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Applicant: **MONSANTO COMPANY**
Patent Department 800 North Lindbergh Boulevard
St. Louis, Missouri 63166(US)

Inventor: **Natarajan, Subbiah**
1396 Green Mist Drive
Fenton, Missouri(US)

Inventor: **Paranjpe, Prabhakar Dinkar**
1619 Preston Park Lane
Creve Coeur, Missouri(US)

Inventor: **Rao, Arshanapalli Kishan**
1810 Strathearn Court
Creve Coeur, Missouri(US)

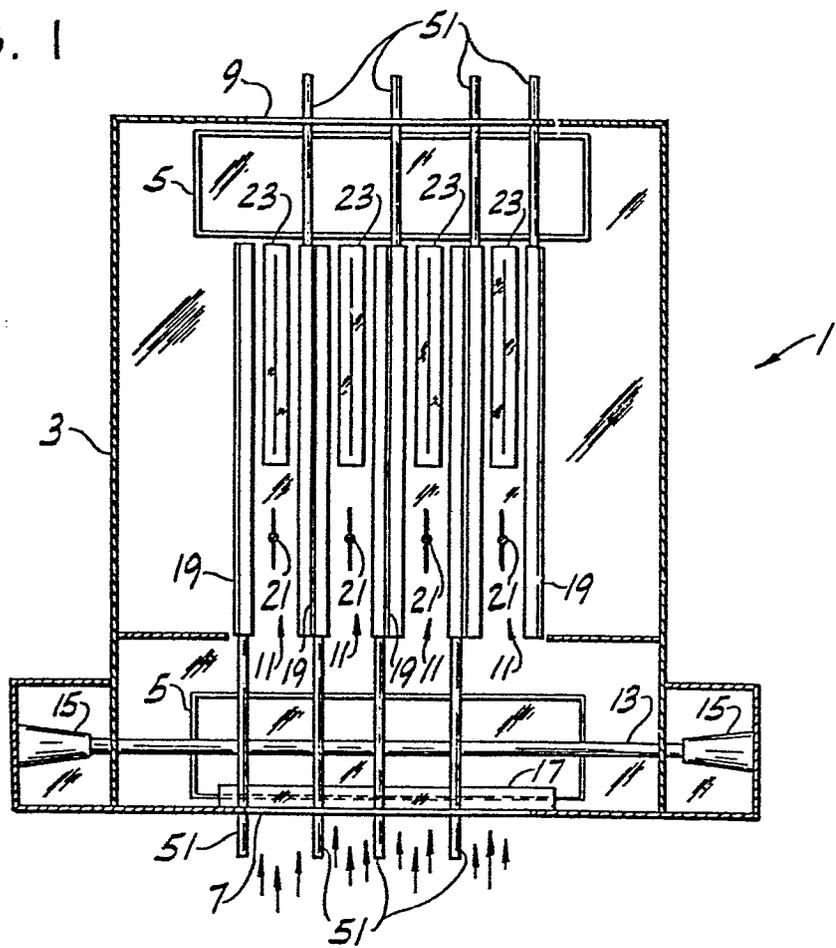
Representative: **Lunt, John Cooper et al,**
Monsanto House 10-18 Victoria Street
London, SW1H 0NQ(GB)

Method and apparatus for charging particles in a gas stream and collecting the particles therefrom.

Apparatus for electrically charging particles in a gas stream comprises an ionizer having at least one plate (19) for connection to one terminal of a high voltage unidirectional current source and a plurality of needles forming at least one corona discharge electrode (21) for connection to the other terminal of said source. For collecting the charged particles, the apparatus includes, downstream of the ionizer, a non-corona deflector electrode (23) for connection to the terminal of the high voltage source having the same polarity as the charge on the particles, and a collecting plate which can be a continuation of plate (19). Preferred embodiments of the invention include circuitry that in combination with the ionizer quenches arcs while maintaining the voltage across the ionizer. A further preferred feature is the inclusion of a wash header by means of which the collecting plate can be continuously irrigated. The apparatus is operated with a voltage gradient in the ionizer of 6KV/cm or higher, and a corona current between the needles and plate (19) having a density of at least 4 ma/m².

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FIG. 1



METHOD AND APPARATUS FOR CHARGING PARTICLES IN
A GAS STREAM AND COLLECTING THE PARTICLES THEREFROM

This invention relates to apparatus for removing particles from a gas stream and more particularly to apparatus for charging and collecting submicron particles entrained in a gas stream.

5 Gas streams, particularly in industrial settings, often contain particulates which must be removed therefrom for environmental or other reasons. Large particles, i.e. above 1-3 microns in size, are relatively easy to separate from the gas stream and
10 conventional apparatus can remove them with high efficiency. Submicron particles, on the other hand, are more difficult to remove and the collection efficiencies of conventional apparatus with respect to them are lower.

15 Various types of apparatus are used to collect submicron particles, some with relatively high efficiency, but they do have disadvantages. These apparatus typically use an ionizer to charge the particles and then provide a large surface area at a different
20 polarity to collect them. However, high charges on submicron particles are difficult to achieve in conventional ionizers. The voltage gradient and current densities of these ionizers are not generally sufficient to quickly and highly charge submicron particles. In many cases
25 this charging can be increased only at the expense of undesirably increased power consumption. Consequently, these apparatus either have a relatively long transit time (e.g., seconds) for particles in the ionizer, which is obtained by flowing the gas stream through the appar-
30 atus at a low velocity, or they have a large amount of collection area to collect the less highly charged particles, or both. These alternatives are all undesirable since they require a larger apparatus to handle a given amount of gas than would be required if the
35 particles were more highly and rapidly charged (e.g., in

milliseconds). In addition, apparatus with large collection areas typically have high distributed capacitances. Arcs and sparkovers occurring in such apparatus are sustained by the charges stored in the apparatus.

5 Some apparatus have electrodes for generating a precipitating field downstream of the ionizer to increase the rate at which charged particles move toward the collecting surface. But these electrodes create another problem, viz., arcing and sparking between the
10 electrodes and the collecting surfaces. During arcing the precipitating fields decrease and particles go uncollected.

 High efficiency collection of submicron particles is achieved in some apparatus at the expense
15 of large pressure drops along the gas stream. For example, fiber beds do a credible job of removing submicron particles, but the pressure drop across the bed is undesirably high.

