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(54) Title of the Invention: **Air cleaning device**
Abstract Title: **Air cleaning device for removing aerosol particles**

(57) An air cleaning device 20 for removing aerosol particles from an air stream comprises: (a) a particle charger 22 with a pin-type electrode 23 for generating air ions in the air stream, the particle charger having a particle charging zone within which, in use, aerosol particles in the air stream are electrically charged via collision with the air ions; (b) a filter 26 for precipitating electrically charged aerosol particles from the air stream moving through the device; and (c) an air mover for moving the air stream through the device; wherein the particle charger and the air mover are provided upstream of the filter; and wherein the particle charger and the air mover are intimately coupled together. The particle charger and the air mover may be directly joined together in an airtight manner or may be provided as a single unit. The air cleaning device can further comprise an earthed counter-electrode 24. Suitably, the air mover is a mechanical fan 25, bellows, a convective airflow device or a centrifugal fan. Also described is an air cleaning method for removing aerosol particles from an air stream.

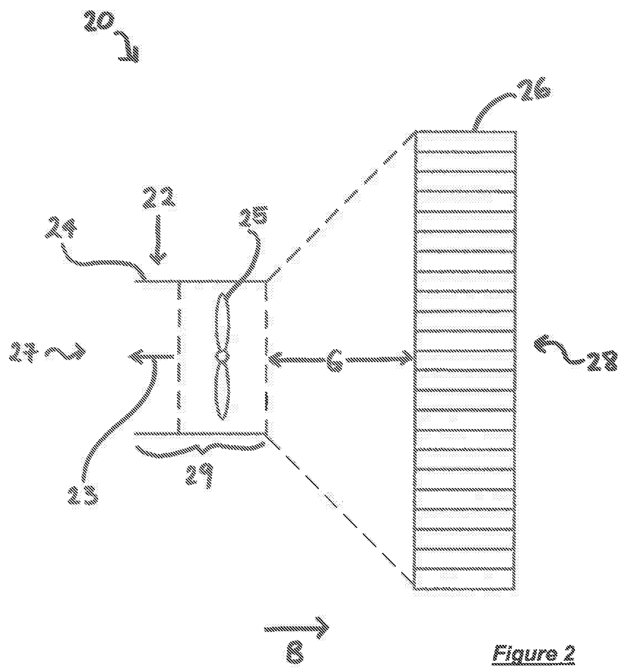

Figure 2

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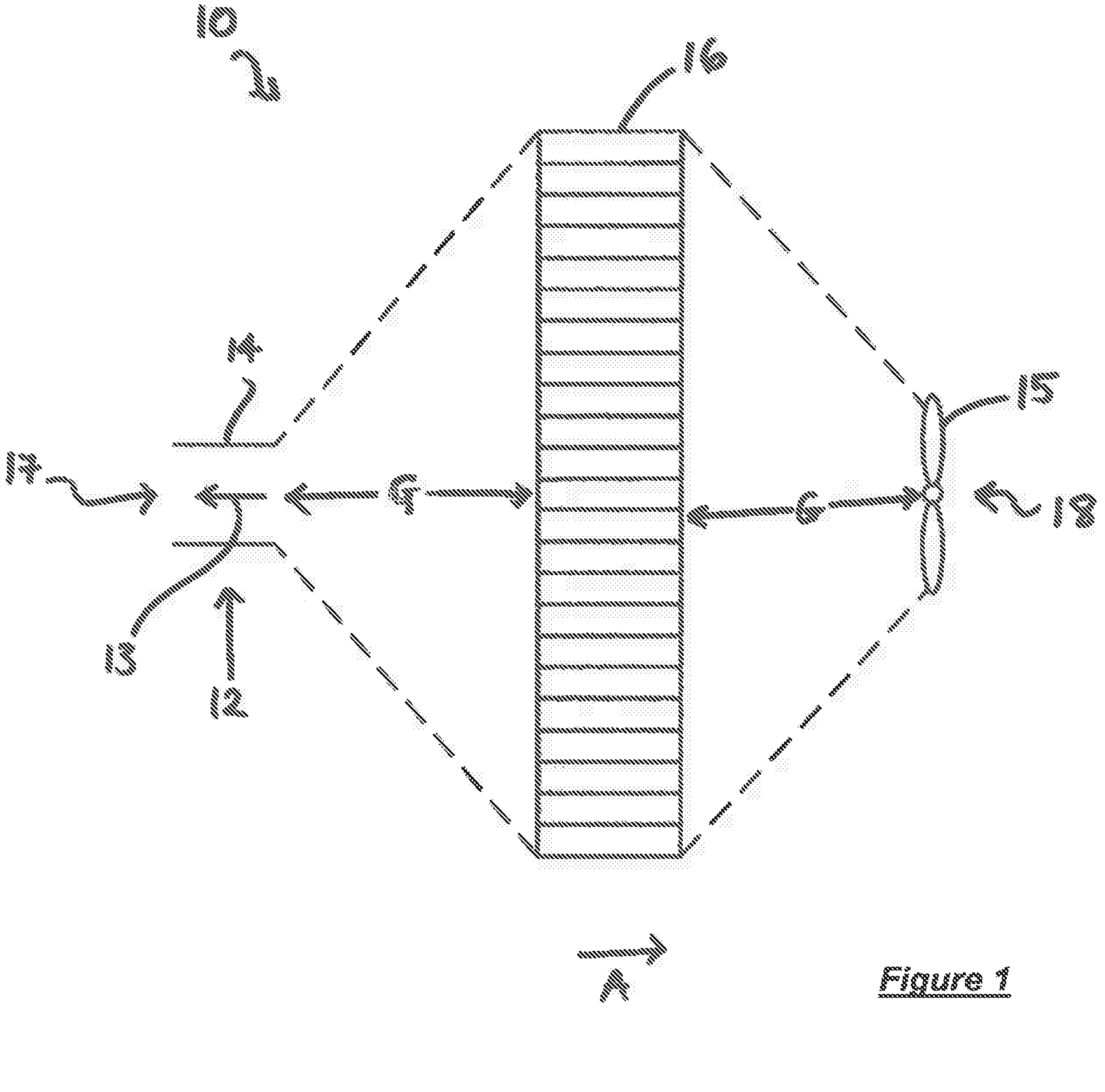

