles with negative charge will be repelled by the plate with the lowest potential and attracted to the plate with the highest potential and be trapped by the plate with the highest potential. The stack of plates 8A functions in a similar way as the stack of plates of commonly known electrostatic precipitators.

In the embodiment shown in Fig 10, the ionization stage 67 comprises four fluid displacement devices having a short tubular housing 4. Fig. 11 shows schematically the four fluid displacement devices seen from the inlet 14A of the air cleaning device 21. The fluid displacement devices are placed in an array of 2x2 elements. Four needle-like corona electrodes 6A are placed circularly around a central axis 13 of the tubular housing 4. Preferably, the tips of the corona electrodes 6A are radially equidistant from each other and radially equally distributed around a centre of tubular housing 4. The tips of the corona electrodes 6A are positioned circularly in the tubular housing 4 and have a distance from the inner surface of the tubular housing 4. The tubular housing 4 is made from three parts as shown in Fig. 8. A first separation wall 20A and second separation wall 20B are provided between the exterior of the tubular housing 4 of the fluid displacement devices to prevent an air backflow between the fluid displacement devices from the outlet to the inlet. The first and second separation wall may be made from a conductive material, for example metal. In this way, the first separation wall electrically couples all corona electrodes to the high voltage pole 11A and the second separation wall electrically couples all non-corona electrodes to the reference pole 11B.

Each fluid displacement device will generate an amount of airflow through the tubular housing from the inlet to the outlet. In an embodiment, the tubular housing 4 forms a duct with a radius of 69 mm and comprises 9 corona electrodes 6A and one central electrode 7A. The distance between a tip of the 9 corona electrode and non-corona electrode is about 25 mm. When a potential difference of 16 kV is applied to the corona electrodes and non-corona electrode a single fluid displacement device is able to generate an airflow of 10 – 15 m^3/h. The tip of the central electrode 7A is positioned 2 – 7 mm downstream the tips of the 9 corona electrodes. The number of parallel placed fluid displacement devices applied in a common housing 14 will determine the capacity of the air cleaning device. For example, an air cleaning device with a capacity of 250 m^3/h requires about 20 tubular elements.

Figure 12 shows schematically a sectional view of a second embodiment of an air cleaning device comprising fluid displacement devices according to the invention. This embodiment differs from the first embodiment of an air cleaning device in that the ring shaped non-corona electrode is replaced by a plane grid 6B' with openings to pass the airflow. The fluid displacement devices 6 further comprises only corona electrodes 6A which are radially equidistant from each other and equally distributed along a cross section of the inner surface of the tubular housing 4. A fluid displacement device with a plane grid electrode has a charging efficiency of 95%. It has been found that central corona electrode does not improve the charging efficiency nor the flow through the fluid displacement device. Therefore, a central corona electrode is omitted. For some applications of an air cleaning device a cleaning efficiency of 95% is sufficient.

An air cleaning device with four tubular fluid displacement devices each with a number of five corona electrodes as shown in Fig. 10 is just chosen as an example to illustrate the invention. Parameters of the air cleaning device such as the required capacity, size of a cross section of a tubular element and differential voltage will determine the number of fluid displacement devices and number of electrodes in each fluid displacement device. Instead of tubular housing with a circular cross section, a tubular housing with angled cross section could be used.

The corona electrodes 6A may be in the form of carbon fibre rods. Such carbon rod is a composite of carbon fibres and a binding agent, for instance epoxy resin, vinyl ester resin or polyester resin, formed into rods by for instance pultrusion. It has been found that the material of carbon fibre rods suitable for use in kites can also be used as corona electrodes. In that case, the elongated body and tip are made from the same material. In the description above the tip of a corona electrode is sharp pointed. Due to the harsh environment of the corona region around the tip, the form of the tip changes in time. Therefore, the tip of a corona electrode is not necessarily a part next to the elongated body but could be the distal end of the elongated body. The tip could thus have any form, i.e. sharp pointed, curved, rounded, and could also be a flat distal end of the elongated body. During use, a flat distal end will become a curved tip.

