United States Patent

Gourdine et al.

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[54] **ELECTROSTATIC PRECIPITATOR SYSTEM**

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[52] **U.S. Cl.** **55/126,** 55/138, 55/139, 55/143, 55/145, 55/146, 55/152, 55/154

[51] **Int. Cl.** **B03c 3/01**

[58] **Field of Search**........55/136, 137, 138, 139, 142, 55/143, 145, 154, 150, 152, 124, 126, 146

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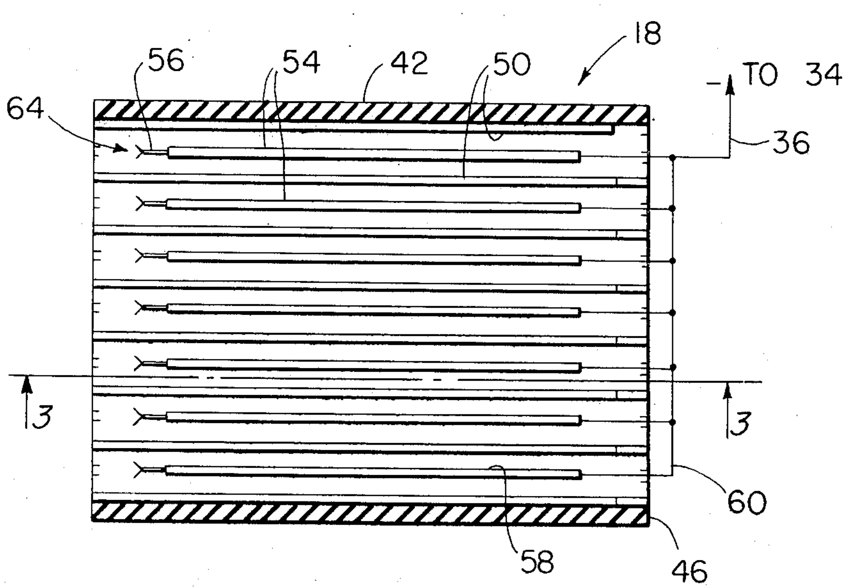
[57] **ABSTRACT**

An improved electrostatic precipitator device capable of significant size reduction having flat parallel plates consisting of an ionizing corona discharge portion as a unitary structure which is utilized to effectuate precipitation of entrained particles from an air stream onto the surface of a plurality of associated collection members, as an air stream containing entrained particles is cleaned in passing through the precipitator device. The ionizer discharge portion of the unitary structure comprises a plurality of substantially uniformly spaced apart sharp electrical conductive protrusions directed to alternate sides of the unitary structure; thereby forming a uniform ionization region with a parallel portion of the collector extending the full length of the ionizer. The remainder of each of the unitary structure functions as a passive electrode which cooperates with the remaining portion of the collector to form highly concentrated electrostatic fields therebetween for enhanced collection efficiency with minimum re-entrainment of the particles to be collected.