Figure 1

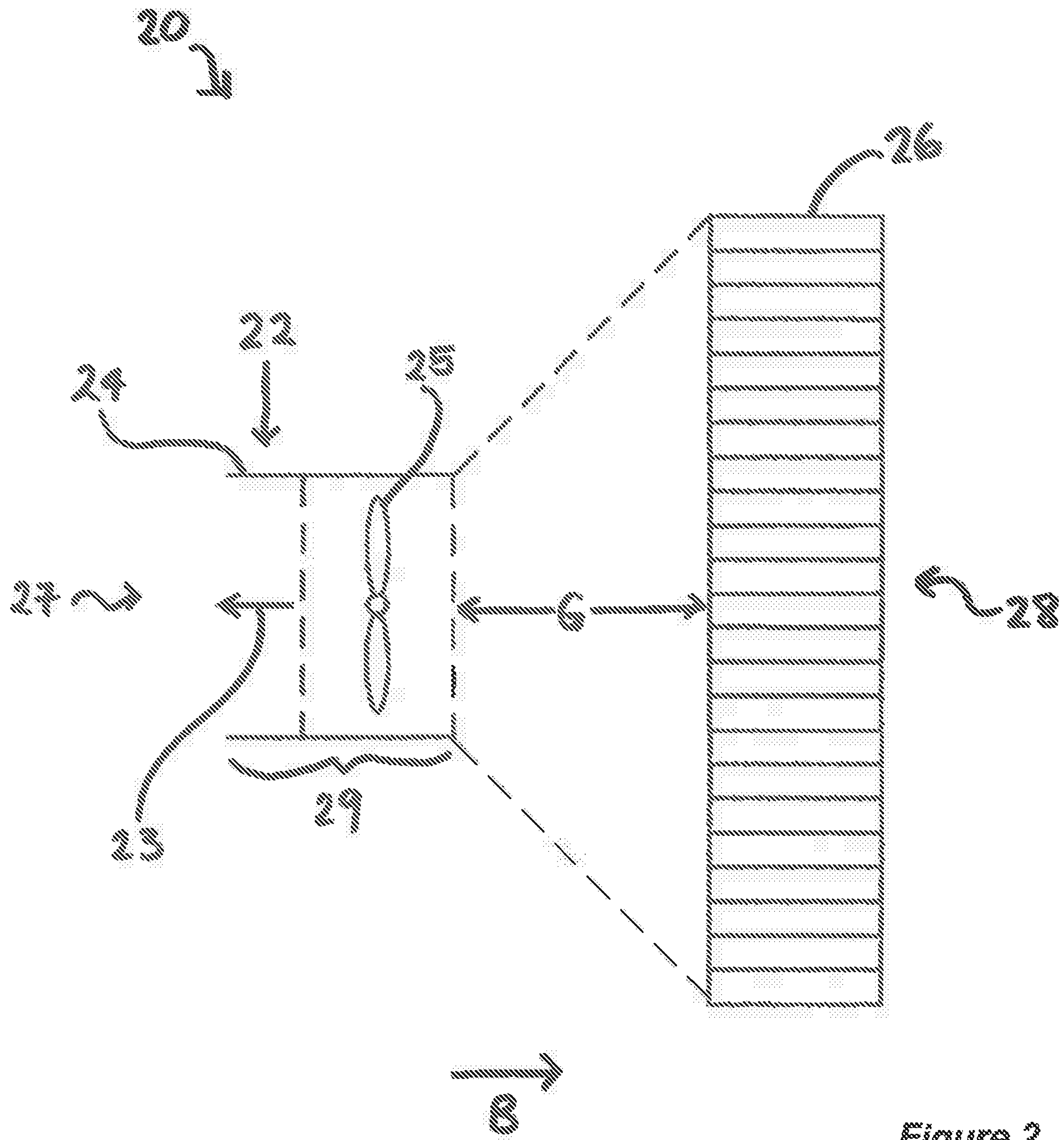

Figure 2

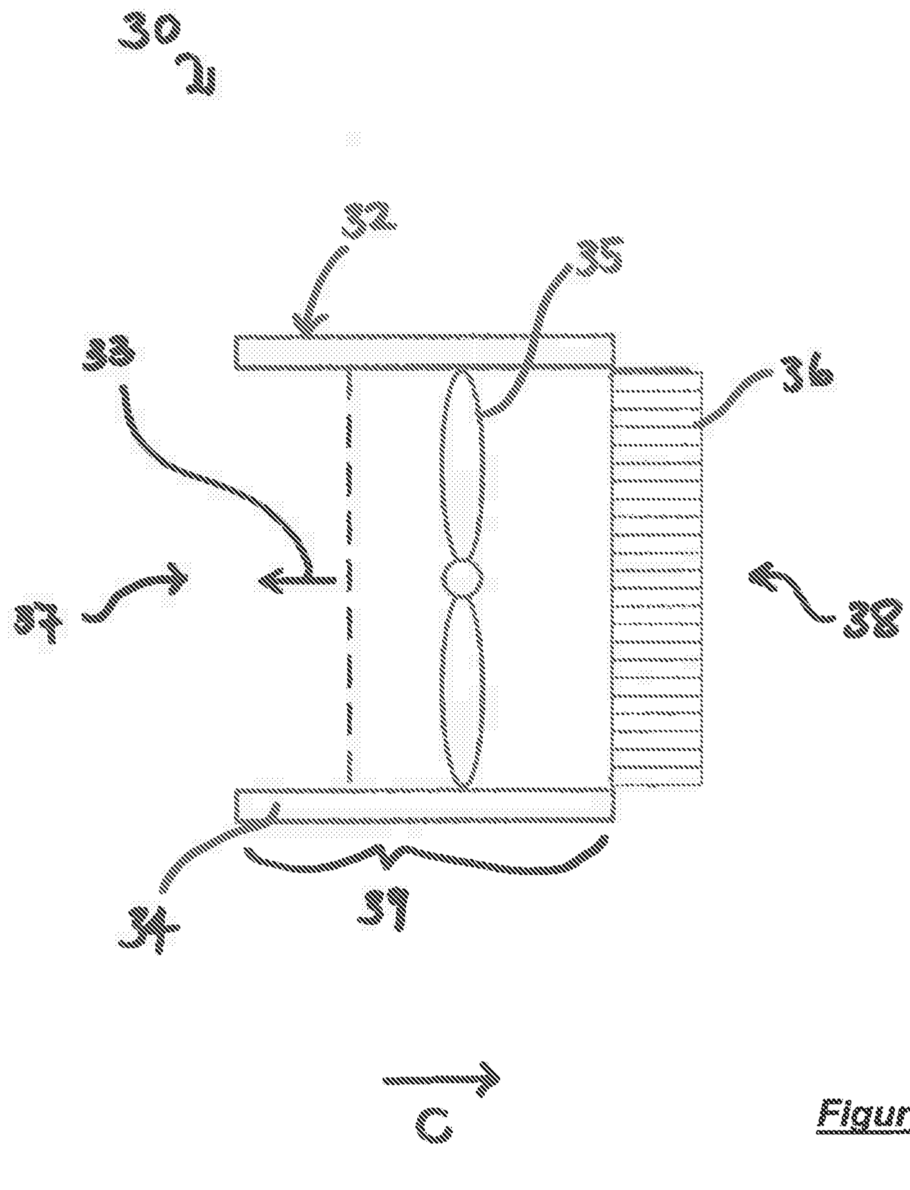

Figure 3

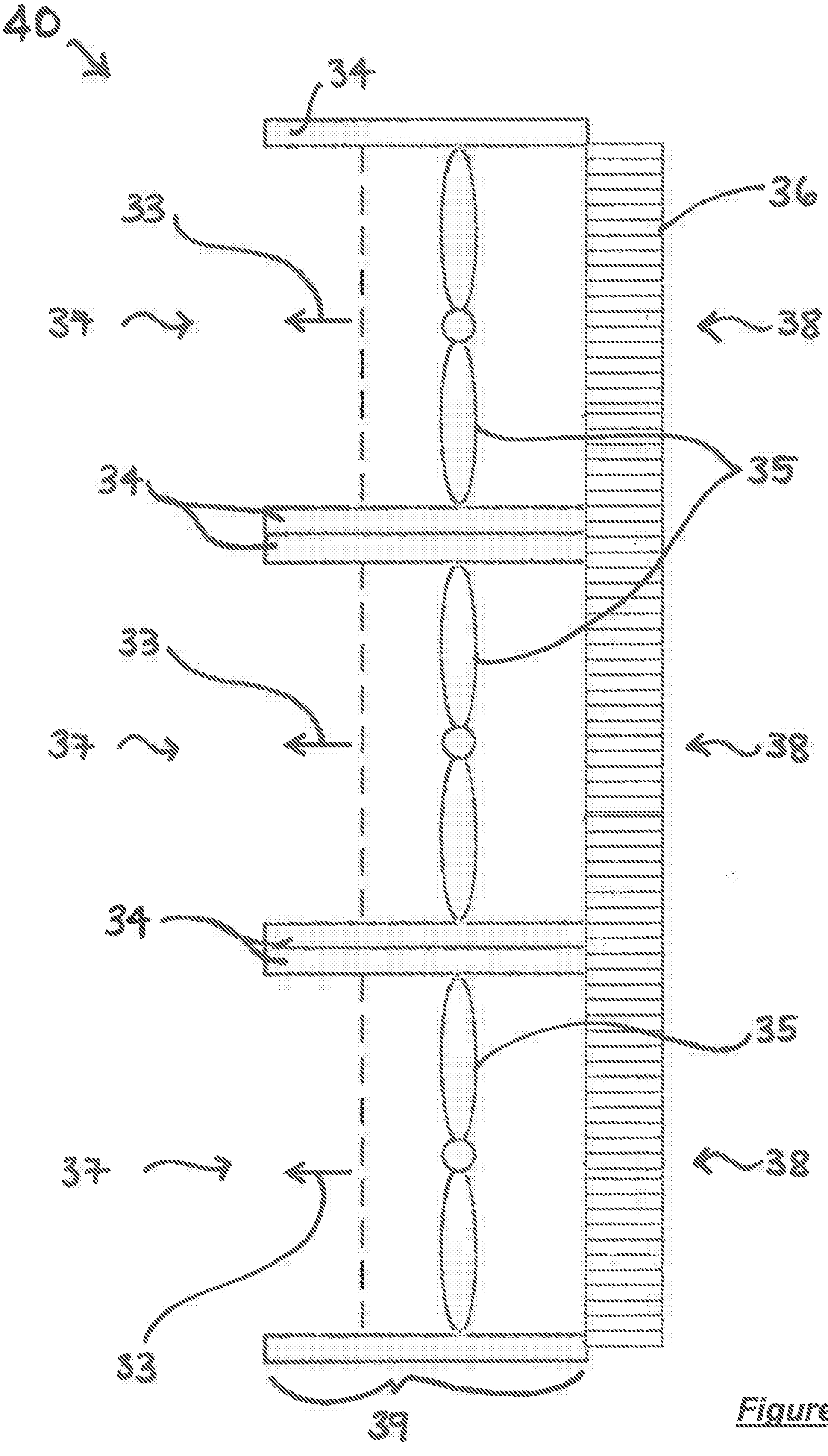

Figure 4

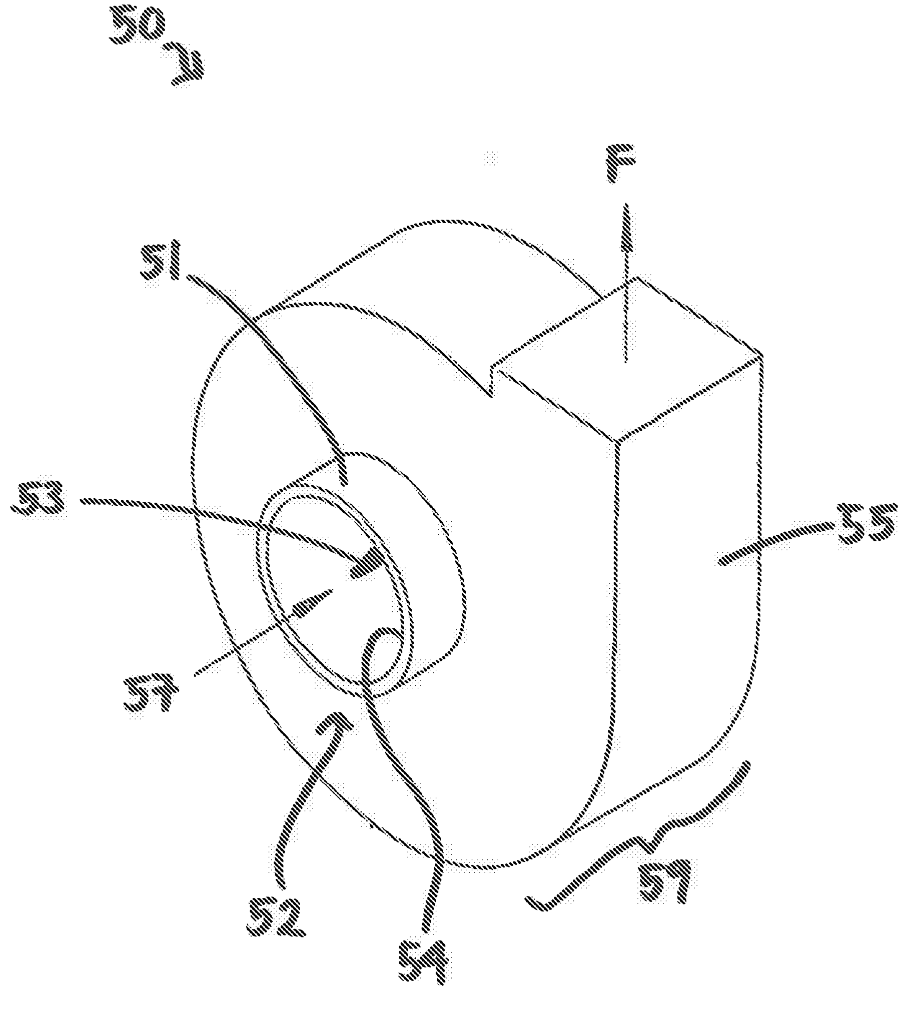

Figure 5

AIR CLEANING DEVICE

The present invention relates to an air cleaning device. The invention relates more particularly, but not necessarily exclusively, to an electrostatic precipitation device for use in air cleaning and filtration.

Air cleaning and other air filtration devices are used to remove unwanted aerosol particles from air. Typically, air filtration is achieved using a filter component configured to entrap aerosol particles from air as it passes through the filter.

Electrostatic precipitation air cleaning devices operate by transferring an electric charge to aerosol particles in the air prior to their passage through the filter or particle collector component thereof (hereinafter collectively referred to as a “filter” for simplicity). An electric field may be applied to the filter, such that said electrically charged particles are attracted to, and precipitated onto, a surface of the filter during passage through the device, thereby effecting removal of the particles from the passing air stream with greater efficiency as compared to removal of uncharged aerosol particles.

Electric charging of the particles can be achieved in a number of ways. One such way, utilising a “field charger”, is typically used in filtration applications. A field charger comprises a particle charger, which comprises an emission electrode and a counter-electrode, which together are operable to form a particle charging zone. In use, an electric field is established between the emission electrode and its counter-electrode because of the difference in their respective electrical potentials: the emission electrode is typically of a small radius of curvature, e.g. it may be in the form of a fine conducting wire or sharp conducting pin, and is usually raised to a high voltage as compared to the counter-electrode, which is typically held at earthed potential. Such an arrangement leads to corona discharge at the emission electrode within the field charger (care being taken to ensure that the voltage difference between the electrodes does not cause electrical breakdown and lead to electrical arcing between the electrodes). Air ions created by the corona discharge are accelerated by the electrical field and collide with aerosol particles passing through the particle charging zone, resulting in those particles becoming electrically charged.

