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Whetten et al.

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[54] **AIR FILTER UTILIZING ALTERNATING CURRENT ELECTRIC FIELDS**

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[51] **Int. Cl.** **B03c 3/08**

[58] **Field of Search** .... 55/123, 124, 138, 55/139, 145, 149, 154, 137, 136, 108, 120, 101; 209/127 R

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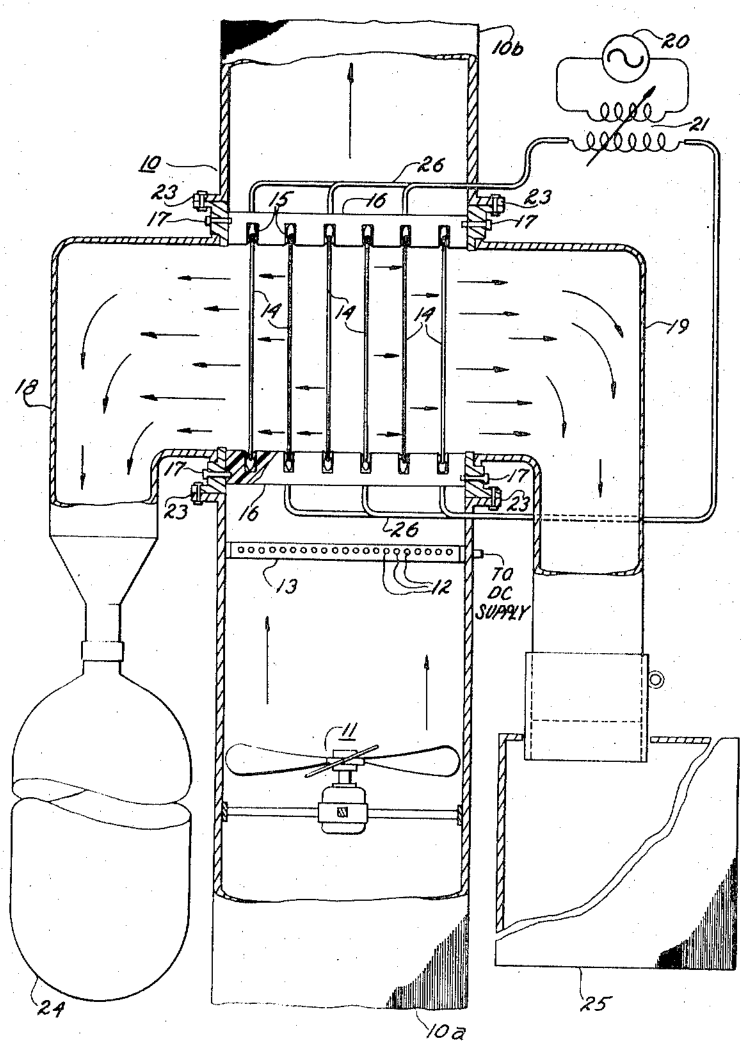
[57] **ABSTRACT**

A duct for the transmission of an air flow therethrough is provided with a plurality of parallel plates oriented parallel to the air flow. The plates have aligned holes therethrough and are connected to a source of alternating current voltage for generating alternating current electric fields in the region of the holes. The electrical forces generated by the electric fields trap charged particles in the air flow and direct them through the holes to the sides of the duct for collection and subsequent removal. The trapping of the particles is enhanced by coating the plates with a high dielectric strength material.