12 Claims, 6 Drawing Figures



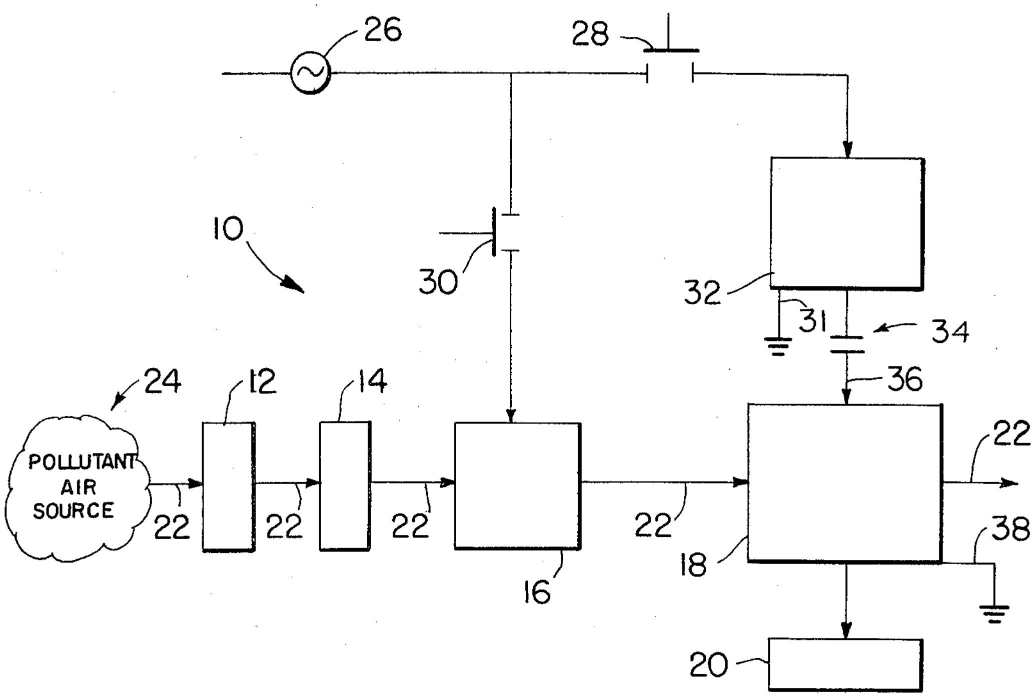


FIG. 1

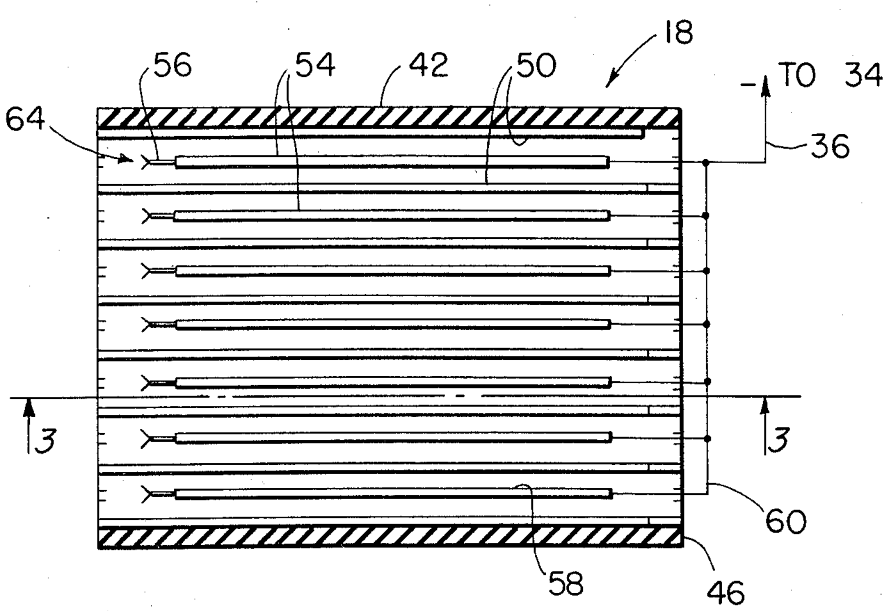


FIG. 2

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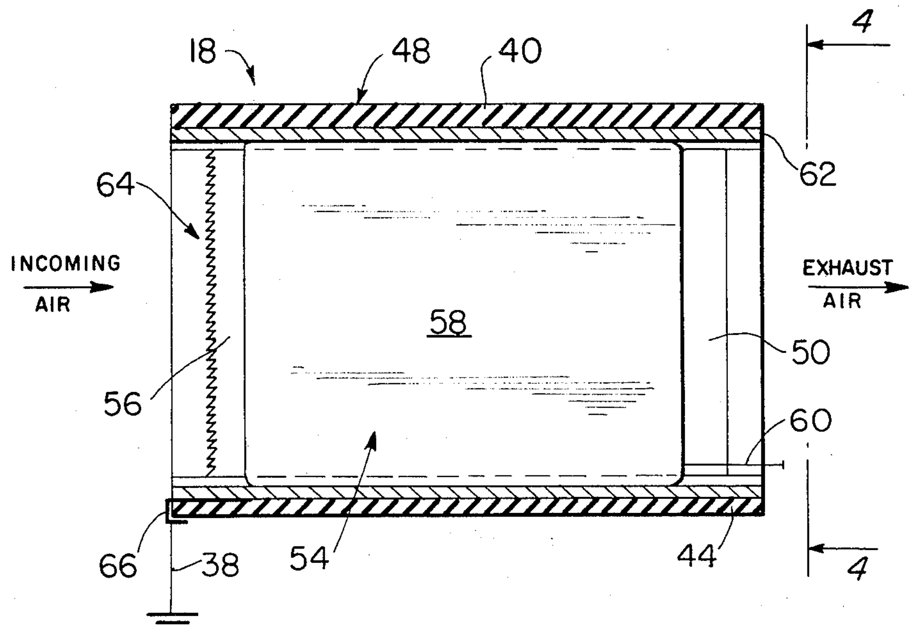