Prior art electrostatic air filtration devices most commonly incorporate an array of thin wires (of the order of millimetres in diameter) as the emission electrodes in the field chargers therein. Such wire arrays form a corona discharge around every wire in the array and, therefore, can be shaped to fit numerous applications. However, wire arrays can be hindered by deposition of unwanted, deleterious substances on the wires, impacting charging effectiveness. Additionally, emission of ozone can be undesirably high from coronas supported on wires. Furthermore, because the wires have to be attached to supporting framework, in the regions of the ends of the wires where attachment occurs, corona emission is reduced to the extent that aerosol particles in the air flowing past the ends of the wires are not effectively charged, which ultimately leads to reduced aerosol particle collection efficiency.

Also known for use in field chargers, although much less commonly (indeed perhaps only by the present applicant), are “pin-type” emission electrodes. As compared to a wire array electrode, a pin-type electrode forms a corona only in a relatively small volume around its sharp tip. The corona intensity at the tip of a pin-type electrode is higher as compared to the corona intensity of a wire array electrode for a given applied current because of the physical differences between the two – the electron concentration at a sharp (diminishing) point is greater than the electron concentration in a wire of substantially constant cross-section, which improves particle charging effectiveness. Furthermore, a pin-type emission electrode produces less ozone for a given particle charging capacity as compared to a wire array equivalent because the corona distributed along a wire requires more electrical current than a pin-type corona and ozone production is proportional to said electrical current. Moreover, as compared to wire array electrodes, pin-type electrodes are less affected by deposition of substances which might otherwise hinder corona discharge, the reason for this being two-fold: firstly, the surface area of the sharp tip of a pin is much less than that of the surface of a wire (around both of which corona discharge occurs) and thus less deposition of corona-hindering substances can occur, and secondly, the higher intensity of the corona at the pin tip as compared to the corona along the length of the wire leads to a greater air ion flux at the pin tip which assists with prevention of deposition of, and flushing away of deposited, corona-hindering substances. Additionally, because a pin-type electrode does not have to be attached to surrounding framework in the same manner as is required for the wires of a wire array electrode, there are no regions of reduced corona emission with pin-type electrodes, which leads to a higher proportion of aerosol particles being charged (as compared to with a wire array electrode). Indeed, the radial symmetry of air ion flux achievable with a pin-type electrode can lead to aerosol particle capture efficiencies of 99.99%. Thus, despite the greater prevalence of wire array emission electrodes in known field chargers, the use of a pin-type emission electrode in a field charger offers many advantages over and above those achievable with otherwise equivalent field chargers which incorporate wire array emission electrodes.

With either type of air cleaning device (i.e. using a wire array electrode or a pin-type electrode in the field charger), an air mover, for example a fan, is typically incorporated to urge uncleaned air to pass through the device. A usual arrangement of components in an air cleaner is, in the direction of airflow: particle charger, filter, air mover. Such a prior art arrangement is shown schematically in Figure 1 of the accompanying drawings.

Referring to Figure 1, there is shown therein a prior art electrostatic precipitation device 10 for removing unwanted aerosol particles from an air stream. The electrostatic precipitation air cleaning device 10 comprises a particle charger 12, an air mover 15 in the form of a mechanical fan, and a filter 16 for removing charged aerosol particles from the air stream (not shown) as it flows through the device 10 *via* an inlet 17 at the entrance to the particle charger 12, in the direction of arrow A, through the filter 16, to an outlet 18 downstream of the fan 15.

The particle charger 12 comprises a pin-type electrode 13 (represented by an arrow, the head of which points upstream to represent the tip of the pin) mounted centrally relative to a counter-electrode 14 so as to enable corona discharge from the tip of the pin and the generation of air ions for charging aerosol particles in the air stream in the manner discussed earlier in this specification. As shown clearly in Figure 1, the particle charger 12 and the filter 16 are provided upstream of the fan 15 with significant spatial separation or gaps, labelled G, between each of these components.

Figure 1 shows that the device 10 undergoes two changes in its cross-sectional area between the inlet 17 and the outlet 18, in the region of the gaps G, illustrated by the dotted lines shown joining, firstly, the particle charger 12 to the filter 16, and secondly, the filter 16 to the fan 15. Once air to be cleaned has passed through the particle charger 12, it experiences an expansion in cross-sectional area through which it can flow until it reaches the filter 16, which has a larger cross-section (perpendicular to airflow) than the particle charger 12. Downstream of the filter 16, cleaned air experiences a contraction in cross-sectional area through which it can flow to accommodate the fan 15, which has a smaller cross-section (again perpendicular to airflow) than the filter 16. The changes in cross-sectional area in the gaps G between the particle charger 12 and the filter 16, and between the filter 16 and the fan 15, result in unwanted air turbulence, greater air resistance, high energy consumption and noise. Furthermore, a means of bridging the gaps G between the particle charger 12 and filter 16, and between the filter 16 and air mover 15, is required: often expensive, tapered cowling or ducting must be provided to overcome the mismatch in cross-sectional areas and the spatial separation of the components.

To overcome at least one of the described mis-matches of cross-sectional area, it is known in the prior art to replace a single pin-type electrode with an array of multiple pin-type electrodes, each surrounded by an earthed counter-electrode, in order to substantially match the area of the filter to the area of the particle charger, the fan being on the opposite side of the filter to the particle charger (in the same manner as is shown in Figure 1).

Such an arrangement is described in, for example, WO2005/102534. However, in addition to the disadvantages of the pin array electrode being more expensive to fabricate than a single pin-type electrode and leading to the production of more ozone as compared to a single pin-type electrode, the spatial separation or gaps between the three components (particle charger, filter and fan) discussed in relation to the device shown in Figure 1 still exist, and the problems of unwanted air turbulence, greater air resistance, high energy consumption, noise and the need for tapered cowling/ducting remain. Indeed, such an array of multiple pin-type electrodes must be spatially separated from the filter in the device because, if placed too close to the filter, any air ion flux grounding on the filter rather than the earthed counter-electrode of the field charger can interfere with the filter operation, significantly reducing its efficiency. Moreover, as the region between the field charger and the filter is under negative pressure with respect to the ambient air when the device is in use, there is an increased possibility that air may bypass the pin-type electrodes, leaking into the region separating the array from the filter. Such bypass is detrimental as it typically leads to uncharged aerosol particles in the air entering the filter, thereby reducing particle capture efficiency.

It is an object of the present invention to obviate or mitigate some, or preferably all, of the abovementioned disadvantages.

According to a first aspect of the present invention there is provided an air cleaning device for removing aerosol particles from an air stream, the device comprising:

(a) a particle charger, comprising a pin-type electrode for generating air ions in the air stream, the particle charger having a particle charging zone within which, in use, aerosol particles in the air stream are electrically charged *via* collision with the air ions;

(b) a filter for precipitating electrically charged aerosol particles from the air stream moving through the device; and

(c) an air mover for moving the air stream through the device;

wherein the particle charger and the air mover are provided upstream of the filter; and

wherein the particle charger and the air mover are intimately coupled together.

The particle charger and the air mover may be intimately coupled as particle charger/air mover in the direction of air flow (such that the particle charger is upstream of the air mover) or as air mover/particle charger (such that the air mover is upstream of the particle charger) – in both instances, the “couple” is upstream of the filter. This unconventional arrangement in the order of components in the air cleaning device is advantageous because the region between the couple and the filter is at positive pressure as compared to the ambient surrounding air, meaning that any air bypass will be outward of said region such that few, or most preferably no, uncharged aerosol particles can enter the filter, resulting in maximised particle capture efficiency.