25 Claims, 5 Drawing Figures



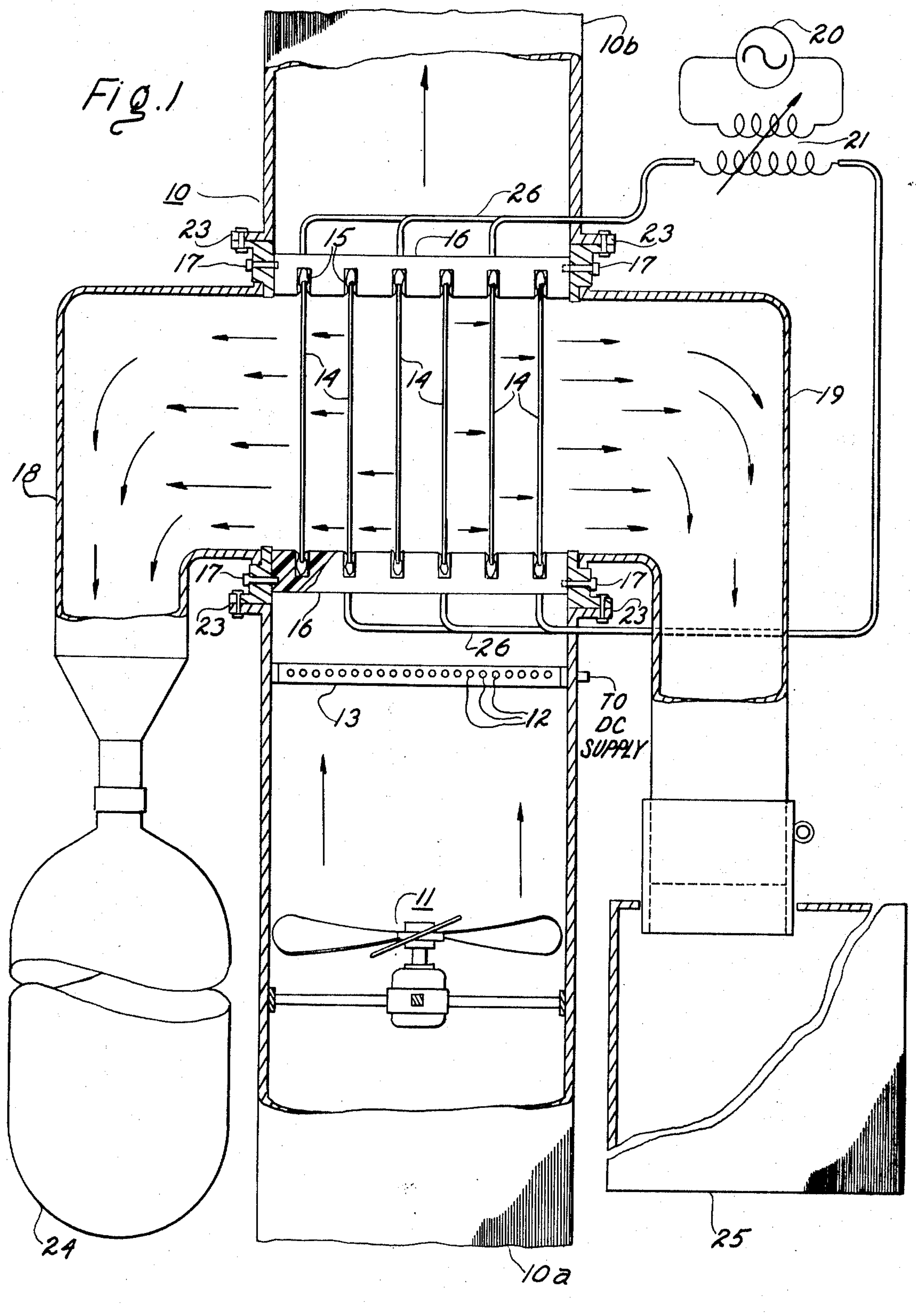


Fig.1
10b
20
21
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10a
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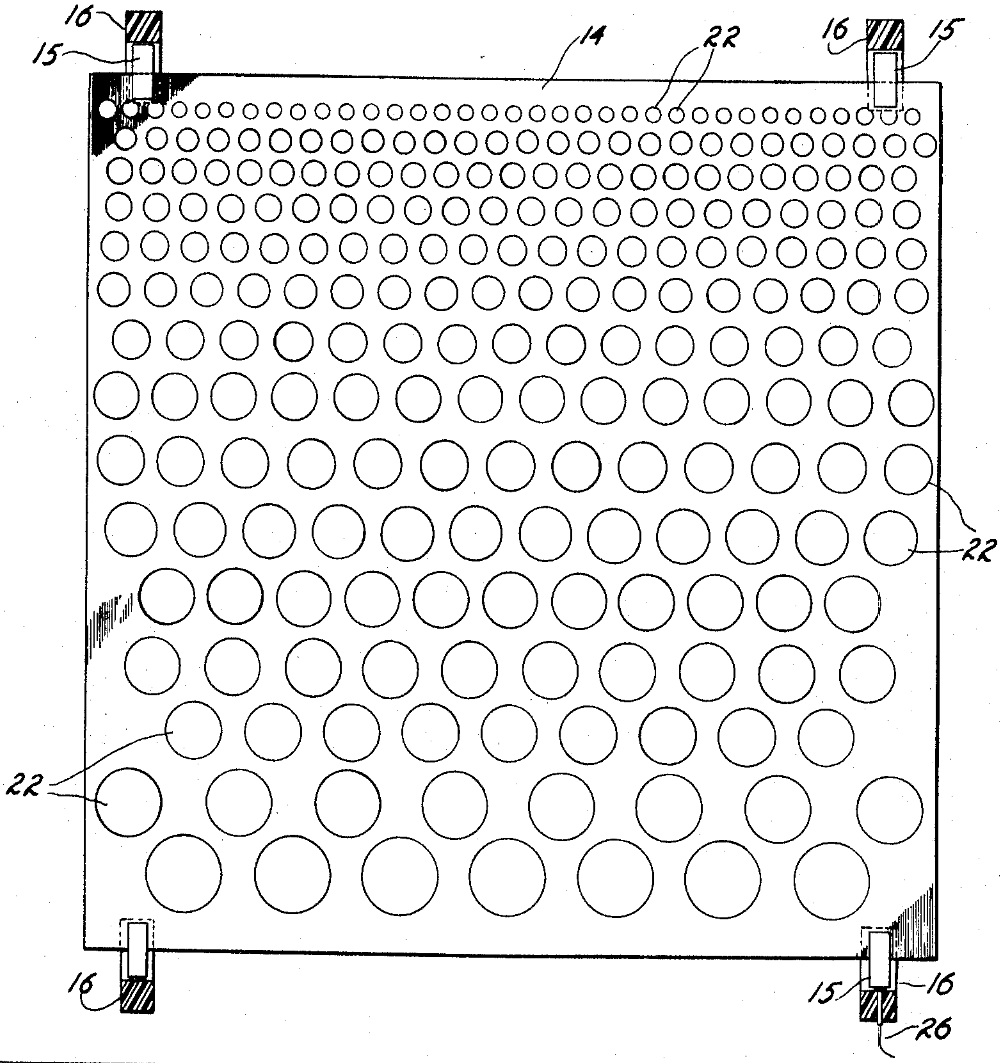
Fig. 2