FIG. 3

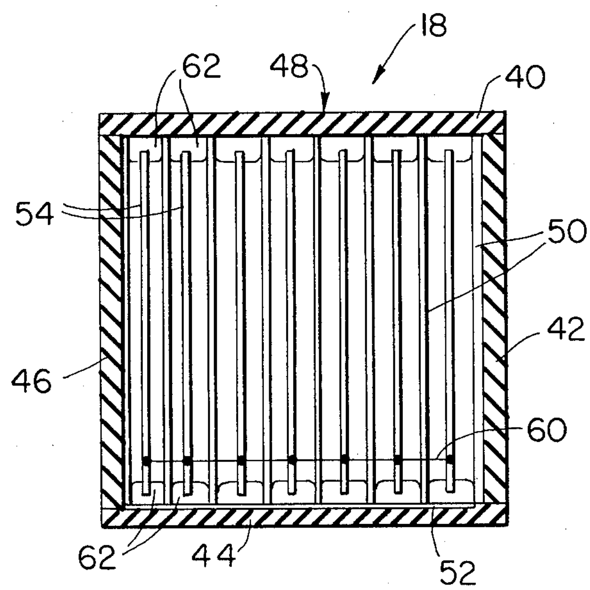

FIG. 4

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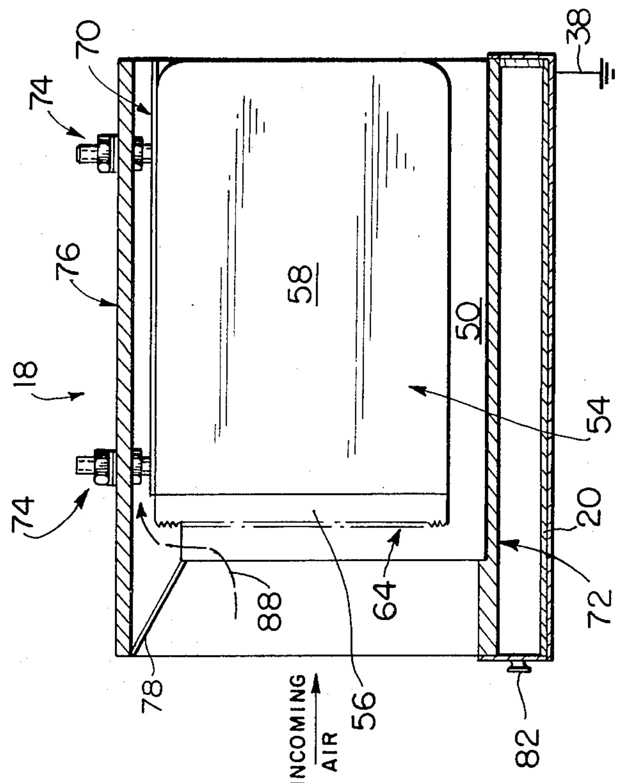

FIG. 6

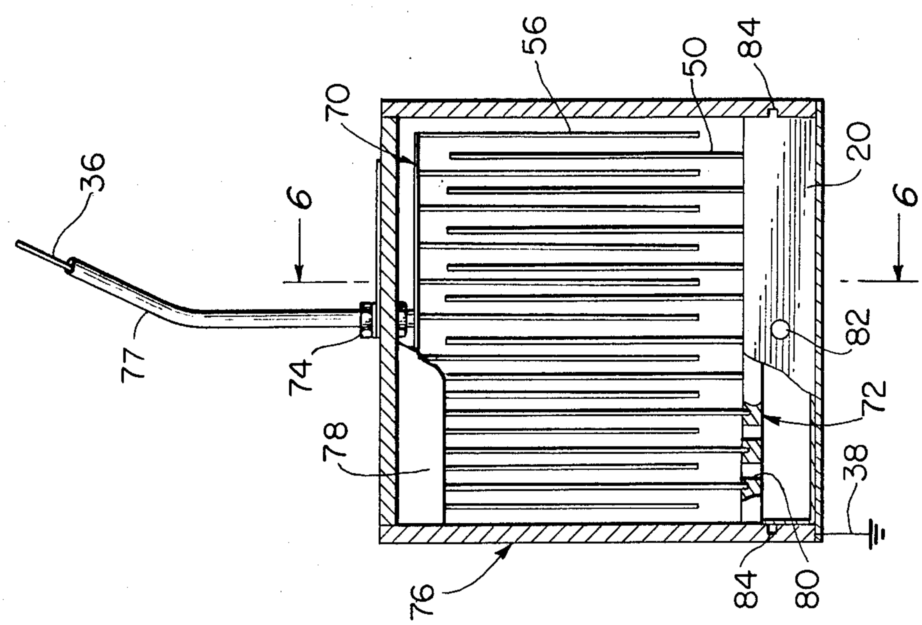

FIG. 5

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ELECTROSTATIC PRECIPITATOR SYSTEM

BACKGROUND OF THE INVENTION

In the prior art, electrostatic precipitators for the removal of entrained particles from air streams have employed upstream ionizer chambers in which the particles entrained in the air stream are electrostatically charged, followed by one or more separate downstream collection chambers containing collector plates upon which the charged particles are precipitated during the air cleaning process. The ionizer electrodes most widely and usually used for such precipitators consist of a plurality of very fine (small-diameter) wires, spaced-apart and spaced between relatively widely spaced non-discharging electrodes, commonly known as attractor electrodes. The non-discharging attractor electrodes have been either curved towards or away from the wires, or substantially flat, plate surfaces. In many cases, the flat plates are preferred for the non-discharge electrodes, since they are simpler, less expensive and easier to assemble and clean.