 In apparatus where charged particles are
20 electrostatically collected on vertical collector plates, it is important that the plates be continuously and completely irrigated to remove the particles before they either build up a charge on the plates or are re-entrained into the gas stream. The plates, moreover,
25 must be uniformly irrigated. Any inadequately washed areas on the plates will build up a charge and performance of the apparatus will quickly deteriorate. In addition, splashing and squirting of the liquid is undesirable because the collecting plates are often dis-
30 posed only a short distance, e.g. two inches, from an electrode at high voltage. Thus, spraying the liquid on the plates is undesirable. Problems in providing a uniform film of liquid also arise from the fact that conventional pumps generate surges of pressure in the
35 liquid being pumped, which surges tend to cause an uneven

distribution of liquid. Problems also result when liquid is distributed by a long line. Because of pressure drops along the line, the distribution of liquid along the line is uneven in conventional apparatus.

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SUMMARY OF THE INVENTION

Among the several objects of the invention may be noted the provision of apparatus which is very effective in charging and collecting submicron particles; the provision of such apparatus which highly charges submicron particles with minimal power consumption; the provision of such apparatus which efficiently charges and collects submicron particles entrained in a gas stream flowing through the apparatus at a relatively high velocity; the provision of such apparatus which quickly quenches sparkovers while maintaining the voltage in the charging area and which suppresses arcs in the collecting area; the provision of such apparatus which provides a more uniform region of ions for charging particles in the gas stream; the provision of such apparatus which has a relatively low amount of particle-collecting area; the provision of such apparatus which has a low pressure drop; the provision of such apparatus which has a relatively short residence time (e.g., milliseconds); the provision of such apparatus which continuously and evenly distributes liquid to irrigate the surface of a collecting plate to remove charged particles therefrom; and the provision of such apparatus which distributes the liquid without splashing or squirting.

Briefly, in a first aspect apparatus of the invention comprises at least one substantially planar plate constituting a plate electrode for connection to one terminal of a high voltage, unidirectional-current source, a plurality of substantially evenly spaced-apart needles forming a corona discharge electrode for connection to the other terminal of the source, and a passage defined by the plate and the needles for flow therethrough from an inlet to an outlet thereof of a gas stream containing particles to be charged. During operation an electrostatic field is formed between the

needles and the plate and a corona current flows therebetween. The needles are disposed substantially parallel to the plate and spaced from the plate a distance such that the voltage gradient of the electrostatic field during operation is at least 6 KV/cm. The needles are arranged in at least first and second groups, the needles of the second group being offset transversely to the direction of flow of the gas stream. The effective area of the plate and the spacing between adjacent needles is such that the corona current has a current density of at least 4 ma/m². During operation high corona current density and high voltage gradient of the electrostatic field are achieved, corona suppression is reduced, high particle charges of substantially a single polarity are achieved, and a minimal amount of electrical power is consumed.

In a second aspect the present invention comprises a system for quick recovery from arcing and sparkover conditions in an ionizer having a corona discharge electrode, a plate electrode, and relatively low capacitance. This system includes a high voltage, unidirectional-current power supply for connection to the corona discharge electrode and the plate electrode to impress a high operating voltage thereacross to create an electric field and a corona current between the corona discharge electrode and the plate electrode. The power supply includes protective circuitry for automatically opening the circuit between the power supply and the ionizer during arcing and sparkover conditions to quench any arcs and sparkovers and then automatically reclosing the circuit. The system also includes means for maintaining the voltage across the discharge and plate electrodes above some predetermined level for a predetermined length of time but without supplying sufficient current to the ionizer to maintain

an arc or sparkover for the predetermined length of time, whereby the voltage across the discharge and plate electrodes quickly recovers to the operating voltage once any arcs and sparkovers are quenched and the circuit
5 between the ionizer and the power supply is reclosed.

In a third aspect apparatus of the invention comprises a non-corona deflector electrode for connection to a first terminal of a high voltage, unipolar source, the first terminal having the same polarity as
10 the charges on substantially all charged particles entrained in a gas stream. The apparatus also includes at least one collecting plate disposed substantially parallel to the deflector electrode for connection to the other terminal of the source. The collecting plate and
15 deflector electrode have an air gap therebetween for passage of the gas stream in which the charged particles are entrained. When the collecting plate and the deflector electrode are connected to their respective terminals they create an electrostatic field across the air gap
20 for deflecting the charged particles in the air gap toward the collecting plate. The deflector electrode includes at least one conductor for connection to the first terminal of the high voltage source. This conductor is separated from the air gap by a layer of
25 dielectric material having a dielectric constant greater than that of air. During operation sparkover between the deflector electrode and the collecting plate is suppressed and high electrostatic fields therebetween are achieved.

30 In a fourth aspect apparatus of the invention comprises a pair of generally parallel plates constituting collector electrodes for connection to one terminal of a high voltage, unidirectional-current source, a corona discharge electrode for connection to the other
35 terminal of the source, and a deflector electrode disposed

between the collector electrodes and downstream of the discharge electrode along the direction of flow of the gas stream. The collector electrodes are spaced apart a first distance to form a passage therebetween having inlet and outlet ends for flow therethrough of a gas stream containing particles therein to be charged. The corona discharge electrode is disposed between the collector electrodes and generally towards the inlet end of the passage, whereby during operation an electrostatic field is created and a corona current flows between the discharge electrode and the collector electrodes to charge the particles entrained in the gas stream as the stream flows past the discharge electrode. The deflector electrode is generally equidistant from both collector electrodes and has a width measured perpendicular to the collector electrodes in the range of from approximately one-twentieth the first distance to approximately one-half the first distance. The distance between the discharge electrode and the deflector electrode is in the range of from one-third the first distance to approximately the first distance. During operation a decelerating electric field is generated in the vicinity of the deflector electrode in the zone between the corona discharge electrode and the deflector electrode, the space charge and precipitating fields in the region along the gas stream between the discharge and deflector electrodes are increased, the electric field and ion density in that region are made more uniform, and higher particle charge and increased particle treatment times are achieved.

In a fifth aspect, apparatus of the invention includes a housing for flow therethrough of a gas stream containing charged submicron particles to be collected, and first, second and third substantially identical rows of generally vertical strips. The housing has a top, bottom, sides and inlet and outlet ends. Each row

extends transversely of the direction of flow of the gas stream and generally from the top to the bottom of the housing. Each row extends from side to side of the housing with its strips spaced equally apart across the housing to form a plurality of slots having a predetermined slot width of no more than 2.5 cm, which width is equal to the width of the individual strips. The second row is disposed generally downstream from the first row toward the outlet end of the housing at a distance approximately 0.8 times to approximately 3 times the slot width. The strips of the second row are aligned with the slots in the first row along the direction of flow of the gas stream to form a plurality of targets for the charged submicron particles passing through the slots in the first row. The slots of the second row are aligned with the strips of the first row along the direction of flow of the gas stream. The third row is disposed downstream of the second row a distance in the range of from approximately 0.8 times to approximately 3 times the slot width. The strips of the third row are aligned with the slots of the second row along the direction of flow of the gas stream to form a plurality of targets for the charged submicron particles passing through the slots of the second row.