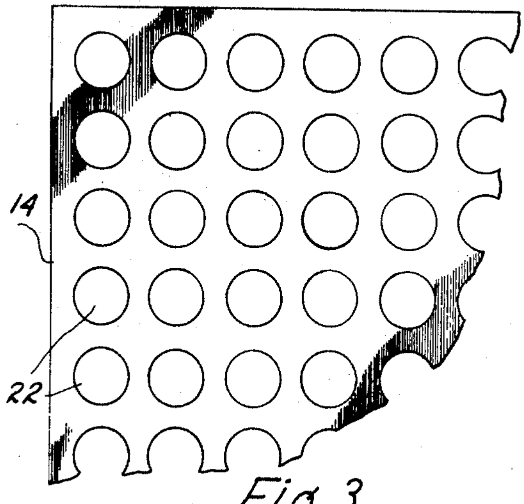


Fig. 3

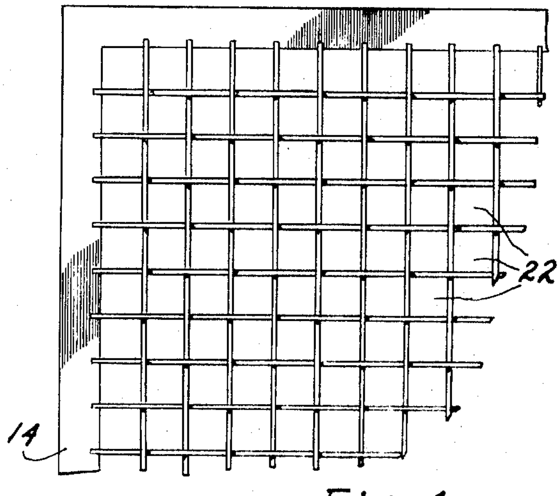
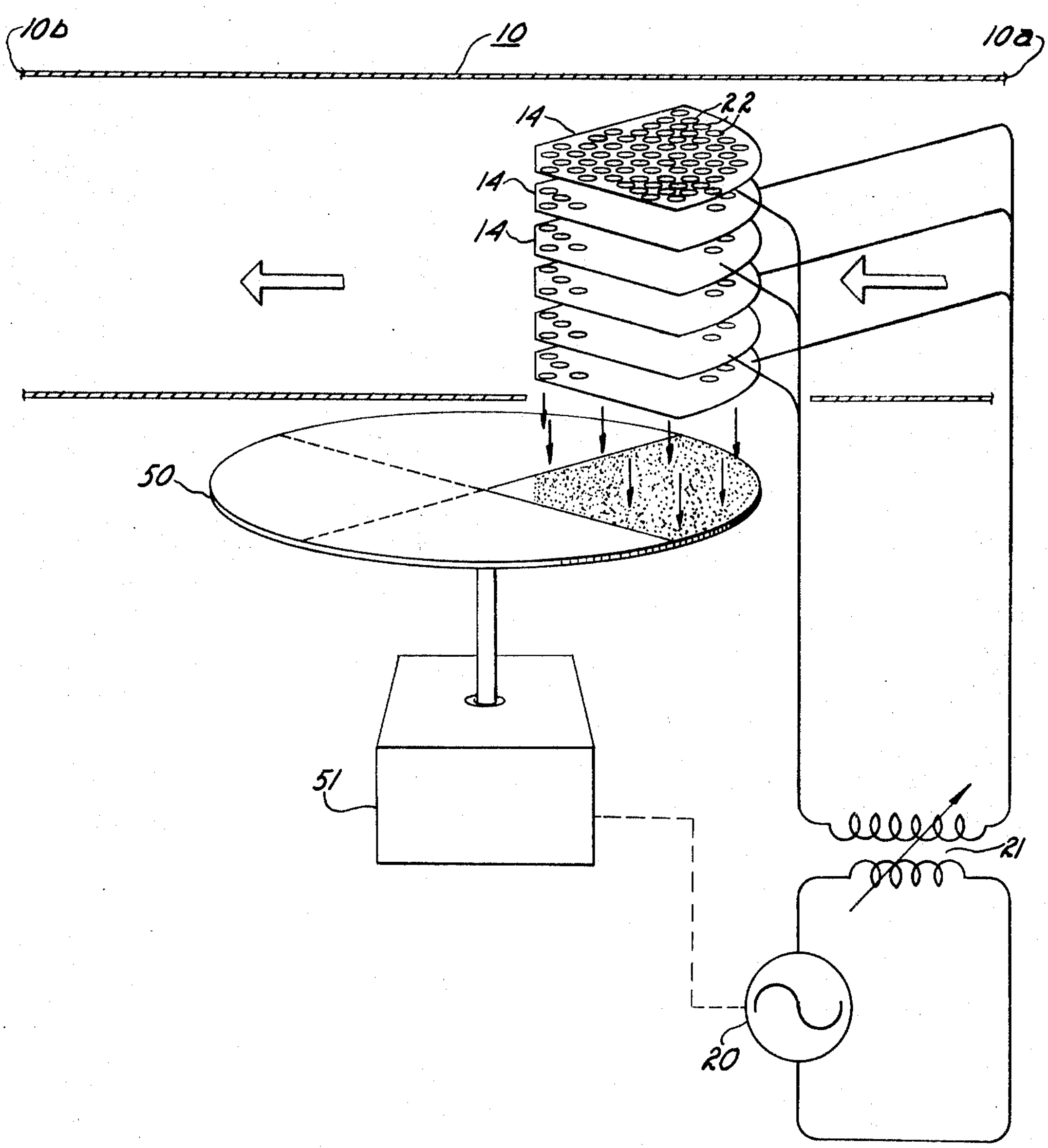