Still other arrangements have been employed, which utilize parallel plates in the collection region of the precipitator having polarities of appropriate sign to adjacent plates. Such typical arrangements are disclosed in U.S. Pat. Nos. 2,662,608 and 3,181,285. In both of these referenced patents, the ionization region for charging particles entrained in an incoming air stream is separated from the collection region, which consists of a plurality of collector electrodes disposed in the path of the air stream with opposite polarities imposed upon adjacent collector electrodes. The primary distinction between the devices in the cited references is the arrangements in the ionizer. In U.S. Pat. No. 2,662,608, the ionizer includes a series of longitudily strung fine wires, while in U.S. Pat. No. 3,181,285, the ionizer is a single steel needle element positioned on the center line of the air inlet tube which functions as the attractor electrode.

The present invention overcomes several obvious disadvantages of the prior art arrangements, one of which arises from the fact that the ionization regions and the precipitation (collection) regions are in separate chambers. Another disadvantage occurs as a result of the charged particles precipitating out onto the surrounding walls of the attractor electrode, that is, the walls of the attractor electrode adjacent to the ionizer electrode in areas which are not accessible for cleaning. Precipitation of particles on the attractor walls in the ionizer section tends to reduce the ionization level in the ionizer region, which in turn, reduces the effectiveness and efficiency for charging the entrained particles in the air stream. In addition, owing to the non-uniform distribution of precipitated particles onto the walls of the attractor, the uniformity of corona discharge along the length of the corona wires will be non-uniform, which in turn, leads to non-uniformity of charge imparted to the particles.

Still another disadvantage arises from the discovery that when the precipitator device is constructed with rather narrow spacing between the corona wires and the attractor electrode, significant electrical arcing or shorting between the two electrodes may occur from the non-uniform deposition of particles on the attractor walls or from being deposited on the corona wires. The occurrence of such arcing substantially reduces the efficiency of operation and, in many cases, when continuous shorting occurs, it may cause the precipitator to become totally inoperative.

Another disadvantage of having the ionizer and the collection chambers separated, as is the case in the prior art, arises from the fact that there is a difference in electric field patterns in the "transition region" between the ionizer region and the upstream end of the collector electrodes. In various cases the electrodes in the collector region may have polarities or potentials different from that of the ionizer electrodes. Such differences may tend to create electric field conditions in the "transition region," which may often cause the charged particles to act in an undesirable and unpredictable manner, and thereby cause non-uniformity of collection in the specific regions designated for such collection. The exact nature of these undesirable effects are not clearly understood; however, the adverse effects of their occurrences have been observed and have been found to be objectionable for the manufacture of commercially acceptable and reliable apparatus.

Still another apparent disadvantage of the prior art arrangement of having the ionizer and collection chamber separated arises from the fact that such arrangements may cause the precipitator to be larger in size than may be desired or required to handle a preselected volume of air to be cleaned. More specifically, in certain applications for example, in a home kitchen range hood air cleaner utilized for cleaning the air in a kitchen, which has become polluted from the cooking process, it has been found for many years to be uneconomical and also requires too much space in the kitchen area to make it feasible to employ such large size prior art precipitators as a means for removing such air pollutants as smoke, grease particles, and odor from the kitchen environmental air, solely because of the large physical size requirements for such purposes with prior art devices. In addition, it is well recognized that such two-stage systems are incapable of effectively removing both submicron smoke, grease particles, and odors in a single-unit. This is apparently so because the two-stage units are handicapped in not being able to adequately handle large size particles.

SUMMARY OF THE INVENTION

In accordance with the present invention, the air cleaning precipitator device is constructed such that the ionization and the collector regions comprise what may be termed as a "continuous system," without a "-transition region" between such functional chambers. More specifically, in one embodiment of the present invention the precipitator comprises at least one unitary substantially flat plate member, essentially consisting of an ionizer electrode section, extending toward the upstream end of the precipitator and a passive electrode section, extending from the ionizer section toward the downstream end of the precipitator. For each unitary plate member there is positioned on opposite sides thereof a substantially parallel and co-extensive collector electrode, having an upstream portion thereof which extends past the ionizer electrode on opposite sides thereof in the direction opposite to the incoming air stream. In the region between the upstream end of the collector electrodes, adjacent to the ionizer there is formed a corona discharge, whereby the entrained particles in the air stream are charged.