It should further be noted that the ring shaped non-corona electrode described above should not necessarily be in the form of a contiguous ring of conductive material. The ring shaped non-corona electrode could also be in the form of two or more conductive elements, wherein each element forms a part of the annular inner surface of the airflow duct. The two or more conductive elements are electrically coupled to the same potential and have all a minimal distance d to a tip of a corona electrode. The two or more conductive elements together have to be considered as one ring shaped non-corona electrode.

The fluid displacement device according to the present invention does not need a fan to generate the flow of air. This makes the device very silent and thus applicable in rooms and spaces where background noise should be prevented such as classrooms, rooms in hospitals, conference rooms and bedrooms. Furthermore, an air cleaning device comprising a fluid displacement device according to the invention enables us to provide a mobile air cleaning device and to install the mobile device in a room where the air has to be cleaned. No additional inlet and outlet provisions have to be present in said room. The technology of the invention enables to provide fluid displacement devices suitable for the consumer market which could be used in a similar way as a household electric fan with propeller style blades. A consumer can take the device in the room where he wants the air to be circulated and in case of an air cleaning device to be cleaned.

The measures described hereinbefore for embodying the invention can obviously be carried out separately or in parallel or in a different combination or if appropriate be supplemented with further measures; it will in this case be desirable for the implementation to depend on the field of application of air cleaning device. The invention is not limited to the illustrated embodiments. Changes can be made without departing from the idea of the invention.

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CLAIMS:

1. Fluid displacement device (2) configured for generating a flow within a fluid, the fluid displacement device comprising:
- an airflow duct (4) with an inner surface (4C) configured to accommodate a flow of fluid (1A, 1B) to flow from an inlet (4A) to an outlet (4B) of the fluid displacement device;
- a number of corona electrodes (6A) disposed in the airflow duct wherein each of the corona electrodes comprises an elongated body (6A2) with a distal end (61) and a proximal end (62), the distal end is provided with a tip (6A1) configured to generate a corona discharge; and
- a non-corona electrode (6B) downstream the corona electrodes,
wherein the tips (6A1) of the corona electrodes (6A) are positioned at a predefined distance (d) from the non-corona electrode (6B), and the proximal end joins the inner surface of the airflow duct (4) at a distance from the non-corona electrode which is longer than the predefined distance.

2. Fluid displacement device (2) according to claim 1, wherein the elongated body is rod-shaped.

3. Fluid displacement device (2) according to claim 1 or 2, wherein the elongated body has a straight body axis.

4. Fluid displacement device (2) according to any of the claims 1 – 3, wherein a line through the tip (6A1) and proximal end (62) forms an angle α with the inner surface wherein $15° < \alpha < 90°$.

5. Fluid displacement device (2) according to any of the claims 1 – 4, wherein the distal end (61) comprises a coupling structure to attach a tip structure to the elongated body.

6. Fluid displacement device (2) according to claim 5, wherein the tip structure and elongated body are made from different conductive materials.

7. Fluid displacement device (2) according to any of the claims 1 – 6, wherein the airflow duct comprises a conductive ring-shaped element (6A3) which forms a part of the inner surface of the airflow duct and the proximal ends (62) are attached to the ring-shaped element.

8. Fluid displacement device (2) according to claim 7, wherein the conductive ring-shaped element has an electrical resistivity ρ, wherein $0{,}001$ ohm·metre $< \rho < 1000$ ohm·metre.

9. Fluid displacement device (2) according to claim 7 or 8, wherein the conductive ring-shaped element is a coating at the inner surface of the airflow duct.

10. Fluid displacement device (2) according to any of the claims 1 – 9, wherein the non-corona electrode is a ring-shaped element which forms a part of the inner surface of the airflow duct.

11. Fluid displacement device (2) according to any of the claims 1 - 10, wherein an annular coating at the inner surface of the airflow duct forms the non-corona electrode.