By describing the particle charger and the air mover as being “intimately coupled”, it is meant that the particle charger and the air mover are joined together, directly or by means of an intermediate component, in an airtight manner, or indeed are provided as a single unit; air is able to flow through the intimate couple by entering at the upstream end thereof and exiting at the downstream end thereof, but is contained substantially entirely, preferably entirely, by the intimate couple prior to flowing on through to the filter. Thus there is no gap between the particle charger and the air mover, meaning that the possibility of air bypass or leakage is eliminated.

In use, air flowing through the air cleaning device flows along an air stream passage from an air inlet of the device to an air outlet of the device. The air inlet of the device may be provided at the inlet end of the intimate couple, i.e. at whichever of the particle charger and air mover is upstream in the couple. The air outlet of the device may be provided at the downstream end of the filter. Throughout this specification, when a first component is described as being "upstream" of a second component, it is intended to mean that the first component is provided further towards the air inlet of the device than the second component. Put another way, in use, air will flow past a first component before a second component if the first component is upstream of the second component. The term "downstream" should be construed accordingly.

In the intimate couple, the particle charger may be directly adjacent, and intimately joined, to the air mover. The adjacency of the particle charger and air mover may facilitate each having a common cross-sectional area, such that their intimate coupling is more easily achieved.

A further advantage of the present invention resides in the altered positioning of components relative to one another as compared to the conventional ordering of such components. In particular, since both the particle charger and the air mover are provided upstream of the filter, it is possible to reduce the number of changes in cross-sectional area of the air stream to one, or potentially eliminate changes in cross-section altogether.

As a result of both the intimate coupling of the particle charger and the air mover with the unconventional ordering of the components discussed above, the present invention may ameliorate or mitigate the aforementioned disadvantages in terms of turbulence, higher air resistance, greater energy consumption, noise, bypass or leakage, and expense of tapered cowling required to match the different cross sections. By extension, it may also remove or reduce what appears to be an industry bias against using pin-type emission electrodes (as opposed to wire array emission electrodes) in field chargers used in air cleaning devices. This may ameliorate issues with ozone generation and the deposition of substances on the wire emission electrodes observed when wire arrays are used in field chargers, while providing for a higher efficiency of particle charging per unit of corona current in a pin-type emission electrode as compared with that achievable with a wire array electrode (for a given applied current).

Any suitable filter for capturing charged aerosol particles may be used in an air cleaning device of the invention. In one preferred embodiment, the filter may be an electrostatic filter, which operates by using an electric field to deflect charged aerosol particles passing therethrough in order to cause those particles to be precipitated onto a filter surface. In another preferred embodiment the filter may be an electret filter. In yet another preferred embodiment of the invention, the filter may be an electrostatic precipitator. Such filters are well known to those of skill in the art.

As described in International patent publication WO00/61293, for example, an electrostatic filter can comprise an array of passages which forms part of the fluid passage through the electrostatic precipitation device and through which a gas stream can pass relatively freely (the passages being provided between plastics walls and the plastics walls having areas of conductive material in contact therewith), and means for applying high and low electrical potentials alternately to isolated areas of the conductive material to provide charged sites in the array for collecting particles from the gas stream.

An electret filter may comprise an array of layers of fluted plastics sheet material or it may be formed of fibrous media, in which the fibres may be charged by electrodes in the filter or during manufacture of the filter.

Alternative configurations for the filter component are well known to those of skill in the art and any appropriate filter may form part of an electrostatic precipitation air cleaning device according to the present invention.

The air mover may take the form of any conventional component well known to those of skill in the art for effecting urging (or movement) of air in a desired direction. The air mover may, for example, take the form of a mechanical fan, bellows or a convective airflow device. Alternatively, the air mover may take the form of a centrifugal fan, also known as a “blower”. Many other suitable components would be well known to those of skill in the art and any appropriate air mover may form part of an electrostatic precipitation air cleaning device according to the present invention.

A pin-type electrode comprised in a particle charger may be supported on a support rod, which may additionally be conductive. Two or more electrodes may be supported on a support rod. Pin-type electrodes preferably have sharp points and may be in the form of pins. Alternatively, the pin-type electrodes may be in the form of triangular teeth.

The electrostatic precipitation air cleaning device of the invention may be provided with a counter-electrode (non-corona) configured to be operable at a different electrical potential to that of the pin-type (corona) electrode in the particle charger, and it may be formed as part of the particle charger. The counter-electrode will surround the tip of the pin-type electrode but will be separated therefrom by a clearance. The counter-electrode may be earthed. Provision of a counter-electrode provides a potential gradient of sufficient strength to ignite the corona discharge required to generate air ions. Furthermore, the resulting electric field accelerates the air ions generated so that they cross the space in the field charger through which air to be cleaned (containing unwanted aerosol particles) passes; as said aerosol particles collide with air ions, charge is transferred from the air ions to the aerosol particles, thus enabling subsequent collection of the aerosol particles by the filter.

The counter-electrode may be shaped such that the distance from the tip of the pin-type electrode to the surface of the surrounding counter-electrode is approximately constant around the periphery of the tip; the air ion flux generated at the tip will thus be substantially symmetrical and radial, ensuring that a very high proportion (99.99 % is regularly achievable) of the unwanted aerosol particles in the air collide with air ions, leading to the desired charge transfer and subsequent particle capture. The counter-electrode may comprise a conductive plate (preferably, but not necessarily, a substantially flat plate) having an aperture therein. Alternatively, the counter-electrode may comprise a hollow cylinder, which may be formed of a conductive material, or which may be provided with a conductive interior surface. The aperture in the plate or the cross-section of the cylinder may be rectangular, square, circular or elliptical, and will have a central longitudinal axis extending orthogonal to the plate or co-extensive with the cylinder. In any of these embodiments, the tip of the pin-type electrode preferably lies substantially co-axial with the axis of the aperture/cylinder, and is preferably centrally disposed within the aperture in the plate or within the cylinder to ensure that the clearance is approximately constant around the periphery of the tip of the pin-type electrode.

In most preferred embodiments, the counter-electrode may be generally annular, i.e. the aperture in the conductive plate may be circular or the hollow cylinder may have a circular cross-section. The tip of the pin-type electrode may be substantially concentric with the counter-electrode.

In a particular embodiment, when the air mover takes the form of a blower having an air intake and an air outlet perpendicular to the intake, the pin-type (corona) emission electrode may be provided in the air intake of the blower. The counter-electrode (non-corona) may also be located in the air intake of the blower. In such an embodiment, the air intake may comprise a conductive portion, e.g. a conductive ring or a conductive interior surface, forming the counter-electrode. Location of the counter-electrode in this way facilitates a particularly compact design of the device of the present invention. Such location is made possible since the filter component is not located in between the air mover and particle charger, and indeed will often be external of, and remote to, the blower.

The conductive interior surface of counter-electrode in embodiments may be comprised of a conductive ink or paint. Conductive inks and paints offer a convenient way to apply a counter-electrode to otherwise non-conductive surfaces.

In a most preferred embodiment, the present invention provides an electrostatic precipitation air cleaning device comprising a cylindrical field charger (particle charger) that is of similar cross-sectional area to the inlet of the air mover (e.g. fan) to which it is intimately coupled, thus efficiently charging incoming aerosol particles before they enter the filter. The filter may be of the same cross-sectional area as the intimate couple or it may be significantly greater.

A device according to the invention may comprise two or more air movers and/or two or more particle chargers, each having a pin-type emission electrode, i.e. two or more intimate couples, which may be provided in a side-by-side arrangement so as to effectively double the cross-sectional area available for air to be cleaned to move through. In such an arrangement, the two (or more) intimate couples may be used with a common filter, or with a filter each. In the event that more than one particle charger is provided, the device may further comprise a corresponding number of counter-electrodes therefor.