In a sixth aspect, apparatus of the invention comprises a closed low pressure chamber, extending generally along the path or line where a film or curtain of liquid is needed, and a high pressure line for carrying the liquid at relatively high pressure to the low pressure chamber. The low pressure chamber has a plurality of relatively large apertures spaced along the path to allow liquid in the chamber to drain out of the chamber uniformly and at relatively low pressure. The high pressure chamber extends generally along the length of the low pressure chamber and has a plurality of

means, spaced along the length of the chamber, for discharging liquid into the chamber. Pressure of the liquid above the apertures in the low pressure chamber is maintained substantially even over the length of the path
5 so that liquid flows substantially uniformly and continuously out of the apertures without splashing or squirting.

Other objects and features of the invention will be in part apparent and in part pointed out
10 hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a top plan, with parts removed of particle collecting apparatus;

Fig. 2 is a front elevation of the apparatus
15 of Fig. 1;

Fig. 3 is a cross-sectional view of a needle discharge electrode used in the apparatus of Fig. 1;

Fig. 3A is a schematic representation of the regions of ionization created by the discharge electrode
20 of Fig. 3 during operation;

Fig. 4 is a schematic representation in plan of a single collecting section used in the apparatus of Fig. 1 showing the ionized regions and precipitating fields;

Fig. 5 is a schematic representation on a larger scale of a portion of the collecting section of Fig. 4;

Figs. 6 and 6A are plans of segments of alternative electrodes used in the apparatus of Fig. 1 with parts
30 of the surfaces broken away;

Fig. 7 is a front elevation, with part of the surface broken away of a precipitating electrode used in the apparatus of Fig. 1;

Fig. 8 is a side elevation of the electrode of
35 Fig. 7 with part of the electrode broken away;

Fig. 9 is a cross section on a larger scale than Figs. 7 and 8 of an electrode having a construction alternative to that of the electrode of Figs. 7 and 8;

5 Fig. 10 is a cross section on the same scale as Fig. 9 of another electrode having a construction alternative to that of the electrode of Figs. 7 and 8;

Fig. 11 is a schematic diagram of a circuit for maintaining the voltage across the ionizer of the apparatus of Fig. 1 during arcing conditions;

10 Fig. 12 is a bottom plan, with parts broken away and on a reduced scale, of a wash header for irrigating the collecting plates of the apparatus of Fig. 1;

Fig. 13 is a cross-sectional view of the wash header of Fig. 12;

15 Fig. 14 is a cross-sectional view, taken along lines 14--14 of Fig. 13, of a portion of the wash header of Figs. 12 and 13;

Fig. 15 is a cross-sectional view, similar to Fig. 13, showing an alternative construction of the wash header of Figs. 12-14;

20 Fig. 16 is a schematic representation in plan of an apparatus containing two stages, each including the collecting apparatus of Fig. 1;

Fig. 17 is a schematic representation, on an enlarged scale, of a portion of a set of baffles used in the apparatus of Fig. 17; and

Fig. 18 is a front elevation of a portion of one row of the baffles of Fig. 17;

30 Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings, there is shown in Figs. 1 and 2 an apparatus 1 for removing particulates, and particularly insoluble particulates, from a gas stream.

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This apparatus includes a housing 3, two drain wells 5, an inlet 7 for entrance of the gas stream into the apparatus, an outlet 9 for exit of the stream from the apparatus, and a plurality (in this case, four) collecting sections 11 arrayed in a bank to provide a plurality of parallel paths for the gas stream. Sections 11 are also sometimes called ionizer sections. A frame 13, having stand-off insulators 15, is provided to support sections 11 and for making the necessary electrical connections.

10 A gas stream (indicated by arrows throughout the Figs.), having entrained therein particles to be charged and collected, continuously enters inlet 7, is directed by top and bottom baffles 17 (only the bottom of which is shown) toward sections 11, and is there split up
15 into four, smaller gas streams for flow through the collecting sections. Each collecting section is defined by a pair of substantially parallel plates 19, and has disposed therebetween a high-intensity, needle-to-plate corona discharge electrode 21 and a deflector electrode 23.
20 Discharge electrode 21 is disposed generally near the inlet end of the section while deflector electrode 23 is disposed generally downstream from the discharge electrode along the direction of flow of the gas stream. The discharge electrode includes a plurality of evenly
25 spaced-apart needles 25 (see Fig. 3) arranged in a row or group pointing generally upstream and a plurality of evenly spaced-apart needles 27 arranged in a second row or group pointing generally downstream. Both rows are secured to a rigid mount or tube 28 of insulative or
30 conductive material, said tube being generally perpendicular to the direction of flow of the gas stream and generally parallel to plates 19. When mount 28 is of insulative material, there is disposed inside the mount a conductor 28A electrically connected to the needles
35 of both rows. The needles may be of various sizes and

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shapes, but it is preferred that the needles have body diameters between 10 mils (0.025 cm) and 100 mils (0.25 cm), and more preferably between 30 mils and 75 mils. Excellent results have been achieved with needles having body diameters of 47 mils (0.12 cm). It is preferred that the needles have a taper angle measured from the longitudinal axis in the range of from 3° to 10°. Excellent results have been achieved with sharp needles having a taper angle of 4.3°. Needles 25 and 27 are parallel to each other and to plates 19 and are perpendicular to tube 28.

An enlarged view of a collection section is shown in Fig. 4. In operation discharge electrode 21 and plates 19 are connected to terminals of a high voltage source, e.g. a power supply such as is shown in Fig. 11, to form an electrostatic field between the discharge electrode and the plates and to cause a corona current to flow therebetween. It is preferred that the potential of the discharge electrode with respect to the plates, which plates function as plate electrodes, generally always retain the same polarity and that the corona current generally always flow in the same direction during operation. Accordingly, the high voltage source is preferably unipolar, (i.e., the relative polarity of the output terminals of the source does not change during operation). Specifically, discharge electrode 21 is connected to one terminal of a high voltage, unidirectional-current (i.e., pure DC or rectified current) which source is also unipolar, and the plates are connected to an other or opposite terminals of the source (i.e., to a terminal which is grounded or has a potential different from the potential of the terminal connected to the discharge electrode). It is preferred, especially when the gas stream contains electronegative gases, that the polarity of the discharge electrode with respect to the plates be negative and that the plates themselves be connected to the ground terminal of the high voltage source. Of course, the discharge electrode may be operated with a positive polarity and the plates

need not be grounded—indeed the plates may have a high voltage imposed upon them which is of opposite polarity to that imposed upon the discharge electrode—but very satisfactory operation is achieved using the preferred connection of the discharge electrode and the plates.