12. Fluid displacement device (2) according to any of the claims 1 – 11, wherein the fluid displacement device further comprises a ionizing section disposed in the airflow duct, the ionizing section comprising a cylindrical non-corona electrode which forms a part of the inner surface of the airflow duct, and a central corona electrode having a tip, wherein the tip is positioned in the airflow duct upstream the cylindrical non-corona electrode at a cylinder axis of the cylindrical-shaped non-corona electrode.

13. Fluid displacement device (2) according to claim 12, wherein the cylindrical non-corona electrode and the non-corona electrode (6B) are the same element.

14. Fluid displacement device (2) according to claim 10, wherein the number of corona electrodes (6A) and the central corona electrode (7A) are electrically coupled and the tip of the central corona electrode (7A) is positioned in the airflow duct downstream the number corona electrodes (6A) and has a distance from the non-corona electrode (6B) which is at least the predefined distance d.

15. Fluid displacement device (2) according to any of the claims 1 – 14, wherein a tip of the corona electrodes comprises a multitude of conductive wires forming a broom.

16. Fluid displacement device (2) according to any of the claims 1 – 15, further comprising an electrostatic filter positioned downstream the non-corona electrode (6B).

17. Use of a fluid displacement device to generate an airflow in a space of a building, wherein the fluid displacement device comprises all technical features of a fluid displacement device according to any of the claims 1 – 16.

18. Use of an air cleaning device to remove particulate material from air in a space of a building, wherein the air cleaning device comprises all technical features of a fluid displacement device according to any of the claims 1 – 16.

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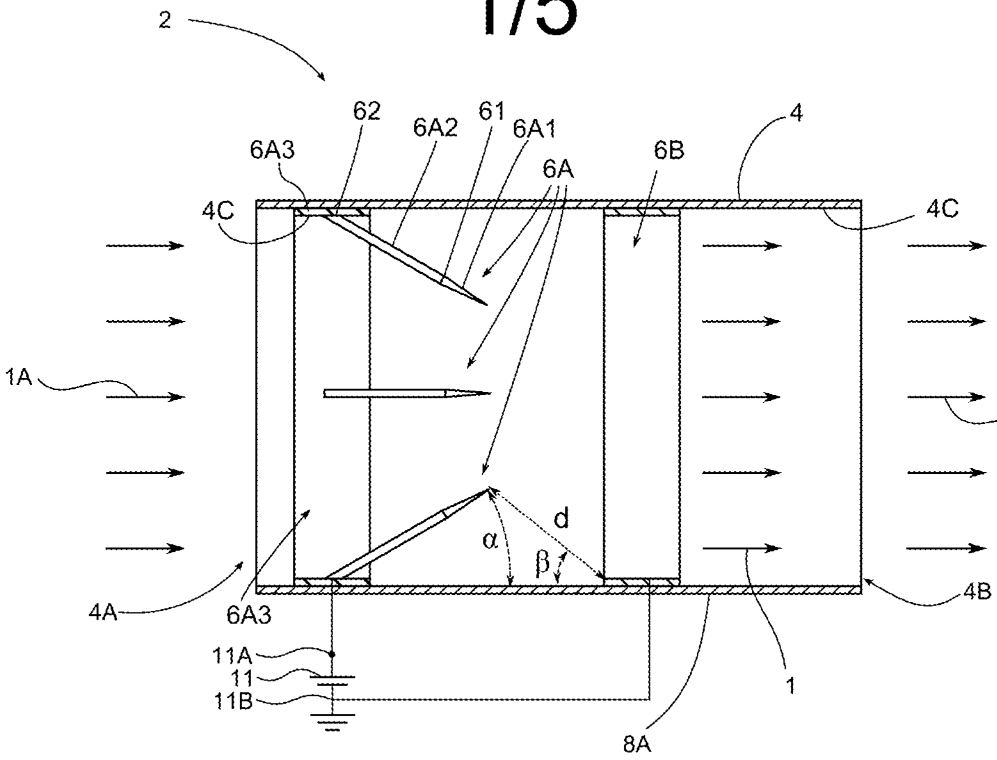