Fig. 4

Fig. 5



AIR FILTER UTILIZING ALTERNATING CURRENT ELECTRIC FIELDS

Our invention relates to a home appliance type air filter, and in particular, to an air filter which may be utilized as an adjunct to a room air conditioner for precipitating out particles from an air stream by the space trapping of charged particles in alternating current electric fields.

Home appliances such as room air conditioners are provided with filters which provide some degree of air filtration but in many cases such filter is inadequate. Various types of air filters are known and some of them undoubtedly may be utilized as an adjunct to room air conditioners, however, such filters generally remove only the larger size particles, i.e., having diameter dimensions in excess of 100 microns.

Electrostatic filters, also known as electrostatic precipitators of the direct current type, are known and are capable of precipitating out particles of size smaller than 100 microns. However, the charged particles in D.C. precipitators are driven into contact with electrode plates and build up a layer which must be removed periodically if the apparatus is to continue satisfactory operation. The layer of particles on the electrodes is usually removed by washing the filter. This procedure for the removal of the particles is inconvenient, time consuming, subject to damage and is obviously undesired.

Therefore, a principal object of our invention is to provide an air filter which traps particles in space rather than on the surface of an electrode.

Another object of our invention is to provide an air filter which is adapted to be an adjunct to a room air conditioner.

In accordance with our invention, we provide a home appliance in the form of an air filter which is suitable as an adjunct to room air conditioners. The invention utilizes the space trapping of charged particles in the filtering process and includes a duct having a first end through which an air flow is admitted. A plurality of electrical conductors distributed across the duct are connected to a source of high voltage D.C. potential for providing a corona discharge which charges particles in the air stream as they flow thereby. Further downstream in the duct are positioned a plurality of parallel plate members fabricated of electrically conductive material and oriented parallel to the axis of the air flow in the duct. The plate members are provided with aligned holes and are connected to an A.C. voltage source for generating A.C. electrodynamic fields across the duct. The electrical forces generated by the A.C. fields trap the charged particles in the air flow and direct them through the holes to sides of the duct from which they can be removed. The particle trapping is enhanced by coating the plate members with a high dielectric strength material which permits operation at higher A.C. voltage, which may be sufficiently high to produce corona discharge and charge the particles and thereby obviate the need for the separate conductors operated at high voltage D.C. The filter is especially well adapted for removing particles in the size range of 0.01 to 100 microns diameter.

The features of our invention which we desire to protect herein are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawings wherein like parts in each of the several figures are identified by the same reference character and wherein:

FIG. 1 is a top view, partly in section, partly in schematic form, of an air filter constructed in accordance with out invention;

FIG. 2 is a view taken along line 2—2 in FIG. 1 illustrating one of the particle trapping plates having unequal size holes formed therethrough;

FIG. 3 is a view of a portion of a second embodiment of the plate having equal sized holes formed therethrough;

FIG. 4 is a view of a portion of a third embodiment of the plate wherein such plate and holes is in the form of a square mesh; and

FIG. 5 illustrates the air filter adapted for analysis of particle size distribution.