It is preferred that the voltage difference between the discharge electrode and plates 19 be in the vicinity of 30 kilovolts (30 KV) and that the spacing between plates 19 be on the order of 3 inches (3 in.) (8 cm). The present invention is certainly not limited to such operating voltages and plate spacings, however. With correspondingly wider plate spacing, apparatus within the scope of this invention may be operated at higher voltages such as 100 KV; and with correspondingly narrower plate spacing, such apparatus may be operated at voltages less than 30 KV. Even at 30 KV, the plate spacing need not be precisely 3 in. (8 cm). Discharge electrode 21 is disposed between and generally equidistant from plates 19 with its needles generally parallel to each other and to the plates. In the preferred embodiment, the spacing between the needles and the plates is approximately 1.5 in. (3.8 cm) and the voltage gradient therebetween (i.e., the mean gradient of the average voltage) is approximately 7.9 KV/cm. Generally, this voltage gradient should be in the range of from 6 KV/cm to the breakdown gradient of the gaseous medium, and it is preferred that it be in the range of from approximately 7 KV/cm to 15 KV/cm, and it is further preferred that the gradient be in the range of from approximately 7.5 KV/cm to 10 KV/cm. Excellent results have been achieved with voltage gradients of approximately 7.9 KV/cm and approximately 8.7 KV/cm.

For efficient charging of particles, particularly particles 0.5 micrometers (microns) in size and larger, it is desirable to have the voltage gradient

between the needles and plates 19 as great as possible without significant arcing and sparkover occurring between the needles and the plates. Once the preferred range set forth above is significantly exceeded, arcing becomes such a problem that performance of the apparatus (measured in terms of particle charging and collection) degrades significantly. It is also desirable that the electrostatic field formed between the discharge electrode and the plates extend for some distance along the path of the gas stream to adequately charge these relatively large particles. In apparatus having the dimensions set forth above, needles 25 and needles 27 should extend from tube 28 at least 1/2 in. (1.3 cm) to provide a field of sufficient length. Of course the longer the needle, the better for this purpose; but for compactness and because of manufacturing tolerances it is desirable that the length the needle extends from the tube not exceed 3 in. (7.6 cm), and preferably not exceed 1-1/2 in. (3.8 cm). Very satisfactory results have been achieved at 30 KV with the exposed length of the needles being 1 in. (2.5 cm).

Whenever a high voltage gradient, e.g., 8 KV/cm, exists between the needles and the plates, each needle of the discharge electrode (specifically, the tip of each needle) emits a corona. Because of the spacing between adjacent needles, these needle coronas do not combine to form one or two continuous coronas but rather form a first spatially discontinuous corona 29 (see Fig. 3) disposed toward the inlet end of collecting section 11 and extending from the top to the bottom of the section and a second spatially discontinuous corona 31 disposed downstream from said first corona, also extending from the top to the bottom of the section. These discontinuous coronas create first and second bands of ionization, each extending generally from top to bottom of section 11,

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which bands are generally identical in shape (the shape of either being shown in Fig. 3A). Each contains regions of relatively low ionization, indicated by the reference numeral 33, bordered by regions of relatively high ionization, indicated by reference numeral 35. The high ionization regions are generally centered on their respective coronas and extend from the tips of the needles to each plate.

The high ionization regions of each band in combination with the high voltage gradient of the electrostatic field are very effective in charging submicron particles, particularly those less than 0.5 microns in size, whereas the low ionization regions are much less effective. Therefore, if such a particle were to pass discharge electrode 21 without entering a high ionization section, it could leave the area of the discharge electrode without having picked up a substantial charge. To reduce this possibility, the needles of the discharge electrode are offset (as shown in Fig. 3) so that the low ionization regions of each band are aligned with the high ionization regions of the other band. It has been found that merely offsetting needles from needles 27 is not sufficient to maximize the possibility that submicron particles entrained in the gas stream will pass through a highly ionized region. It is also necessary to optimize the spacing between adjacent needles in each row. As the needles of a row are spaced farther apart, the corona current per needle increases and to a point the corona current density per unit area of the plate electrodes also increases. Since the degree of ionization is directly related to the magnitude of the corona current, this increase is desirable. However, increasing the spacing also increases the number of particles that bypass the high ionization regions of the discharge electrode and thus fail to become sufficiently

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charged. Conversely, decreasing the spacing decreases the number of particles that pass the discharge electrode without being charged but also decreases the corona current. The optimum charging is not achieved at the
5 needle-to-needle spacing that gives the highest corona current density but rather at a somewhat shorter spacing that provides a sufficient level of charging of particles with a minimum of particle bypassing. It has been found that for operation at approximately 30 KV with the
10 present system, the best balance between these competing effects is achieved with a needle-to-needle spacing in each row of from approximately 3/8 in. (0.9 cm) to approximately 1 in. (2.5 cm). It is preferred that this spacing be from approximately 1/2 in. (1.3 cm) to approxi-
15 mately 3/4 in. (1.9 cm). Good results were achieved with a spacing of 1/2 in. (1.3 cm).

When needles 25 and 27 are offset one half the needle-to-needle spacing of each row from each other and the needle-to-needle spacing itself is optimized as
20 described above, it has been found that very high corona current densities are achievable with a minimum of non-corona emission and with little or no corona suppression under both constant and surging high particulate loading. Corona currents having a density of at least 4 ma per
25 square meter of the effective area of plates 19 are easily achievable with the present apparatus and current densities of 20 ma/m² and higher are possible in particle-free gas streams. Notice should be taken that these current density figures are computed using the "effective
30 areas" of plates 19. The effective area of a plate is determined according to the following formula:

$$\text{Effective area} = h \times (n + 2P),$$

where h is that portion of the height of the plate exposed to the gas stream, n is the distance measured
35 parallel to the needles from the tip of the needles of

one row to the tip of the needles of the other row (see Fig. 5), and $2P$ is the distance along the plate upstream and downstream of the needles where significant current flow between the needles and the plates occurs.

5 Of course, some current flow will take place between the needles and those areas of the plates beyond the distance P , but this current can be neglected. The distance P in turn is computed using the formula $P = S \times \tan \alpha$, where α is an angle in the range of from approximately 45° to approximately 65° , and S is the distance from the needles to each plate. It is preferred that this angle be about 62° .