According to a second aspect of the present invention there is provided a method of removing aerosol particles from an air stream, the method comprising:

generating air ions in the air stream using a particle charger comprising a pin-type electrode;

electrically charging aerosol particles in the air stream *via* their collision with air ions in a particle charging zone of the particle charger; and

moving the air stream towards a filter using an air mover, whereby electrically charged aerosol particles in the air stream are precipitated onto the filter,

wherein the air stream is moved through an intimate couple of the particle charger and the air mover prior to its arrival at the filter.

Preferred features described above in relation to the first aspect of the present invention also represent preferred features of the above second aspect of the present invention subject to a technical incompatibility that would prevent such a combination of preferred features. Furthermore, it will be evident to the skilled person that advantages set out above in respect of the first aspect of the present invention are also offered by the second aspect of the present invention.

For the avoidance of any doubt, it should be noted that various features of the invention discussed above may be used in combination. So, for example, in a specific embodiment of the present invention, the air mover is in the form of a blower and comprises a cylindrical intake formed of conductive material, the conductive material being earthed and forming a circular counter-electrode for the particle charger. In this embodiment, the tip of the pin-type emission electrode may be provided co-axially within the cylindrical intake, but separated from the counter-electrode by a clearance.

The invention will now be further described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic side cross section of a prior art electrostatic precipitation device, discussed earlier in this specification;

Figure 2 is a schematic side cross section of an embodiment of an electrostatic precipitation air cleaning device according to the present invention;

Figure 3 is a schematic side cross section of a second embodiment of an electrostatic precipitation air cleaning device according to the present invention;

Figure 4 is a schematic side cross section of a third embodiment of an electrostatic precipitation air cleaning device according to the present invention; and

Figure 5 is a schematic perspective view of a fourth embodiment of an electrostatic precipitation air cleaning device according to the present invention.

Referring to Figure 2, which illustrates a first embodiment of the invention, there is shown an electrostatic precipitation air cleaning device 20 for removing unwanted aerosol particles from an air stream. In a similar manner to the prior art device 10 shown in Figure 1, the air cleaning device 20 of Figure 2 comprises a particle charger 22 (represented by an arrow, the head of which points upstream to represent the tip of the pin), an air mover 25 in the form of a mechanical fan, and a filter 26 for removing charged aerosol particles from the air stream (not shown) as it flows through the device 20.

Unlike the device 10 shown in Figure 1, however, the order of the components and the relative spatial orientation of the components in the device 20 shown in Figure 2 is quite different: the particle charger 22 and the fan 25 are joined together in an airtight manner as an intimate couple 29, with the particle charger 22 being upstream of the fan 25. The air stream flows *via* an inlet 27 at the entrance to the particle charger 22, in the direction of arrow B, through the intimate couple 29 of particle charger 22 and fan 25, to the filter 26 *via* a gap, G, (illustrated by the dotted lines) therebetween and on to an outlet 28. In practice, this gap, G, would be contained by tapered cowling or other such suitable ducting.

In the device 20 in Figure 2, the particle charger 22 comprises a pin (corona) electrode 23, which is mounted centrally relative to a surrounding counter-electrode 24 so as to enable corona discharge from the tip of the pin and the generation of air ions for charging aerosol particles in the air stream in the manner discussed earlier in this specification.

As shown clearly in Figure 2, the particle charger 22 and the fan 25 are joined together in an airtight manner forming the intimate couple 29 upstream of the filter 26; there is no gap between the particle charger 22 and the fan 25, and although a gap, G, is shown as being present between the intimate couple 29 and the filter 26, it is under positive pressure with respect to ambient air and thus any bypass or leakage of uncharged aerosol particles to the filter 26 is minimised, if not completely eliminated. In other words, unlike the prior art device 10 shown in Figure 1, the air stream passageway in the device 20 in Figure 2 undergoes only a single change in cross-sectional area (perpendicular to the direction of air flow) from the inlet 27 to the outlet 28. The passageway is relatively narrow (i.e. has a small cross-sectional area) at the inlet 27 of the device 20 to ensure that substantially all of the aerosol particles in the air flowing therethrough encounter air ions for charge transfer. Downstream of the particle charger 22 is provided the fan 25, and the passageway remains substantially constant in cross-section from the particle charger22 to the fan 25, assisting formation of the intimate couple 29. Downstream of the fan 25, the passageway undergoes an expansion in cross-sectional area to accommodate the relatively large filter 26.

As there is only a single change in cross-sectional area of the air stream passageway, air passing through the device 20 in Figure 2 encounters less turbulence, air resistance, requires less energy and produces less noise; and the need for relatively costly cowling/ducting required to match the different cross sections as compared with the prior art device 1 in Figure 1 (which comprises two changes in cross sectional area of the gas passageway) is reduced.

Referring now to Figure 3, there is shown therein a second embodiment of an electrostatic precipitation air cleaning device 30 in accordance with the present invention for removing aerosol particles from an air stream. The device 30 of the second embodiment is similar to the first embodiment shown in Figure 2, and only the differences between the devices 20, 30 will be described in detail below. In Figure 3, the components corresponding to those described above in relation to Figure 2 take the reference number used in Figure 2 but raised by 10.

Unlike the device 20 in Figure 2, because the filter 36 is sized such that its cross-section is the same as the cross-sectional area of the intimate couple 39 (formed by joining in an airtight manner of the particle charger 32 and the air mover in the form of a fan 35), the air stream passageway in the device 30 in Figure 3 undergoes no change in cross-sectional area from the inlet 37 to the outlet 38. As there is no change in cross-sectional area, air flowing through the device in Figure 3 encounters less turbulence, air resistance, requires less energy and produces less noise; and there is no need for any relatively costly cowling/ducting to match different cross-sections as compared with the devices 10 and 20 shown in Figs. 1 and 2. Also bypass and/or leakage is reduced and particle charging efficiency and therefore capture is increased over and above that already achieved with the embodiment of the invention shown in Figure 2.

Referring now to Figure 4, there is shown therein a further electrostatic precipitation air cleaning device 40 in accordance with the present invention for removing aerosol particles from an air stream. The device 40 of the third embodiment is effectively a stack of three of the devices 30 shown in Figure 30, and as such the same reference numbers as those used to describe Figure 3 will be used in Figure 4.

Three particle chargers 32, each having a pin electrode 33, and three air movers in the form of mechanical fans 35 are provided upstream of a single filter 36 in the device in Figure 4 (*cf.* one of each respective component in the devices 20, 30 in Figures 2 and 3), i.e. three intimate couples 39 are provided upstream of the single filter 36. The presence of a single filter, spanning the three intimate couples 39, rather than three separate filters (one per couple) is the only modification made as compared to an exact stack of three of the devices 30 shown in Figure 3. Of course, the embodiment shown in Figure 4 could be so modified such that the filter 36 spanned just two of the intimate couples 39 (with the third couple being provided with its own filter), or such that each intimate couple is provided with its own filter. All of these combinations are within the scope of the present invention.

The three particle chargers 32 are provided in the air stream passageway in a side-by-side arrangement (in this case, stacked one on top of the other), such that air flowing through the device encounters one or the other two particle chargers 32. Similarly, the three fans 35 are also provided in a side-by-side arrangement (again stacked one on top of the other and each being substantially co-axial with a respective particle charger 32), such that air flowing through the device 40 is drawn through one or the other two fans 35.