Referring now to FIG. 1, there is shown a top view of our filter wherein a duct **10** encloses the filtering elements of our invention and has a first end **10*a*** for the admission of an air flow thereto and a second end **10*b*** for the exit of the air flow therefrom. The duct may be of various shapes, however, a square or rectangular cross section appears to be the most simple form and would generally be preferred, although a circular or other curved or noncurved cross section could also be utilized. A fan **11** which is typically motor driven is located adjacent the first end **10*a*** of the duct for producing the flow of air thereto. Fan **11** may be located within the duct **10** proper or outside the duct, in the latter case generally comprising the fan motor in a room type air conditioner. In the latter case, the first end **10*a*** of the duct is connected to the output end of the room air conditioner such that the air after passing through the air conditioner passes through duct **10** prior to exiting into the room. The flow of air produced by fan **11** may contain particles of various sizes which were not filtered out in the room air conditioner filter, and in particular, our air filter is especially well adapted for filtering out particles in the size range of 0.01 to 100 microns in diameter. It should be understood that our air filter is not restricted in its ability to filter out particles in only this size range as will be explained in detail hereinafter.

Downstream of fan **11** and located within duct **10** is a means for electrically charging the particles in the air flow. As one example, the electrical charging means may consist of a planar array of spaced parallel conductors **12** extending across substantially the total cross section area within duct **10** and oriented preferably normal to the axis of the air flow. Conductors **12** are preferably of equal size in the range of 0.002 to 0.05 inch in diameter and are preferably equally spaced apart in the range of 0.25 to 2.0 inch. Conductors **12** may pass separately through a wall of duct **10** but preferably are retained in an electrically insulated frame member **13** positioned along the inner surface of duct **10** as depicted in FIG. 1 and the ends of these conductors are connected to a common bus within duct **10** which passes through the wall for interconnection to a D.C. high voltage source which has a voltage output in the order of 10 to 20 kilovolts. Conductors **12** may be oriented vertically as shown in FIG. 1, or may be oriented horizontally, or at other angles, as desired. Duct

10 may be fabricated of an electrically nonconductive material such as plastic, or alternatively, of a conductive material such as aluminum or other metal. In the latter case, it is essential that electrical conductors 12 are electrically insulated from the walls of duct 10. The D.C. voltage applied to conductors 12 is sufficiently high to cause a corona discharge around each of the conductors which thereby electrically charges particles in the air flowing thereby.

Downstream of electrical charge producing means 12 are a plurality of plate members 14 positioned within duct 10 and oriented parallel to the air flow and which comprise the basic aspect of our invention. Plate members 14 are distributed across substantially the whole width of duct 10 and are of height dimension to extend along substantially the full height of the duct. Plate members 14 are each flat plates fabricated of an electrically conductive material such as aluminum or copper and are parallel both to each other and the side walls of duct 10. The plates 14 preferably, although not necessarily, are equidimensioned in width, height and thickness. Plates 14 are also generally equally spaced apart, this again not being a limitation. Plates 14 may be of any number of shapes, a square, rectangular or circular shape appearing to be the most convenient. Obviously, the orientation of plates 14 could be rotated 90° such that the plates are parallel to the top and bottom walls of duct 10 rather than to the side walls as illustrated in the top view of FIG. 1. The illustrated orientation of plates 14 is preferred since it permits a much simpler means for collecting the particles through both side walls of the duct rather than moving them through only the bottom wall or the bottom and top walls whereby passage through the top wall of the duct would necessitate means for counteracting gravity. Plates 14 are rigidly supported within duct 10 by any suitable means, and as one example, the four corners of each plate are gripped by clip devices 15 which are retained in four horizontally oriented members 16 attached to opposite side (or top and bottom) walls of duct 10 along the uppermost and lowermost portions thereof. Alternatively, members 16 may be two frame members retained along the inner surface of duct 10 and disposed perpendicular to the axis of the air flow. Screws 17 passing through opposite side walls of duct 10 into opposite ends of members 16 are one suitable means for attaching members 16 to the duct. Members 16 are obviously fabricated from an electrically nonconductive material such as a plastic in the case wherein duct 10 is fabricated of metal.

Plates 14 each have a plurality of holes 22 formed therethrough which are aligned with holes in the other plates. The holes may be of decreasing size in the downstream direction as illustrated in FIG. 2 or may be of equal size as illustrated in FIG. 3. In the case of the unequal sized holes, the embodiment with the holes in decreasing order of size in the downstream direction is preferred in order to precipitate out the larger size particles first through the larger holes, although our filter is also operable if the sequence of hole sizing is reversed. For purposes of ease in manufacture, the holes are formed through plates 14 in a plurality of rows wherein the orientation of a row is perpendicular to the direction of air flow in the duct. In the case of the plates having unequal sized holes 22 as depicted in FIG. 2, each row would have equal sized holes and subsequent (downstream) rows would have smaller but equal sized

holes. In the case of equal size holes 22 throughout the plate as illustrated in FIG. 3, such holes would be formed in aligned rows and columns. The size of the holes in either of the FIG. 2 or FIG. 3 embodiments is generally in the range of 0.25 to 1.0 inch and the spacing between adjacent holes is in the order of 0.5 diameter of one of the adjacent holes. The thickness of plates 14 may be approximately 0.05 inch, i.e., sufficient to provide rigidity of the plate member. The spacing between adjacent plates is in the range of 0.25 to 1.0 inch and is directly related to the size of holes in the plates, the larger size holes permitting greater spacing between adjacent plates. The length and height dimensions of plates 14 is obviously determined by the cross-sectional area within duct 10 and a typical plate dimension may be 1 foot by 1 foot.