10 Plates of shorter length can, of course, be used but there is some decrease in efficiency.

As the particles pass the needles of the discharge electrode, they come under the influence of the deflector electrode. Deflector electrodes, or precipitating electrodes, are used in the art to generate a field which forces charged particles to a collecting plate or plates. Deflector electrode 23 does serve this function and its precipitating field is shown by stress lines on Fig. 4. It has been discovered, however, that the spacing d (see Fig. 5) between the needle electrode and the deflector electrode is very important, as is the width W of the deflector electrode itself. When d is in the range of from $1/4$ the plate-to-plate spacing (or equivalently $1/2$ the spacing S between the needles and each plate) to approximately the plate-to-plate spacing (i.e., $2S$), a decelerating field is produced which opposes the motion through the collecting section of the particles charged by the discharge electrode. This results in an increase in the space charge, indicated by the speckled cloud in Fig. 4, between the discharge and deflector electrodes and in an increase in the precipitating fields in the same region. In addition the electric fields and ion densities in that region are made more uniform.

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As a result, particles are even more likely to pass through a region of high ionization, and they are subjected to the fields and ions for a longer period of time than is the gas in which they are entrained. Consequently, higher particle charging is achieved. Thus, deflector electrode 23 is also a decelerating electrode. It is preferred that this spacing d be at least $2/3 S$, and more preferably be in the range from approximately 0.75 S to approximately 1.5 S . If spacing d is less than the distance 0.75 S , the possibility exists that current from the needles will sustain a sparkover between electrode 23 and plates 19. The desired width W of the deflector electrode, which is the maximum distance across the electrode measured perpendicular to the plates, may also be selected advantageously to be in the range of from $1/20$ of the plate-to-plate spacing to approximately $1/2$ said spacing. Excellent results have been achieved with W equal to $1/3$ the plate-to-plate spacing and d equal to $2/3$ said spacing.

For purposes of serving the decelerating and precipitating functions, deflector electrode 23 may be any shape and be either an insulator (see Fig. 6) or a conductor (see Fig. 6A) or some sort of composite electrode. And electrode 23 need not be used in conjunction with discharge electrode 21. Indeed it may be used to precipitate and decelerate charged particles created by any kind of ionizer. However, it is preferred that electrode 23 have the constructions shown in Figs. 7 - 10. The deflector electrode shown in Figs. 7 and 8 includes a thin film 37 (e.g., 0.001 in.) of a conductor such as aluminum embedded or encapsulated in a dielectric material 39 having a dielectric constant greater than air and a volume resistivity of at least 10^7 ohm-cm. It is preferred that the dielectric material have a dielectric constant in the range of from approximately 2.5 to approximately 9 and a volume resistivity of

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at least 10^{13} ohm-cm. In choosing a dielectric material to use in electrode 23, it is desirable to choose a material having a high dielectric constant and good mechanical strength so that the thickness of the material over the conductor can be made as thin as possible (to increase the magnitude of the precipitating field) while still protecting against rupture of the dielectric during arcing between the deflector electrode and the plates (which rupturing would require replacement of the deflector electrode). Very satisfactory results have been obtained using a one inch (2.5 cm) thick piece of polymethylmethacrylate as the dielectric material, the aluminum foil being embedded therein approximately 0.5 in. (1.3 cm) from each surface. Any dielectric having a dielectric constant and a volume resistivity in the above ranges would be useful in the deflector electrode, including without limitation alumina, other ceramics, glasses, polymeric materials, mineral and fiber-filled polymeric and resin materials, resins, natural and synthetic rubbers, and thermosetting resins. Among the multitude of useful materials are polyethyleneterephthalate polyvinylchloride, perfluorinated polymers, polycarbonates, polysulfonates, nylon, polyurethane, polyvinylacetals such as polyvinylbutyral and polyvinylformal, phenol formaldehyde, aminoplasts, and polyester and epoxy resins. Also, liquid dielectric materials such as transformer oil may be used to cover conductor 37, in which situation the dielectric must be contained in a case, which case may be either conductive or non-conductive.

Although the shape of deflector electrode 23 is not critical, it is preferred that it be generally flat and parallel to the plates and that conductor 37 be generally the same shape as the electrode itself, although somewhat smaller. As shown in Fig. 4, an air gap exists

between the deflector electrode and each plate and a precipitating electric field, indicated by stress lines, fills these gaps. It is preferred that this field be such as to cause the particles charged by the discharge electrode to be forced towards the plates rather than towards the deflector electrode. To accomplish this it is necessary that electrode 23 build up a charge having the same polarity as the charges on the particles. The preferred way of doing this is to connect conductor 37 to a terminal of the high voltage source having the same polarity as the discharge electrode and the charges on the particles. When so connected, a high voltage difference exists between the conductor and the plates, which voltage difference creates the precipitating fields.

Of course, the conductor need not be embedded in a dielectric to produce these precipitating fields; a bare conductor will also generate these fields when connected to the high voltage source. However, a bare conductor has one problem that is substantially eliminated with deflector electrodes of the present construction, namely, arcing between the deflector electrode and the plates. With electrodes of the present construction, the dielectric material acts as a current limiting resistance between the conductor and the plates. This material limits the amount of current that can flow between the conductor and the plates to such a low value that arcs are not readily generated and if generated cannot be sustained. It has been found that if the dielectric material is an electret such as polymethylmethacrylate, not only are arcs and sparkovers suppressed but also the precipitating fields are maintained even during temporary losses of voltage from the high voltage source.

The deflector electrodes shown in Figs. 9 and 10 are alternative embodiments of that shown in Figs. 7 and 8. Externally they are substantially identical to the

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deflector electrode of Figs. 7 and 8, but they differ internally. The electrode of Fig. 9 includes two foil conductors 37A and 37B, each embedded in a dielectric material 39 a predetermined distance, e.g., 1/16 in.

5 (0.2 cm), below the surface of the electrode and connected by a conductor 41 to the high voltage source. Accordingly each conductor is spaced the same distance from its respective plate as the other, but neither is disposed in the center of the electrode. This construction
10 results in a much thinner layer of dielectric between the conductors and their associated airgaps, and hence in stronger precipitating fields.

The electrode shown in Fig. 10 is similar to that of Fig. 9 except that it includes six conductors 37C
15 - 37H embedded in the dielectric, only the innermost two of which (conductors 37C and 37D) are connected to the high voltage source. The conductors lying nearest the surface of the electrode (conductors 37G and 37H) are completely insulated from those conductors directly
20 connected to the high voltage source.