In use, some air flowing through the air stream passageway flows through the uppermost particle charger 32and uppermost fan 35 to the common filter 36, some through the middle particle charger 32 and middle fan to the common filter 36, and some through the lowermost particle charger 32 and the lowermost fan 35 to the filter common 36.

Each of the three particle chargers 32 has a similar cross-sectional area to each of the three fans 35, and so the total air stream passageway therebetween remains substantially constant in cross-sectional area. The collective cross-sectional area of the three particle chargers 32 and three fans 35 is similar to that of the single filter 36, (i.e. the filter 36 has a cross-sectional area approximately three times that of each intimate couple 39). Because of the similarity in cross-sectional area, the air stream passageway between the fans 35 and the filter 36 remains substantially constant in cross-section.

In light of the above, as with the device in Figure 3, the air stream passageway in the device in Figure 4 undergoes substantially no change in cross-sectional area from its inlets 37 to its outlets 38. As there is substantially no change in cross-sectional area, air passing through the device 40 in Figure 4 encounters less turbulence, air resistance, requires less energy and produces less noise; there is no need for relatively costly connecting tubes required to match the different cross sections as compared with the devices 20, 30 in Figs. 1 and 2. As shown, the common filter 36 is fitted to the downstream end of the three intimate couples 39 by means of a straightforward housing (not shown). Thus bypass and/or leakage is reduced and particle charging efficiency and therefore capture is increased over and above that already achieved with the embodiment of the invention shown in Figure 2.

Referring now to Figure 5, there is shown therein a further electrostatic precipitation air cleaning device 50 in accordance with the invention for removing aerosol particles from an air stream. The device 50 comprises a particle charger 52, an air mover 55 in the form of a blower, and a filter, which although not explicitly shown here, would be positioned downstream of the air flow exiting the blower 55, which air flow is labelled with arrow F.

The particle charger 52 and the blower 55 are joined together in an airtight manner as an intimate couple 59, with the particle charger 52 being upstream of the blower 55. The air stream flows *via* an inlet 57 at the entrance to the particle charger 52, through the intimate couple 59 of particle charger 52 and blower 55, to the filter (somewhere downstream of air flow shown by arrow F) and on to an outlet (not shown). In practice, cowling or other such suitable ducting would be provided to position the filter externally of the blower 55.

More specifically in Figure 5, the particle charger 52 comprises a pin (corona) electrode 53 mounted centrally in an intake 51 of the blower 55. The intake 51 is conductive and earthed, and as a result the intake 51 behaves as a counter-electrode (also referenced as 54 hereinafter) for the pin electrode 53, thereby improving particle charging effectiveness. The intake 51 is shown as a protruding member in Figure 5, however it could easily be in the form of an opening in the otherwise flat outer surface of the side of the blower 55. The intake 51, whether in the form of a protrusion (as shown) or a flush opening (as an alternative) can itself be conductive (as described above) or, if formed of a non-conductive material, e.g. a plastics material, be provided with a conductive interior surface, e.g. an area, preferably a ring, of conductive ink or paint to form the counter-electrode. The intake 51 of the blower 55 is substantially cylindrical, meaning that the counter-electrode 54 is similarly cylindrical, whereas the tip of the pin electrode 53 is substantially a point. The cylindrical counter-electrode 54 and tip of the pin electrode 53 are, therefore, symmetrically arranged, which means, in combination with the pin electrode 53 and the counter-electrode 54 being concentric, that the distance from the pin tip to the inner surface of the surrounding electrode is approximately constant. This means that the air ion flux between the pin electrode 53 and the surrounding counter-electrode 54 is radial, thereby increasing the likelihood of air ion-aerosol particle collisions, which further improves particle charging effectiveness by the corona electrode 53.

Test Data

An electrostatic air precipitation device, of the type schematically shown in Figure 3 of the accompanying drawings, was tested for its aerosol particle capture efficiency by varying the current supplied to the pin-type electrode of the particle charger as a function of captured particle size. Air flow to the device was controlled at 1.2 metres per second filter face velocity for all tests. The filter used was an electrostatic, fluted "ifD filter" of 3 inches (76.2 mm) depth supplied by Darwin Technology International Limited (www.ifdair.com); the ifD filter was operated at 10kV between adjacent electrodes. The number of particles was measured using a laser particle counter (Lighthouse Handheld Model No. 3016) which was operated consistently so that a % particle capture efficiency could be calculated. The results are shown in Table 1 below.

Current Supplied (μA)	**Captured Particle Size (μm)**					
	0.3	0.5	0.7	1.0	2.0	5.0
1.0	99.35	99.46	99.26	99.59	99.03	100.00
2.0	99.88	99.92	99.94	99.88	100.00	100.00
3.0	99.95	100.00	100.00	100.00	100.00	100.00
4.0	99.99	100.00	100.00	100.00	100.00	100.00
5.0	100.00	100.00	100.00	100.00	100.00	100.00

Table 1

The percentage particle capture efficiencies noted in Table 1 above clearly show a general trend of increasing efficiency with increased current supplied, for each of the particle sizes captured, and increasing efficiency with which increasingly large particles are captured for a given current supplied (subject to experimental error).

Larger aerosol particles are generally easier to capture than smaller particles (due in part to there being a greater likelihood of collision of larger particles with air ions and thus more charged particles to capture). However, even with aerosol particle sizes as small as 0.3 μm, with only 1.0 μA of current supplied to the pin-type electrode, greater than 99 % (99.35 %) efficiency is achieved, this rising to 99.99 % with 4.0 μA of current supplied.

It should of course be noted that all of the efficiencies quoted are subject to the operational measurement limitations of the particle counter.

It will be appreciated that certain features of the invention, which are for clarity described separately, particularly those in the context of alternative embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention which are described in combination, in the context of a single embodiment, may also be provided separately, or in any suitable combination.

It will also be appreciated that various modification, alterations and/or additions to the described embodiments may be introduced without departing from the scope of the present invention, as defined in the following claims. Many other possible modifications would be appreciated by one of skill in the art following the teaching in this description.

CLAIMS:

1. An air cleaning device for removing aerosol particles from an air stream, the device comprising:
   (a) a particle charger, comprising a pin-type electrode for generating air ions in the air stream, the particle charger having a particle charging zone within which, in use, aerosol particles in the air stream are electrically charged *via* collision with the air ions;
   (b) a filter for precipitating electrically charged aerosol particles from the air stream moving through the device; and
   (c) an air mover for moving the air stream through the device;

   wherein the particle charger and the air mover are provided upstream of the filter; and

   wherein the particle charger and the air mover are intimately coupled together.

2. The air cleaning device according to claim 1, wherein the particle charger and the air mover are intimately coupled as particle charger/air mover in the direction of air flow.

3. The air cleaning device according to claim 1, wherein the particle charger and the air mover are intimately coupled as air mover/particle charger in the direction of air flow.

4. The air cleaning device according to any of claims 1, 2 or 3, wherein the particle charger and the air mover are directly joined together in an airtight manner.

5. The air cleaning device according to any of claims 1, 2 or 3, wherein the particle charger and the air mover are joined together by means of an intermediate component in an airtight manner.

6. The air cleaning device according to any of claims 1, 2 or 3, wherein the particle charger and the air mover are provided as a single unit.

7. The air cleaning device according to any one of the preceding claims, wherein the filter is an electrostatic filter, an electrostatic precipitator, a fibrous media filter, or an electret filter.

8. The air cleaning device according to any one of the preceding claims, wherein the air mover is a mechanical fan, bellows, a convective airflow device or a centrifugal fan (a “blower”).