FIG. 1

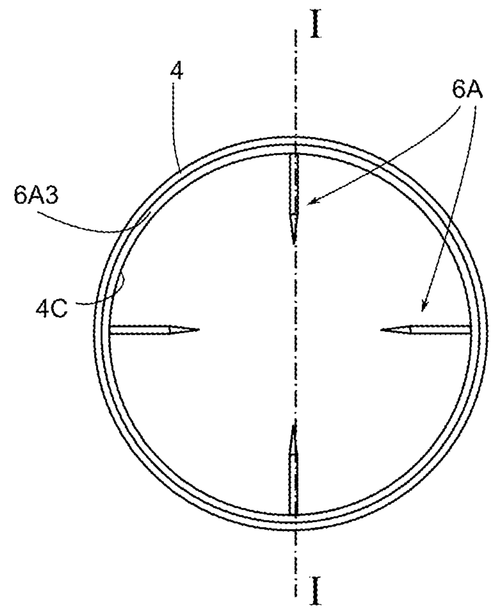


FIG. 2

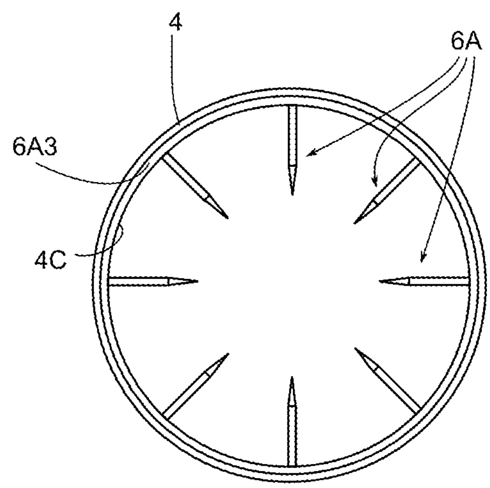


FIG. 3