The ionizer and passive electrodes are at the same electrical potential with respect to ground and polarity, while the collector electrodes are at a different electrical potential with respect to ground and polarity than the corona and passive electrodes. In many instances the collector electrodes are at ground potential. These differences in polarities and potential cause a corona discharge and electrostatic fields to be formed, respectively, between the ionizer and the upstream end of the collector and between the passive electrode and the remainder of the collector for enchanced collection efficiency and to substantially reduce particle re-entrainment.

In addition, it has been found that precipitators operated and constructed in accordance with the present invention are capable of precipitating particles of both large and small (submicron) sizes, produced during the process of cooking foods. Still further, it has been observed by olfactory or smelling tests, that the odor levels produced during cooking processes are significantly reduced. A complete understanding of these observations can not be readily explained; however, it is believed that the close proximity of the ionization and collection regions in the precipitator enables more efficient charging and collection of these large size particles or the agglomeration of small particles to which gaseous odor attach and are removed. This has not heretofore effectively been done.

A further explanation of the precipitation process is based upon the belief that the collection of both large and small particles is in part due to "turbulence" created in the ionizer region which is evidenced by an enhancement of the "corona wind" produced therein.

In another embodiment of the invention the unitary ionizer and passive collector electrodes are each constructed in the form of unitary structures in an interleaved manner. In the embodiment the combination ionizer and passive electrode structure is disposed within the precipitator in a fashion so as to avoid possible collection of particles thereon and thereby reducing, if not eliminating, the occurrence of shorting out of the combined ionizer and passive electrode structural member.

Another important feature of the present invention arises from the fact that a precipitator device may be constructed in a significantly smaller-size volume unit, while still being capable of handling as large a volume of air to be cleaned of pollutants as that of the prior art two-chamber devices. Still further, the unitary combination structure for an ionizer and passive electrode is adaptable to multiple-stage arrangements in a minimum amount of space to add greater air cleaning efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

The realization of the above features and advantages along with others of the invention will be apparent from the following description and the accompanying drawings in which:

FIG. 1 is a schematic, illustrating the precipitator being utilized as a component of a ventilator precipitator system;

FIG. 2 is a diagramatic cross-section, illustrating a top view of an embodiment of the invention;

FIG. 3 is a diamgramatic cross-sectional view taken along line 3—3 of FIG. 2, illustrating a side view;

FIG. 4 is a diagramatic cross-sectional view taken along line 4—4 of FIG. 3, illustrating a back view;

FIG. 5 is a diagramatic cross-section, illustrating another embodiment of the invention; and

FIG. 6 is a diagramatic cross-sectional view taken along line 6—6 of FIG. 5, illustrating a side view.

DESCRIPTION OF REPRESENTATIVE EMBODIMENTS

In FIG. 1, a representative embodiment of an electrostatic air cleaning precipitator constructed in accordance with the present invention is included as a component device of a ventilator air cleaning precipitator system. The precipitator system **10**, includes first and second filters **12** and **14**, a blower fan **16**, and a precipitator device **18**, having an associated sump **20**, for collecting liquids. The first and second filters, the fan and precipitator device, are disposed along a path **22** of an incoming air stream, illustrated as a pollutant air source **24**, containing entrained particles and odors to be removed. Such entrained particles may be in the form of dust, grease, steam, smoke, pollen, and the like, many of which may be of the submicron size.

Also included in the system **10** is an electrical source of alternating current (A.C.) power **26**, push-button interlock switches **28** and **30**, respectively, for interconnecting with a direct current (D.C.) power supply **32** and fan **16**. The D.C. power supply **32**, is connected to precipitator device **18**, through a convenient circuit disconnect **34**, along conductor **36**, while the precipitator is grounded by conductor **38**, and the power supply **32** is grounded by conductor **31**.

The operation of the system is initiated by closing the switch **30** to connect A.C. source **26** to fan **16**. When energized, the fan draws pollutant air **24** into the system along path **22**, through the first and second filters **12** and **14**. It should be noted that the filters are not absolutely required for suitable operation but may be preferred for certain applications. The partially filtered air is then blown into the inlet end of the precipitator **18**, and is exhausted out through the outlet end thereof after having been cleaned. The manner in which the precipitator **18** is constructed and operates will be discussed in greater detail with reference to FIGS. **2–4**.