Alternate (every second) plate members 14 are connected to the same side of an alternating current voltage supply 20 which preferably has its output voltage made adjustable by any suitable means such as a variable transformer 21 connected across the A.C. source. This alternate connection of plates 14 thereby provides that adjacent plates are connected to voltages of opposite polarity. The electrical conductors 26 which connect plates 14 to the A.C. supply may be brought out separately through a wall of duct 10, but preferably are connected to two common busses which pass through a wall of cut 10 for interconnection to the A.C. source. The A.C. supply voltage source may be in the range of 0.5 to 50 kilovolts at 60 Hz frequency, and a typical operating voltage is approximately 15 kilovolts. The application of the A.C. voltage to plates 14 generates alternating current electrodynamic fields around the holes 22 in the plates and electrical forces generated by the fields trap the charged particles in the air flowing by plates 14 and directs them via holes 22 to the nearest sidewall of the duct. The size of the trapped particles for a given set of parameters are not limited to a narrow range but may cover as much as five magnitudes in diameter size.

The electrical forces generated by the A.C. electrodynamic fields can be increased and the particle trapping enhanced by increasing the amplitude of the A.C. voltage applied to plates 14. However, there is a limit to which the voltage can be increased for a particular spacing of the plates before breakdown occurs between adjacent plates 14. We have found that operation at higher voltages without breakdown is achieved by coating the electrically conductive plates 14 with a high dielectric strength material such as a plastic or silicone. The coating thickness may be in the order of 1 millimeter or less and permits an increase in the voltage in the order of 50% or to the point where continuous corona discharge occurs in the region of the holes 22. Operation at the increased voltage increases the efficiency of particle trapping in a given particle size range as well as causing the trapping of larger size particles. Also, operation at a sufficiently high A.C. voltage to produce corona discharge will cause uncharged particles in the air flow to become charged and therefore obviates the need for the conductors 12 and their associated D.C. voltage supply. This operation at increased or adjustable voltage is provided by the variable transformer 21 described hereinabove.

In general, varying the spacing between adjacent plates 14 will vary the size of particles that can be trapped and directed through the holes and in particular, an increase in the spacing will result in the trapping of smaller size particles. A typical range of particle sizes which are trapped and removed by our filter is in the range of 0.01 to 100 microns in diameter.

The charged particles which are directed to the two opposite sides of duct **10** through holes **22** are removed and collected by any suitable means which results in collecting the particles from the duct. As one example, the collecting means may be a pair of ducts **18** and **19** connected at openings in the side walls of duct **10** and which are aligned with plated members **14** and approximately of the same size in entrance end cross section. Particle collecting ducts **18** and **19** are maintained in rigid attachment to the side walls of duct **10** by any means such as flanges **23** provided along the entrance edges of side ducts **18, 19** and along the cut-out portion of duct **10** which forms the communication with the side ducts. The use of flanges or other separable attachment means permit removal and servicing of plate members **14** and the electrical connections thereto, if this is found to be necessary. Alternatively, duct **10** may be fabricated of two separate spaced portions **10**a and **10**b and the entrance end of side ducts **18** and **19** have common top and bottom walls which respectively form the top and bottom walls of the intermediate portion of duct **10** when in place. In this alternative arrangement, flanges **23** permit the entire intermediate portion of duct **10** with plate members **14** to be removed for any servicing that may be required.

The particle collecting means also includes a suitable bag **24** or other container **25** connected to the exit end of ducts **18** and **19** as illustrated in FIG. **1**. The bag **24** or other container **25** is retained on the exit end of the side ducts in any manner adapted for ease of removal therefrom whereby such collecting device can be emptied and utilized again.

A third embodiment of the plate members **14** is illustrated in FIG. **4** wherein, instead of utilizing a plate with circular holes **22** formed therethrough, an electrically conductive screen or square mesh is utilized. Thus, a plurality of layers of the square mesh are oriented and retained in spaced apart relationship in the same manner as plates **14** depicted in FIG. **1** and are connected to the same source of A.C. voltage.