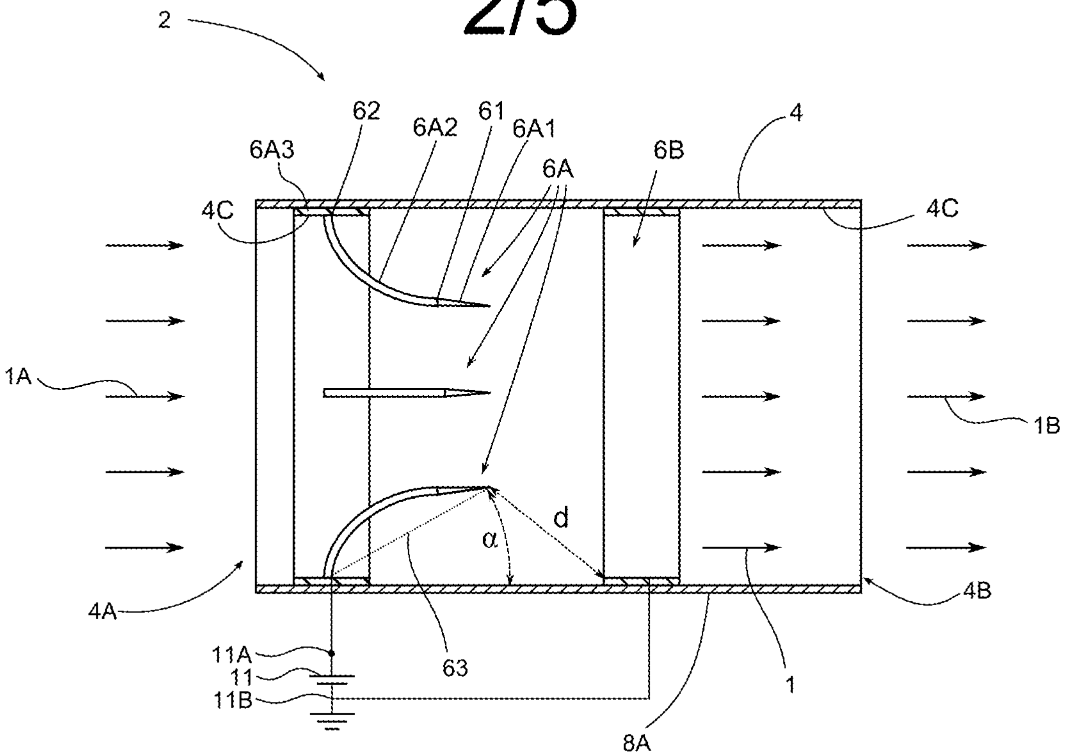


FIG. 4

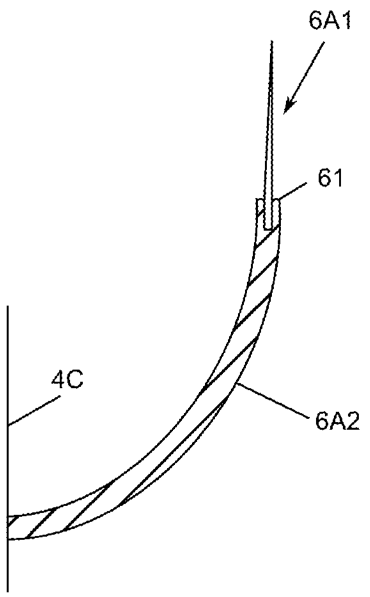


FIG. 5

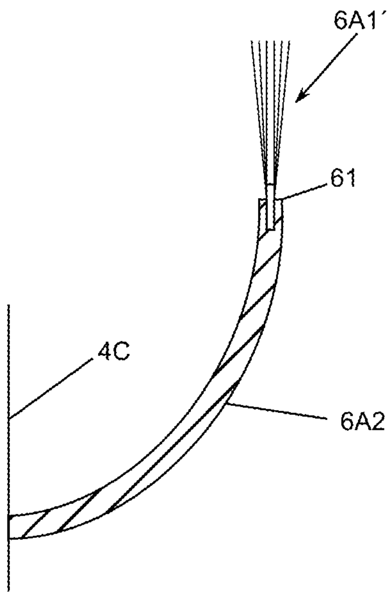