Referring now to FIGS. **2–4**, wherein like characters in each view are given the same reference designations, there is shown the precipitator **18**, which includes four insulator frame members **40–46**, connected to form a rectangular support frame **48**. Within the walls of the frame **48** are a plurality of parallel disposed spaced-apart elements, essentially comprised of alternately spaced conductive substantially flat collector plate members **50**, which are electrically interconnected by grounding bridge wire **52** (see FIG. **4**) a plurality of unitary plate members **54**, each having an ionizer electrode **56** at the upstream end and a passive electrode **58** extending from the ionizer electrode **56** to the downstream end. The upstream end of the device is adjacent to the incoming air, while the downstream end is near the exhaust air outlet. Each of the unitary plate members **54** is electrically interconnected by a bridging conductive member **60**.

Referring specifically to FIG. **4**, it can be seen that each unitary plate member **54** is electrically insulated from each collector electrode by a series of grooved insulation support members **62**, which extend the full length of the frame **48** (also see FIG. **3**). These insulative support members **62** are positioned at both the top and the bottom of the frame **48**, adjacent frame members **40** and **44**. However, it should be recognized that these insulative support members **62** may be included as an integral part of adjacent frame members **40** and **44**.

Referring now to FIGS. **2** and **3**, the physical configuration of the ionizer electrode **56** is shown in greater detail. As shown in the drawings, a saw-toothed edge member **64**, forms the active corona discharge tips or points for the electrode. In contrast to the fine wire or single tip corona needle most commonly utilized in the prior art, the present ionizer electrode is provided with multiple corona discharge points, for which the corona discharge may advantageously be maintained. Upon closer inspection with reference to FIG. **2**, it can be seen that the saw-blade configuration of the ionizer electrode has a "set," that is, alternate teeth of the saw-blade member point to opposite sides of the corona discharge region.

The unique-feature of the "set" in the corona teeth or tips of the corona electrode **64** enable the corona discharge to be substantially uniformly distributed in a fixed manner along the entire length of the structure and corona discharge region. In general, it is believed that the individual teeth of the saw-blade structure are capable of substantially independent operation, and, thereby providing a structure of novel functional capabilities. In contrast to the single fine-wire electrode commonly employed in the prior art, the saw-blade configuration **64** of the present invention provides several advantages. Firstly, it provides multiple needle points for independent high current paths, such that any entrained particles which may be collected thereon may be burned off readily by high currents drawn by the points of the teeth. Secondly, the needle points are staggered from point to point, such that substantially fixed uniform corona discharge exists along the entire length on either side thereof when negative corona is utilized whereas, if the corona electrode was a fine wire the corona discharge therealong when negative corona is utilized would not always be in fixed positions, but would vary in their position depending on whether or not there was a build-up of impurities on the wire, thereby causing a significant degradation of performance.

Thirdly, as illustrated in FIG. **2**, the ends of the needle points are located outward of the sides of the plate members **54** so as to be closer to the collector electrodes **50** than any other point on the plate members **54**. This prevents or greatly deters the creation of corona conditions between impurities settling on downstream areas of the plate members **54** and the opposed collectors **50**, and thereby further ensures proper ionizer performance.

In conclusion, the precipitator device **18** may be considered completed by the presence of a grounding shim **66**, which is shown in FIG. **3**, as being connected to conductor **38**, and then to ground potential. The grounding shim **66** is connected to all of the collector electrodes **50**, so as to place them at ground potential with respect to the polarity of the unitary member electrodes **54**, which are connected to another polarity with respect to ground by conductor **36**, which is connected to the D.C. power supply **32**. The D.C. power supply is also grounded on one side. The polarity of the ionizer may be either positive or negative with respect to ground for operation. However, in practical operation of the precipitator, it has been found that the use of a negative potential is preferred.

In operation, the precipitator device **18**, in the representative embodiment of FIGS. **2–4**, has the unitary members **54**, including the ionizer **56** and the passive electrode **58**, at a negative potential with respect to ground potential and the collector electrodes **50**, which, as noted, are connected to ground potential by means of shim **66** and conductor **38**.

Such connections produce a negative corona discharge in the upstream portion of the device between the saw-blade teeth section **64** of the ionizer **56** and the upstream end of collector electrode **50**. Between the passive electrode **58** and the remainder of the collector electrodes **50**, there is produced a strong electric field on the non-corona discharge type.

The incoming pollutant air **24** carrying both large and small particles and odors, which were not filtered out by the first and second filters, enters the corona discharge region adjacent to the saw-blade teeth **64**, where they pick-up negative charge from ions in the corona discharge, either by diffusion charging or electric field charging. In general, the larger particles acquire their charge by electric field charging, while the smaller particles, such as submicron particles, acquire their charge principally by diffusion charging.