The electric field forces which provide stability in the direction along the radius of the holes **22** in the plates **14** are generally stronger than the lateral forces (i.e., along an axis perpendicular to plate members **14**). Thus, the motion of the particles when entering the stack of plate members **14** is interrupted by the strong radial forces, but once the particles are trapped, they have a greater freedom to move in the lateral direction into the side ducts **18, 19** since they are caused to vibrate in the holes with a lateral motion. However, in the case wherein the electrical field forces are such as not to provide adequate lateral vibration of the particles and passage to the side ducts, the A.C. voltage supplied by source **20** is modulated with a suitable sawtooth ramp voltage whereby an additional lateral force is impressed on the particles to cause the trapped particles to move to a side of duct **10** at which is located a side duct for the collection of the particles. The sawtooth ramp or sweep voltage can be integrated with the A.C. voltage in source **20** to form a single unit. For further enhancement of the lateral movement of the particles within the stack of plates **14**, the aligned holes **22** in the plates are not all of equal size as described hereinabove, but rather, the aligned holes are made larger in each subsequent plate relative to the centermost plate **14**. Thus, as the voltage is increasing (ramping up), the trapped particles become unstable in the smaller holes and move laterally to an adjacent more outer positioned plate **14** in order to achieve momentary stability in the larger holes therein before proceeding laterally to the next more outer positioned plate and eventually to the side duct. The larger size holes in adjacent plates relative to the centermost plate may be utilized with the plate members illustrated in FIGS. **2, 3** or **4**. Thus, in the case of unequal size holes in a single plate (FIG. **2**), the plates which are positioned closer to the sidewalls of duct **10** have unequal size holes which are slightly larger than the aligned holes in the adjacent plate that is positioned closer to the center of the duct. In like manner, in the case of equal size holes in a single plate (FIG. **3**), the holes in each subsequent plate from the centermost plate also contains equal size holes, but of increasing size relative to the centermost plate. Finally, in the case of a square mesh (FIG. **4**), the size of the mesh is increased slightly with each subsequent mesh from the centermost one.

FIG. **5** illustrates an embodiment of our invention which is adapted to sort the charged particles according to size and utilizes the sawtooth modulated A.C. voltage described hereinabove for providing higher electric filed forces in the lateral direction such that the charged particles are swept downward through the holes in horizontally oriented plate members **14** and through a hole in the bottom wall of duct **10** for impingment on a rotating disk **50**. Plate members **14** preferably have shapes similar to the sectors of the disk **50** and are of size approximately equal to the disk sectors. As one example, disk **50** is illustrated as being divided into four sectors, it being obvious that a lesser or greater number of sectors may also be utilized. The sweep (sawtooth) voltage is synchronized with the motor **51** driven rotation of disk **50** such that there is one sweep per revolution of the disk resulting in particles of a particular size (or narrow size range) emerging from the bottom of the stack of plate members **14** and always arriving on the same sector of the disk **50**. Particles of different sizes arrive at the disk at different times due to the particular mass of the particles crossing the stability limits of charged particle motion at different voltages. Thus, after several revolutions of disk **50**, the charged particles will be arranged around the disk in the order of size and this embodiment may therefore be utilized for analysis of particular size distribution, or, for collecting quantities of particles of a particular size.

From the foregoing description, it can be appreciated that our invention makes available an improved home appliance air filter which is especially well adapted as an adjunct to a room air conditioner for removing particles in the size range not generally removed by the passive type filters utilized in the air conditioner device. It should be understood that the room air conditioner mentioned herein is not limited to the window mounted cooling type device but is meant to include the pure fan type device as well as the conventional home heating and cooling system, especially hot air systems. Finally, our invention may also be used as an adjunct to applicances such as stoves for removing odors and to room electric heaters, as further examples of utility. Our air filter operates on the principal of trapping particles in an air flow in A.C. electrodynamic fields generated by plate members having holes therein and connected to an A.C. source. Having described several embodiments of our invention, it is obvious that other shapes of the plate members and distribution of the holes therein may be utilized to obtain the particle trapping effect and therefore it is to be understood that changes may be made in the particular embodiments as described which are within the full intended scope of the invention as defined by the following claims.

What we claim as new and desire to secure by Letters Patent is:

1. An air filter utilizing alternating current electric fields and comprising
a duct having a first end for the admission of an air flow thereto and a second end for the exit of an air flow therefrom,
means adjacent the first end of said duct for producing the flow of air which may contain particles especially in the size range of 0.01 to 100 microns in diameter,
means downstream of said air flow producing means and located in said duct for electrically charging the particles in the air flow, and
parallel planar means positioned in said duct downstream of said air flow producing means and oriented parallel to the air flow for generating alternating current electrodynamic fields, the electrical forces generated by the fields trapping the charged particles and directing them to at least one side of the duct for removal therefrom.

2. The air filter set forth in claim 1 and further comprising
means in communication with the sides of said duct to which the particles are directed for removing the particles from said duct whereby the air flow exiting from the second end of said duct has a significantly smaller amount of the particles as compared to the air flow admitted to the first end.

3. The air filter set forth in claim 2 wherein
said parallel planar means consists of a plurality of parallel aligned plates of electrically conductive material oriented parallel to the air flow and having aligned holes therein and connected to a source of alternating current voltage.