FIG. 6

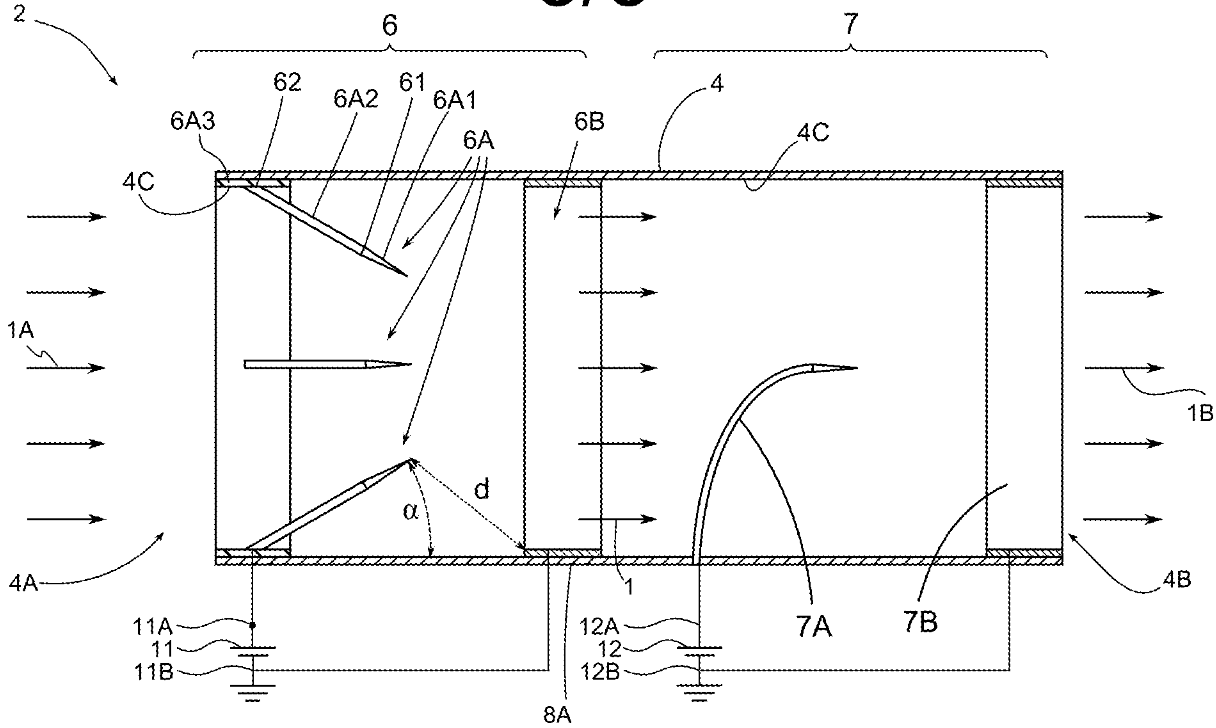


FIG. 7

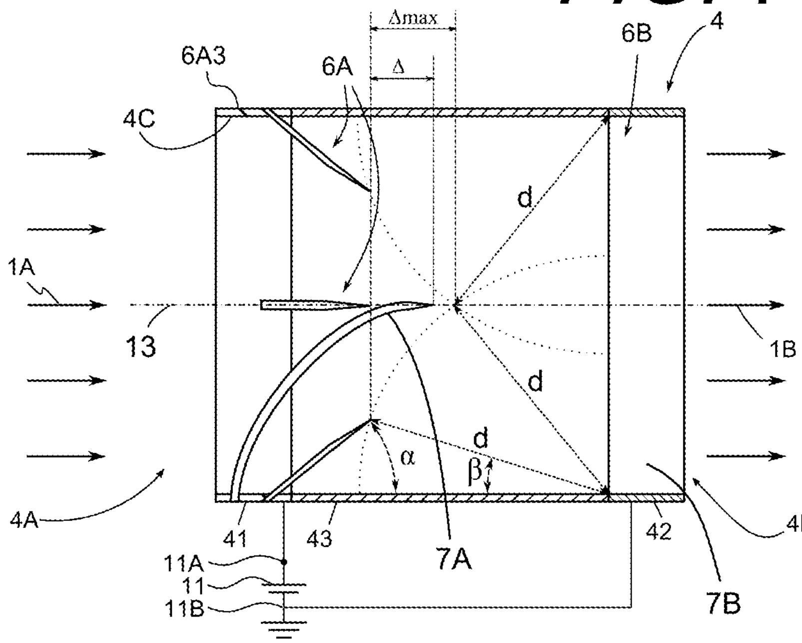


FIG. 8