It is noteworthy to observe that diffusion charging is known to occur more readily when there is "corona wind" such as that generated by the saw-blade teeth ionizer in the present invention which causes turbulence in the ionization region. With the saw-blade arrangement of the present invention, it is believed that greater "corona wind" is generated than heretofore known in compact precipitators. Thus, high efficiency in the present device is caused in part by the "corona wind." The turbulence caused by such corona wind can cause an increase in the residence time of the particles in the ionization region and an increase in the particle size due to agglomeration resulting from the presence of turbulence. Both of these effects will result in a much higher charge per particle level on those particles entering the collection region of the device. The above mentioned turbulence can also cause an increase in particle collection in the collection region of the device due to the transport of charged particles to the collector walls as a result of what may be termed "large scale" turbulence.

Referring now to FIGS. **5** and **6** there is shown another embodiment of the invention wherein the precipitator **18** has disposed therein a unitary structure **70**, including a plurality of combination ionizers **56** and passive electrodes **58**, and a unitary structure **72**, including a plurality of collector electrodes **50** forming an interleaving arrangement therebetween. The unitary structure **70** is disposed within the precipitator **18** by at least two stand-off electrical connectors **74** which are supported by a housing enclosure **76** of the precipitator. Connected to one of the connectors **74** is a cable **77**, including the conductor **36**, for applying a D.C.

potential to the combined ionizer and passive electrode as discussed hereinabove. The remainder of the device, which is metal, including the collector electrode structure 72, may be connected to ground potential by the conductor **38**. Also shown in FIG. **5** is a deflection baffle **78** disposed in the upstream end of the precipitator **18** and a sump **20** as an integral component of the precipitator **18** with a plurality of gravity-flow apertures **80** opening into the sump **20** for permitting the flow of liquids from the precipitation region to the sump. For convenience the sump **20** is in the form of a drawer, is slidably removable by pulling a knob **82**, and is guided along support guide grooves **84**.

In FIG. **6** the relative space relationships of the elements of the precipitator **18** may be seen more clearly. Baffle **78** may be deflected at an angle to the flow of air through the device, and has been disposed with respect to the ionizer **56** and passive electrode **58** to prevent any air from flowing along a path indicated by a curved broken-line arrow **88**. This arrangement insures that no entrained airborne particles are collected on top of the unitary structure **70**, where they may cause shorting between structure **70** and the enclosure **76**, which is at ground potential while the structure **70** may be at high negative potential.

The electrical operation of the precipitation shown in FIGS. **5** and **6** is essentially the same as that discussed hereinabove with respect to other embodiments. However, it should be noted that the illustrated arrangement has the very important advantage of eliminating the possibility for shorting between the elements which may occur readily if there are conductive particles in the pollutant air source.

Thus, it can be readily appreciated that the present invention has several additional advantages over prior art precipitator arrangements. The most noticeable one being its ability to collect particles of all sizes more effectively and efficiently in a smaller package. Another advantage of the invention is the elimination of the two-chamber precipitator arrangements, which enable the device to be built economically and compactly, in contrast to prior art devices. Precipitators in accordance with the present invention have been built, tested, and compared with data covering existing commercial precipitators. The results of several comparisons are set forth below in a table:

Commercial Precipitator Example	Capacity in Cubic Foot Per Minute	Frontal Area	Thruput in Cubic Foot/ Min/Square Inch
1	1400	21¼"×17½"	3.86
2	2800	21¼"×36¾"	3.58
3	800	16 1/16"× 11 11/16"	4.20
4	1200	27⅞" × 11¾"	3.66
5	2000	31½" × 16 7/16"	3.86
Present Invention	600	5¼" × 5¼"	21.60

From the foregoing data illustrating comparisons, it is believed that the precipitator, in accordance with the present invention, is capable of cleaning approximately five times as much air per unit time per unit cross-sectional area as prior-art commercial air cleaning apparatus.

The foregoing would certainly support the belief that the present invention is capable of greater efficiency per unit frontal area and is adaptable to compactness in packaging in its construction.

Still another advantage may be derived from the present invention, namely, that of making the precipitator a multiple-stage device by placing two or more of the unitary plate members **54** in series, such that the upstream end of the passive electrode is far enough removed from the next succeeding ionizer sawblade element **64** not to interfere with the corona discharge to be produced with such positioning. It is obvious that under certain conditions, it may be highly desirable to utilize such a multiple-stage precipitator, such as, for example, where greater air volume capability is required along with minimum volume and size of precipitator device. For example, the efficiency of the precipitator may be increased by staging the unitary plate members in series along the flow path of air while capacity in terms of cubic inches of flow per minute (CFM) may be increased by adding units in parallel to the flow path of the air stream.

Finally, the simplicity of construction of the present invention offers another advantage for economy of manufacture for commercial use.

It will be understood by those skilled in the art that the above-described embodiments are intended to be merely exemplary, in that they are susceptable to modification and variation without departing from the spirit and scope of the invention. For example, it will be apparent that the precipitator of the present invention may be adapted for high-pressure oil separation systems, vacuum cleaners and other numerous air pollution control devices. All such modifications and variations, therefore, are intended to be included within the scope and spirit of the invention, as defined by the appended claims.