4. The air filter set forth in claim 3 wherein
alternate of said electrically conductive plates are connected to the same side of the source of alternating current voltage to thereby establish the alternating current electrodynamic fields.

5. The air filter set forth in claim 3 wherein
adjacent said electrically conductive plates are connected to opposite sides of the source of alternating current voltage to thereby establish the alternating current electrodynamic fields.

6. The air filter set forth in claim 5 wherein
said electrically conductive plates are equally spaced apart.

7. The air filter set forth in claim 5 wherein
the holes in said electrically conductive plates are of equal size.

8. The air filter set forth in claim 5 wherein
the holes in each of said electrically conductive plates are of decreasing size in the downstream direction of the air flow whereby the larger size particles are precipitated out through the larger size holes and the smaller size particles through the downstream smaller sized holes.

9. The air filter set forth in claim 5 wherein
each electrically conductive plate has a thickness of approximately 0.05 inch.

10. The air filter set forth in claim 5 wherein
the holes in the electrically conductive plates are in a diameter size range of 0.25 to 1.0 inch.

11. The air filter set forth in claim 5 wherein
the spacing between adjacent holes in each electrically conductive plate is approximately one-half the diameter of an adjacent hole.

12. The air filter set forth in claim 5 wherein
said electrically conductive plates are in spaced apart relationship across substantially the total cross-sectional area of the space within said duct.

13. The air filter set forth in claim 5 wherein
the alternating current voltage applied to said electrically conductive plates is in the range of 0.5 to 50 kilovolts.

14. The air filter set forth in claim 13 wherein
the alternating current voltage applied to said electrically conductive plates is approximately 10 kilovolts.

15. The air filter set forth in claim 5 wherein
the alternating current voltage source is an adjustable voltage source, an increase in the voltage applied to said electrically conductive plates resulting in an enhanced trapping and collection of the particles.

16. The air filter set forth in claim 5 wherein
said source of alternating current voltage includes modulating means for modulating the alternating current voltage with a sawtooth ramp for aiding the lateral movement of the trapped particles through the holes in the electrically conductive plates toward the sides of said duct.

17. The air filter set forth in claim 16 wherein
the aligned holes in said electrically conductive plates are of unequal size being of the smallest size in the centermost positioned plate and of gradually larger size in the subsequent plates positioned closer to the sides of said duct to thereby enhance the lateral movement of the trapped particles toward the sides of said duct.

18. The air filter set forth in claim 2 wherein
said particle removing means are two bags in communication with outlets formed through opposite sides of said duct in alignment with said parallel plates.

19. The air filter set forth in claim 2 and further comprising
means in communication with said particle removing means for collecting the particles and sorting them according to size.

20. The air filter set forth in claim 19 wherein
said particle collecting and sorting means is a rotating disk, the rotation of said disk being synchronized with a modulating sweep voltage applied to said parallel planar means whereby one cycle of sweep voltage occurs per revolution of said disk and the particles of a particular size emerging from said particle removing means arrive on the same area of said disk to thereby obtain analysis of particle size distribution.

21. The air filter set forth in claim 1 wherein
said particle electrical charging means comprises a plurality of electrical conductors disposed across said duct upstream of said parallel planar means and connected to a direct current high voltage source for producing a corona discharge around

said conductors which charges the particles as they flow thereby.

22. The air filter set forth in claim **1** wherein
said parallel planar means consists of a plurality of layers of square mesh of electrically conductive material supported in parallel spaced apart relationship and oriented parallel to the air flow, adjacent layers being connected to opposite sides of a source of alternating current voltage to thereby establish the alternating current electrodynamic fields.

23. An air filter adapted as an adjunct to a room air conditioner or the like and comprising
a duct having an admission end for an air flow and an exit end,
means for electrically charging particles which may be in the air flow, and
a plurality of parallel plate members fabricated of an electrically conductive material and positioned across substantially the total cross-sectional area of the inside of said duct parallel to the air flow, said plate members provided with aligned holes and alternately connected to opposite sides of an alternating current voltage source for generating alternating current electrodynamic fields across the duct, the electrical forces generated by the fields trapping the charged particles in the airflow in the duct and causing the charged particles to be directed through the holes to at least one side of the duct for subsequent removal therefrom.

24. The air filter set forth in claim **23** wherein
the admission end of said duct is connected to the output of a room air conditioner or the like, and
the plate members coated with a high dielectric strength material thereby permitting application of higher alternating current voltage to said plate members without causing breakdown between adjacent plate members and resulting in increased efficiency of particle trapping.

25. The air filter set forth in claim **23** wherein
the admission end of said duct is connected to the output of a room air conditioner or the like, and
said particle electrical charging means consists of a high dielectric strength material coating on said plate members thereby permitting application of a sufficiently high alternating current voltage to cause corona discharge in the region of the holes which charges the particles.

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