When deflector electrodes having the constructions shown in Figs. 7-10 are used in combination with the high-intensity discharge electrode shown in Figs. 3 and 3A, very high efficiencies of collection of submicron
25 particles are obtained with a small effective collecting area. In the present embodiment, that collecting area is the area of plates 19 and for each collecting section 11 is equal to 17.5 square feet/1000 cubic feet per minute of gas (17.5 sq. ft./1000 cfm) (1.6 square
30 meters/1000 cfm). Generally with the present apparatus, the total collecting area per collecting section is between approximately 3 and approximately 50 square feet/1000 cfm (0.28 to 4.6 sq. m/1000 cfm), and preferably is between 10 and 30 square feet/1000 cfm (0.93 to 2.8 sq.
35 m/1000 cfm). More preferably this collecting area is in

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the range of from 15 to 20 square feet/1000 cfm (1.4 to 1.86 sq. m/1000 cfm). Of course, additional collecting area [e.g., up to 500 square feet/1000 cfm (46 sq. m/1000 cfm) or higher] can be added to achieve even
5 higher efficiencies.

It should be appreciated that the distributed capacitance of the ionizer of the present apparatus, which ionizer is constituted by discharge electrode 21 and plates 19, has a very low distributed capacitance.
10 In the example shown in the drawings, the plates themselves are only 16 in. (41 cm) in length, and even when this entire length is taken into account the distributed capacitance of the ionizer is only 467 picofarads (467 pF) per 1000 cfm. Consequently the ionizer itself
15 does not have enough charge stored therein to long maintain an arc once one starts. Since conventional high voltage power supplies, such as power supply 43 shown in Fig. 11, include circuitry for automatically opening the circuit between the power supply and the ionizer
20 during arcing and for automatically closing said circuit once the arc is quenched (which circuitry is indicated by the legend "protective means" in Fig. 11); the present apparatus quickly quenches any arcs that do occur.

25 The low distributed capacitance of the ionizer although it does have the beneficial effect outlined above, also has an undesirable effect. When an arc does occur, the voltage between the discharge electrode and the plates drops precipitously. As a result particles
30 passing the discharge electrode at that time might not become fully charged. Particularly when the gas is flowing through the apparatus at a high flow rate, e.g., 10 feet/second (10 ft/sec) (3m/sec), a particle can flow past the discharge electrode while there is no significant
35 voltage gradient existing between the electrode and

the plates. In apparatus operated at a slower gas flow rate, this is not as significant a problem; but at high flow rates the problem becomes very important.

At 10 ft/sec (3m/sec), a particle to be charged passes
5 the discharge electrode in approximately 25 milliseconds (25 msec) and passes through the effective length of the ionizer, which is $n + 2d$, (8 in. (20 cm) in the present example), in approximately 0.06 seconds. If the voltage between the discharge electrode and plates 19 is low for
10 a large portion of that time, most of the particles passing through the collecting section will remain substantially uncharged. This is the reason why ionizers are typically operated slightly below the level at which a significant amount of sparkover occurs. If
15 one operates in the sparkover region, the number of particles that pass through uncharged will be substantial since the voltage between the discharge electrode and the plates will often be low.

To solve the problem of voltage loss after
20 sparkover, means indicated at 44 (see Fig. 11) have been developed for maintaining the voltage across the discharge electrode and the plates above some predetermined level, e.g., 26 KV, for a predetermined length of time, e.g., 16 msec or longer, but without supplying sufficient current to the ionizer to maintain an arc or sparkover for
25 the predetermined length of time. Means 44 includes a capacitor C1, a resistor R1, and a high voltage diode D1, which are connected in series with each other across the discharge electrode and plates 19. The capacitor has a
30 capacitance of, e.g., 0.1 to 1.0 microfarads (0.1 to 1.0 micro-F) and preferably 0.3 to 0.4 micro-F, and during normal operating conditions it is charged to nearly the operating voltage of 30 KV. During arcing the charge on capacitor C1 serves to maintain the voltage across the
35 discharge electrode and the plates at a relatively high

level. Merely connecting a capacitor across the discharge electrode and the plates does not solve the problem however. This would simply provide a source of additional charges for the ionizer which would maintain the arc.

5 Accordingly, resistor R1, having a resistance of, e.g., 1-10 megohms (1-10 M-ohms) and preferably 3 M-ohms, is connected in series with the capacitor. This limits the current that can flow through the capacitor to a value sufficiently low that arcs are not maintained.

10 Additionally, a high voltage diode such as diode D1, which is forwardly biased in normal operating conditions, may be added to this series circuit to further limit the current which flows through the capacitor during arcing. The leakage through diode D1, which is inherent in high

15 voltage diodes, serves to provide additional ions to the region near the discharge electrode during arcing conditions, which further promotes charging of the particles passing the discharge electrode at that time. Additionally, a second resistor R2 (e.g., having a

20 resistance of 10-20 M-ohms) may be added in parallel with diode D1 to provide some leakage across the diode. Of course, adding capacitor C1 does lower the sparkover voltage between the discharge electrode and the plates somewhat. But the sparkover voltage with the present

25 discharge electrode is so high that this does not severely affect the operation of the apparatus. Although the capacitor and resistor can in general have a range of values, it is preferred that their RC time constant be between approximately 16 msec and approximately 900 msec.

30 In the preferred embodiment the RC time constant is 300 msec.

It should be appreciated that some way of cleaning plates 19, either periodically or continuously, is necessary. In the absence of cleaning, a surface charge

35 builds up on the plates and affects performance. These

plates can be cleaned by rapping or washing and the like, but it is preferred that they be continuously irrigated with a thin film of liquid such as water or some other wash liquor. Since the plates in this example are approximately 16 in. (41 cm) in length, it has proved difficult to obtain a substantially even and uniform film of liquid over the length of each plate. This problem is compounded by the fact that squirting or splashing of the liquid is highly undesirable due to the very small spacings between the discharge electrode and the plates on one hand and the deflector electrode and the plates on the other. Less than two inches (5 cm) away from the liquid on the plates (in this example) is an electrode at 30 KV. Clearly splashing or squirting of the liquid onto the plates in such circumstances is intolerable. But the elimination of splashing and squirting cannot be had at the expense of leaving portions of the collecting plates dry, since that is also undesirable.