What is claimed is:

1. An electrostatic precipitator for removing particles entrained in a fluid stream comprising;
   - a housing having a fluid inlet and a fluid outlet and forming therebetween a flow path for the fluid stream;
   - at least one plate electrode member positioned transversely of the flow path and extending in a direction generally parallel to the direction of flow from an upstream end adjacent the fluid inlet to a downstream end adjacent the fluid outlet;
   - a plurality of pointed members spaced along the upstream end of each plate electrode member and extending upstream therefrom at an acute angle to the longitudinal centerline of the electrode member, said pointed members being symmetrically disposed on opposite sides of said longitudinal centerline;
   - a plate collector electrode positioned on either side of each plate electrode member in generally parallel relation thereto, each collector electrode having an upstream end located upstream of the pointed members of the adjacent plate electrode member and a downstream end located adjacent the downstream end of said plate electrode member; and
   - means for establishing a potential difference between each plate electrode member and the adjacent collector electrodes productive of (1) a corona discharge between each pointed member and the opposed region of each collector electrode that is directed in substantial part against the direction of flow and (2) a nondischarging precipitation field

between the region of each plate electrode member downstream of the pointed members and the opposed region of each collector electrode.

2. An electrostatic precipitator as defined in claim 1 wherein a plurality of said plate electrode members are positioned within the flow path in spaced-apart generally parallel relation, and said plurality of electrode members are connected together at one edge thereof to form a first unitary plate assembly in parallel array.

3. An electrostatic precipitator as defined in claim 2 wherein the collector electrodes positioned on opposite sides of said plate electrode members are connected together at one edge thereof to form a second unitary plate assembly in parallel array.

4. An electrostatic precipitator as defined in claim 3 wherein said potential difference establishing means includes means for electrically grounding said collector electrodes and means for applying a negative potential to said plate electrode members.

5. An electrostatic precipitator as defined in claim 1 further comprising sump means for receiving and storing particles precipitated from the fluid stream.

6. An electrostatic precipitator as defined in claim 5 wherein each plate electrode member and collector electrode is vertically disposed within the housing; and

the housing further includes a member forming a lower boundary for the flow path, said member having formed therein a plurality of apertures, and sump means positioned below said member for receiving therethrough particles precipitated from the fluid stream.

7. An electrostatic precipitator as defined in claim 6 wherein the collector electrodes are supported in parallel spaced relation to the associated plate electrode members by the lower boundary forming member.

8. An electrostatic precipitator as defined in claim 6 wherein:

a plurality of plate electrode members are positioned within the flow path;

said plurality of electrode members are connected together at their upper edges so as to form a first unitary plate assembly in parallel array; and

the collector electrodes associated with said plurality of plate electrode members are connected together at their lower edges by the lower boundary forming member so as to form a second unitary plate assembly in parallel array, the plates of the first and second assemblies being interleaved.

9. An electrostatic precipitator as defined in claim 1 wherein the upstream ends of said pointed members extend outward of the sides of the associated plate electrode member so as to be positioned closer to the adjacent collector electrodes than any other part of the electrode member.

10. An electrostatic precipitator as defined in claim 1 wherein alternately spaced ones of said pointed members are disposed on opposite sides of the longitudinal centerline of the electrode member.

11. An air cleaning system for treating environmental air in a building enclosure, including means for flowing the environmental air through the system, a mechanical air filter at an upstream location within the system and an electrostatic precipitator for electrostatically removing particulates from the air at a downstream location within the system, wherein the improvement comprises;

at least one plate electrode member positioned within the precipitator to extend from a upstream end adjacent the precipitator inlet in a direction generally parallel to the direction of flow to a downstream end adjacent the precipitator outlet, said upstream and downstream ends of each plate electrode member thereby extending transversely of the direction of flow;

a plurality of pointed members spaced along the upstream end of each plate electrode member and extending upstream therefrom at an acute angle to the longitudinal centerline of the electrode member, said pointed members being symmetrically disposed on opposite sides of said longitudinal centerline;

a plate collector electrode positioned on either side of each electrode member in generally parallel relation thereto and having an upstream end located upstream of the pointed members of the adjacent electrode member and a downstream end adjacent the downstream end of said electrode member; and

means for establishing a potential difference between each electrode member and the adjacent collector electrodes productive of (1) a corona discharge between each pointed member and the opposed region of each collector electrode that is directed in substantial part against the direction of flow and (2) a nondischarging precipitation field between the region of each electrode member downstream of the pointed members and the opposed region of each collector electrode.

12. An electrostatic precipitator as defined in claim 11 wherein said potential difference establishing means and said means for passing air through the system are independently energizable.

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