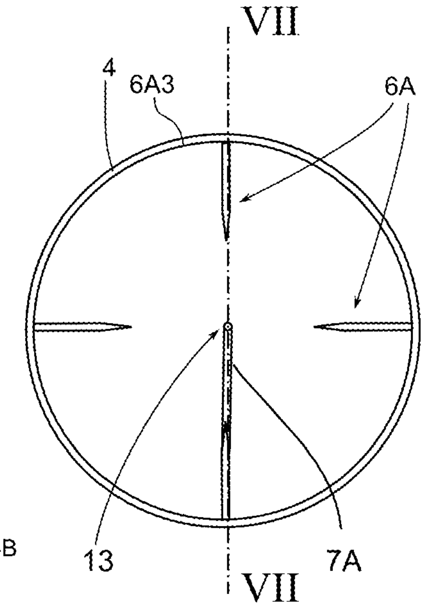


FIG. 9

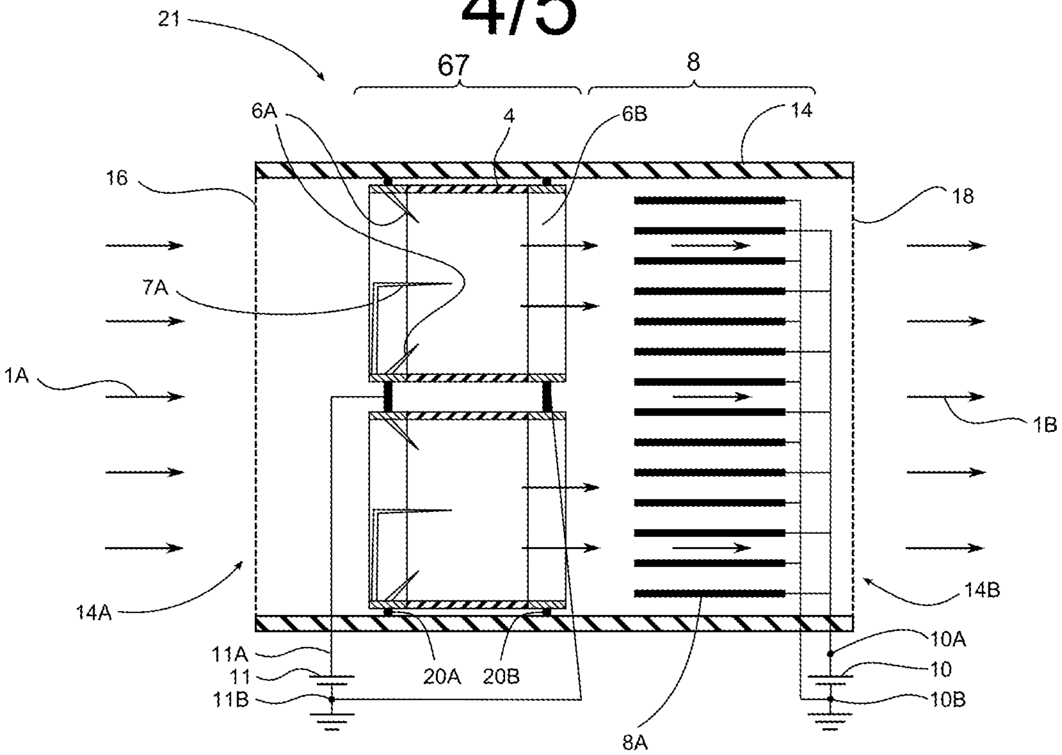
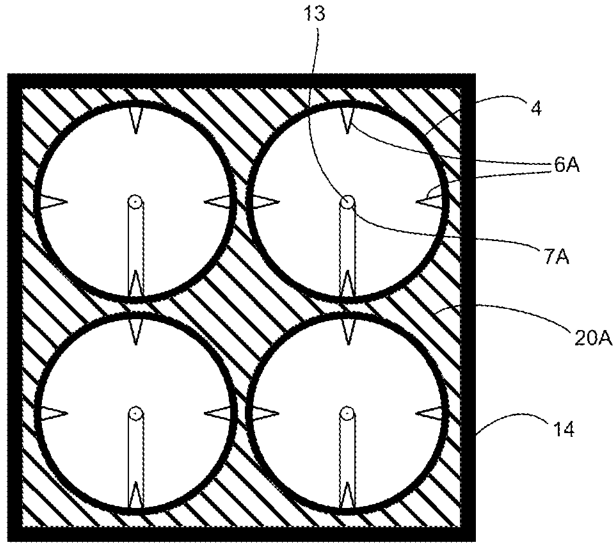