This washing dilemma has been solved by a new wash header, alternative embodiments of which are shown in Figs. 12 - 15. Although designed for use in irrigating collecting plates of particle collecting apparatus, the wash header is not so limited in application. Rather it can be used wherever a substantially uniform and continuous film or curtain of liquid is needed. This wash header can supply a substantially uniform film or curtain of liquid along a surface or in general along any horizontal path or line whether or not that path or line is associated with a surface.

The first embodiment of the wash header, wash header 45, has a dual form, shown in Figs. 12 - 14 and a single form (not shown) which is simply one half of the dual form. Single wash headers 45 are used to irrigate the leftmost and rightmost collecting plates 19 shown in Fig. 1, while dual wash headers are used to irrigate

both sides of the intermediate plates. Each half of wash header 45 includes a closed, low pressure (e.g., 6 inches of water) chamber 47 extending generally along the surface, path or plate 19 to which liquid is to be supplied. Chamber 47 has a plurality of relatively large apertures 49, which in the preferred embodiment are 1/4 in. (0.6 cm) square slots disposed adjacent the surface of the plate to be irrigated at the lower end of the chamber. The slots are evenly spaced along the plate and the space between adjacent slots is approximately 1/4 in. (0.6 cm). Of course the slots need not be square or even of any particular shape, and the space between adjacent slots may be varied as desired. Indeed the apertures may take the form of a single slit broken by spacers. Apertures 49 allow liquid in chamber 47 to drain out of the chamber uniformly and at relatively low pressure. Each half of wash header 45 also includes a high pressure line 51 for carrying the liquid at relatively high pressure [e.g., 20 pounds per square inch (20 psi) (1400 grams per square centimeter)] to the low pressure chamber. Spacers 52 are disposed periodically along line 51 to maintain it in position inside the low pressure chamber. Preferably line 51 extends generally along the length of chamber 47 and has a plurality of 0.086 in. (0.22 cm.) holes or orifices 53 (see Fig. 14) therein spaced on 4" (10 cm) centers which constitute means for discharging liquid into the chamber. The actual size and spacing of orifices 53 is not critical. What is important is that the size of the orifices relative to the size of the apertures in the low pressure chamber is such that the pressure drop through the orifices is approximately twenty or more times the pressure drop through the apertures and also approximately twenty or more times the pressure drop from the first orifice in the high pressure line to the

last. The low pressure chamber evens out most inequalities in the amount of liquid flowing out of the orifices, so that it is not even necessary that all the orifices be exactly the same size. The relative insensitivity of
5 the low pressure chamber to pressure differences in the high pressure line also makes the functioning of the wash header 45 rather free from effects caused by pressure surges in that line. On a very long header, however, consideration should be given to making the orifices at
10 the end of the high pressure line larger than those at the beginning to roughly or approximately equalize the amount of liquid discharged from each orifice.

Although the high pressure line need not be disposed wholly inside the low pressure chamber, that
15 arrangement is preferred. When the line is so disposed, the orifices thereof are directed generally away from the apertures in the low pressure chamber so as not to cause splashing and squirting of liquid out of the apertures. Alternatively, as shown in Fig. 15, a
20 baffle 55 may be added to low pressure chamber 47 to shelter apertures 49 from liquid being discharged downwardly from the orifices in this embodiment.

In the dual form, wash header 45 includes a plurality of 5/16 in. (0.8 cm) holes or openings 57
25 generally spaced on 4 in. (10 cm) centers between the two chambers 47 making up a dual wash header, which openings constitute means for equalizing the pressures in the two chambers. A single high pressure line can be used to supply liquid to both low pressure chambers
30 of a dual wash header, but it is preferred that each half of the wash header have its own high pressure line as shown in Fig. 1. Periodically, one end of each high pressure line may be opened for passage through that line of a high pressure surge of liquid for cleaning out
35 the line.

Particles attracted to collecting plates 19 and those forced to the plates by the precipitating fields of the deflector electrodes are caught by the liquid flowing uniformly over the plates from the wash headers and are
5 carried away from the plates and down drain wells 5 before they can be re-entrained into the gas stream. The substantially particle-free gas stream then exists from the apparatus at outlet 9 (see Fig. 1).

Apparatus 1 collects a substantial fraction of
10 all the particles entrained in a gas stream; but to achieve very high collection efficiencies on submicron particles (e.g., 95% or higher) with minimal power consumption it is desirable to use a two-stage system such as is shown in Fig. 16. This system includes an initial
15 set of baffles 59, a first stage 61, and a second stage 63 all disposed inside housing 3. The first and second stages may be but are not necessarily substantially identical, each consisting generally of an apparatus 1 followed by a set of baffles 65. Since the particles
20 entering the second stage are of much smaller mean particle size than those entering the first stage and since the inlet loading is also lower, the second stage may be designed with these different parameters in mind. A gas stream flowing into housing 3 first passes through
25 baffles 59 which remove relatively large particles (e.g., 10+ microns) from the stream. Then the stream passes through the collecting section 11 of the first stage where most of the smaller particles in the gas stream are collected in collecting plates 19. Some particles
30 do remain entrained in the gas stream as it exits from the collecting sections, but most of these particles have been highly charged by discharge electrodes 21. It has been found that these highly charged, submicron particles can be efficiently collected on baffles. Baffles 65,
35 therefore, constitute means in addition to collecting

charged submicron particles. Of course, other means such as fiber beds, packed-bed scrubbers or any other conventional particle collectors may be used to collect particles outside collecting sections 11, but baffles are preferred.

Baffles 65 have been designed to maximize particle collection with minimal pressure drop. The detail of baffles 65 is shown more clearly in Figs. 17 and 18. These baffles include a first row 67 of generally vertical strips 69 of generally equal width, [e.g., 1/4 in. (0.6 cm)], each strip extending generally perpendicular to the direction of flow of the gas stream and generally from the top to the bottom of housing 3. Row 67 extends from side to side of the housing and the strips thereof form a plurality of slots having a width equal to the width of the strips [(e.g., 1/4 in. (0.6 cm))]. A number of small crosspieces 71 (see Fig. 18) extend between adjacent strips and provide structural integrity to row 67. These crosspieces should have as small a profile as possible to obtain nearly equal open and closed areas for each row. A second row 73 of strips, which are substantially identical to the first row but offset so that the strips of the second row are aligned with the slots in the first row a distance in the range of from approximately 0.8 times to approximately 3 times the width of the strips and slots [e.g., 0.2 in. to 3/4 in. (0.5 cm to 1.9 cm)]. The strips of the second row form targets for the charged submicron particles that pass through the slots in the first row. The baffles also include a third row 75, which is substantially identical to the first and second rows, disposed downstream of the second row a distance in the range of from approximately 0.8 times to approximately 3 times the width of the strips and slots of each row. The strips of

the third row are aligned with the slots in the second row along the direction of flow of the gas stream to form targets for the charged particles which remain uncollected after the second row. For adequate collection of submicron particles the width of the slots and strips in each row of the baffles should be no more than 1 in. (2.5 cm) and it is preferred that this distance be approximately 1/4 in. (0.6 cm).