9. The air cleaning device according to any one of the preceding claims, wherein the pin-type electrode of the particle charger is supported on a support rod.

10. The air cleaning device according to claim 9 wherein two or more pin-type electrode are supported on a common conductor rod.

11. The air cleaning device according to any one of the preceding claims, wherein the pin-type electrode is in the form of a pin or in the form of a triangular tooth.

12. The air cleaning device according to any one of the preceding claims, further comprising a counter-electrode configured to be operable at a different electrical potential to that of the pin-type electrode in the particle charger.

13. The air cleaning device according to claim 12, wherein the counter-electrode is earthed.

14. The air cleaning device according to claim 12 or claims 13, wherein the counter-electrode is formed as a part of the particle charger.

15. The air cleaning device according to any one of claims 12 to 14, wherein the counter-electrode surrounds the pin-type electrode but is separated therefrom by a clearance.

16. The air cleaning device according to claim 15, wherein the pin-type electrode is substantially concentric with the counter-electrode.

17. The air cleaning device according to any one of claims 12 to 16, wherein the counter-electrode is comprised of a plate having an aperture therein.

18. The air cleaning device according to any one of claims 12 to 16, wherein the counter-electrode comprises a hollow cylinder formed of conductive material or having a conductive interior surface.

19. The air cleaning device according to claim 18, wherein the conductive interior surface of the counter-electrode is comprised of a conductive ink or paint.

20. The air cleaning device according to any one of the preceding claims, wherein the air mover is a centrifugal fan (a “blower”) and wherein the pin-type emission electrode of the particle charger is provided in a fluid intake of the blower.

21. The air cleaning device according to claim 20, further comprising a counter-electrode, wherein the counter-electrode is located in a fluid intake of the blower.

22. An air cleaning device substantially as hereinbefore described with reference to Figure 2, Figure 3, Figure 4, or Figure 5.

23. An air cleaning method for removing aerosol particles from an air stream, the method comprising:

generating air ions in the air stream using a particle charger comprising a pin-type electrode;

electrically charging aerosol particles in the air stream *via* their collision with air ions in a particle charging zone of the particle charger; and

moving the air stream towards a filter using an air mover, whereby electrically charged aerosol particles in the air stream are precipitated onto the filter wherein the air stream is moved through an intimate couple of the particle charger and the air mover prior to its arrival at the filter.

Amendment to the claims have been filed as follows

CLAIMS:

1. An air cleaning device for removing aerosol particles from an air stream, the device comprising:
   (a) a particle charger, comprising a pin-type electrode for generating air ions in the air stream, the particle charger having a particle charging zone within which, in use, aerosol particles in the air stream are electrically charged *via* collision with the air ions;
   (b) a filter for precipitating electrically charged aerosol particles from the air stream moving through the device; and
   (c) an air mover for moving the air stream through the device;

   wherein the particle charger and the air mover are provided upstream of the filter; and

   wherein the particle charger and the air mover are directly joined together in an airtight manner.

2. The air cleaning device according to claim 1, wherein the particle charger and the air mover are directly joined together as particle charger/air mover in the direction of air flow.

3. The air cleaning device according to claim 1, wherein the particle charger and the air mover are directly joined together as air mover/particle charger in the direction of air flow.

4. The air cleaning device according to any one of the preceding claims, wherein the filter is an electrostatic filter, an electrostatic precipitator, a fibrous media filter, or an electret filter.

5. The air cleaning device according to claim 4, wherein the electrostatic filter comprises an array of passages through which a gas stream can pass relatively freely, said passages being provided between plastics walls which have areas of conductive material in contact therewith, and means for applying high and low electrical potentials alternately to isolated areas of the conductive material to provide charged sites in the array for collecting particles from the gas stream.

6. The air cleaning device according to any one of the preceding claims, wherein the air mover is a mechanical fan, bellows, a convective airflow device or a centrifugal fan (a “blower”).

7. The air cleaning device according to any one of the preceding claims, wherein the pin-type electrode of the particle charger is supported on a support rod.

8. The air cleaning device according to any one of the preceding claims, wherein the particle charger includes a single pin-type electrode.

9. The air cleaning device according to claim 7 wherein two or more pin-type electrode are supported on a common conductor rod.

10. The air cleaning device according to any one of the preceding claims, wherein the pin-type electrode is in the form of a pin or in the form of a triangular tooth.

11. The air cleaning device according to any one of the preceding claims, further comprising a counter-electrode configured to be operable at a different electrical potential to that of the pin-type electrode in the particle charger.

12. The air cleaning device according to claim 11, wherein the counter-electrode is earthed.

13. The air cleaning device according to claim 11 or claim 12, wherein the counter-electrode is formed as a part of the particle charger.

14. The air cleaning device according to any one of claims 11 to 13, wherein the counter-electrode surrounds the pin-type electrode but is separated therefrom by a clearance.

15. The air cleaning device according to claim 14, wherein the pin-type electrode is substantially concentric with the counter-electrode.

16. The air cleaning device according to any one of claims 11 to 15, wherein the counter-electrode is comprised of a plate having an aperture therein.

17. The air cleaning device according to any one of claims 11 to 17, wherein the counter-electrode comprises a hollow cylinder formed of conductive material or having a conductive interior surface.

18. The air cleaning device according to claim 17, wherein the conductive interior surface of the counter-electrode is comprised of a conductive ink or paint.

19. The air cleaning device according to any one of the preceding claims, wherein the air mover is a centrifugal fan (a “blower”) and wherein the pin-type emission electrode of the particle charger is provided in a fluid intake of the blower.

20. The air cleaning device according to claim 19, further comprising a counter-electrode, wherein the counter-electrode is located in a fluid intake of the blower.

21. An air cleaning device substantially as hereinbefore described with reference to Figure 2, Figure 3, Figure 4, or Figure 5.

22. An air cleaning method for removing aerosol particles from an air stream, the method comprising:

generating air ions in the air stream using a particle charger comprising a pin-type electrode;

electrically charging aerosol particles in the air stream *via* their collision with air ions in a particle charging zone of the particle charger; and

moving the air stream towards a filter using an air mover, the particle charger and the air mover being directly joined together in an airtight manner, whereby electrically charged aerosol particles in the air stream are precipitated onto the filter wherein the air stream is moved through the directly joined particle charger and air mover prior to its arrival at the filter.

Intellectual Property Office

Application No: GB1518713.1 **Examiner:** Dr Alun Owen

Claims searched: 1-23 **Date of search:** 23 November 2015

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 3, 5-14, 17 and 23	US 2011/0171094 A1 (ZAHEDI) See Figure 1B
X	1, 3, 5-8, 11 and 23	CN 202263644 U (SHANTOU) See whole document noting fan 3, discharge needles 5 and filters 6, 7 & 8, the EPODOC Abstract and WPI Abstract Accession Number 2012-H82990
X	1, 3, 5-8, 11-12, 14 and 23	CN 203687216 U (SHANGHAI) See whole document noting fan 1, corona discharge needles 6 and filter 8, the EPODOC Abstract and WPI Abstract Accession Number 2014-R30267
X	1-2, 5-12, 14 and 23	KR 1020080024593 A (AE) See for example Figure 5 noting discharge needles 10, fan 50 and filters 70a, 70b, the EPODOC Abstract and WPI Abstract Accession Number 2008-M59852

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

A61L; B01D; B03C; F24F

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
B03C	0003/34	01/01/2006
B03C	0003/41	01/01/2006