21
67
8
6A
4
6B
14
16
18
7A
1A
1B
14A
14B
11A
11
11B
20A
20B
10A
10
10B
8A

FIG. 10


13
4
6A
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20A
14

FIG. 11

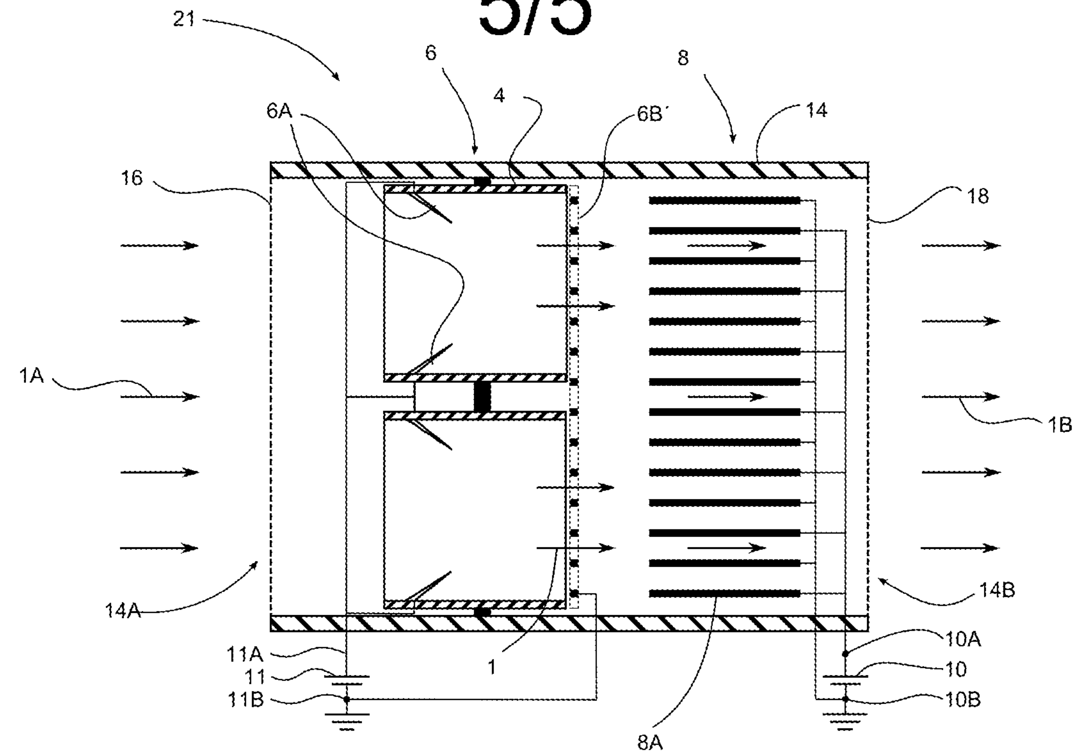

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2013/050324

A. CLASSIFICATION OF SUBJECT MATTER
INV. B03C3/12 B03C3/32 B03C3/41 B03C3/08 B03C3/60
ADD.

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)
B03C

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	CN 101 577 397 A (UNIV XI AN JIAOTONG [CN] UNIV XI AN JIAOTONG) 11 November 2009 (2009-11-11) figures 1-4 page 5, last paragraph - page 6, first paragraph	1-3,5-9, 11-14, 16-18 4,10,15
X	US 2005/194583 A1 (TAYLOR CHARLES E [US] ET AL) 8 September 2005 (2005-09-08) figures 12A-12C paragraph [0079] - paragraph [0089] paragraph [0093]	1-3,7, 12-14,16
Y	WO 2005/102535 A1 (TECHIN AG [LI]; VANELLA SALVATORE [IT]) 3 November 2005 (2005-11-03) figures 1, 2	4,10

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 June 2013	04/07/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Menck, Anja

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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2013/050324

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 4 689 056 A (NOGUCHI HIROKI [JP] ET AL) 25 August 1987 (1987-08-25) figures 1, 2	1-18
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1

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Information on patent family members

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