It is desirable that the strips of each row be periodically or continuously cleaned to prevent a build-up of charge that would reduce their collection efficiency. Means for cleaning, specifically means for irrigating, the baffles are indicated at 77 (see Fig. 18). Irrigating means 77 includes a plurality of nozzles for spraying irrigating liquid on the baffles. In the case of the baffles, there is no need to use the wash headers for irrigation since the baffles may be spaced some distance from the nearest high voltage source. In irrigating the baffles, however, it is desirable to spray irrigating water only on the strips and not in the slots, because in the latter case the irrigating liquid itself becomes entrained in the gas stream.

A series of tests have been performed to determine the overall efficiency of the system shown in Fig. 16 as well as the various parts making up the system. In these tests, DOP aerosol, fly ash, sinter dust (ferric and ferrous oxide particles), and other insoluble particles were used to provide the particles for the gas stream. Excellent results were achieved on all these types of particles. The results of those tests are summarized below. Operating the two-stage system of Fig. 16 at 30 KV, with a total specific collection area in square feet per 1000 cfm of gas flow of forty, simultaneous collection efficiencies of over 99% on particles 1 micron and larger in size and of over 98% on submicron particles have been achieved with less than a 2" of water pressure drop and a power consumption of less than 1 KW/1000 cfm of gas. Similar results, also showing

the effect of the quick voltage recovery circuit shown in Fig. 11, are set forth in Table I.

TABLE I

RUN	GAS				IONIZER				SYSTEM				FRACTIONAL EFFICIENCIES**					
	FLOW RATE	VELOCITY	VOLTS	AMPS	POWER	POWER	AMPS	VELOCITY	VELOCITY	VELOCITY	VELOCITY	VELOCITY	VELOCITY	VELOCITY	VELOCITY	VELOCITY	VELOCITY	VELOCITY
	cfm (m ³ /min)	ft/sec (m/sec)	KV	amps	KW	Actual KW	1000 CFM (kW/1000 m ³ /min)	IN. H ₂ O IN. H ₂ O	INLET	EXIT	INLET	EXIT	INLET	EXIT	INLET	EXIT	INLET	EXIT
2	600 (17)	10 (3)	30	15	0.45	0.75 (0.02)	1.3 (33)	419	7.75	93.83	96.02	97.39	98.15	98.70	99.39	99.39	99.39	99.39
1	600 (17)	10 (3)	30	15	0.45	0.75 (0.02)	1.3 (33)	394	7.19	95.0	96.32	97.56	98.18	98.63	99.61	99.61	99.61	99.61

* Inlet particle mass mean diameter of micron, with 84% of the particles by weight being less than 3.2 microns

** Fractional efficiencies measured by cascade impactor for a number of particle mass mean diameter sizes measured in microns

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Table I reflects two runs of the system, the first with an inlet particle loading of 419 mg/m^3 of sinter dust and the second with a loading of 394 mg/m^3 of sinter dust. During the first run capacitor C1 had a value of 0.025 micro-F and in the second it had a value of 0.32 micro-F. In both runs there was heavy arcing and sparking between the discharge electrodes and the collecting plates 19 caused by a lack of clean irrigation liquid. This condition started at the end of the first run and continued throughout the second. Nevertheless, overall collection efficiencies of over 98% were achieved, as were efficiencies of over 95% for all particles except those less than 0.2 microns in size. Even for particles of that size, the collection efficiencies exceeded 93% for both runs.

Some of the excellent results achieved by the present system, which includes discharge electrode 21, plates 19, deflector electrode 23 and baffles 65, are attributable to the high intensity ionizer consisting of discharge electrode 21 and collecting plates 19. Voltage gradients in the ionizer of this example are preferably in the range of from 7.8 KV/cm to 8.7 KV/cm, and the concomitant corona current densities are in the range of from 10.8 ma/m^2 to 15.0 ma/m^2 . This high gradient and current density result in extremely high particle charges as measured by the ratio of particle charge to mass. For particles with a mass mean diameter of 0.6 micron, as measured after a single stage of section 11, values of this ratio of from 700 to 900 micro-coulomb/gm (micro-C/gm) have been measured. These charges were achieved using particles having a mass mean diameter at the inlet of section 11 of 1.0 micron with 84% thereof having a mass mean diameter of less than 2.2 microns, with an inlet loading of 225 mg/m^3 . These high particle charges result in high collection rates on the collection plates and baffles and a resulting very low specific

collection area for the system. In addition corona suppression with the present ionizer is very small. At 30 KV the corona current of the ionizer was suppressed about 20%, when the total specific surface area of the particles present in the gas stream was about 1 m² per cubic meter of gas, which corresponds to an inlet loading of 450 mg/m³, with a mass mean diameter of the particles of 1 micron, 84% of the particles having a mass mean diameter of less than 2.1 microns. Even the suppressed current density was above 10 ma/m².

The ionizer by itself does a fairly good job of collecting particles entrained in the gas stream. Tests were run on the collection efficiency of an ionizer having a specific collection area (in square feet per 1000 cfm of gas) of only 9 (0.8 m²/1000 cfm) at three different operating voltages. In each case the incoming particles had a mass mean diameter of 1 micron and 84% of the particles had a mass mean diameter of less than 2.2 microns, the gas flowed through the apparatus at a rate of 10 feet per second (3 m/sec), and the inlet loading was 225.0 mg/m³. At 27 KV, the ionizer alone had an overall collection efficiency of over 65%; at 30 KV the overall efficiency was over 72%; and at 33 KV the overall collection efficiency was over 77%. The particle charges measured at the ionizer exit (i.e., on the particles not collected by the ionizer) were 90, 120 and 160 micro-C/gm at 27, 30 and 33 KV respectively.

Tests were also run at 30 KV on the collection efficiency of a single discharge electrode in combination with a single deflector electrode. The particles introduced into the gas stream during these tests had a mass mean diameter of 1.0 micron with 84% of the particles having a mass mean diameter of less than 2.1 microns and the inlet loading was 225 mg/m³. Flow rate of the gas stream was 10 feet/sec (3 m/sec) and the effective collecting area of the deflector electrode was 8.75 ft.²/1000 cfm (0.8 m²/1000 cfm). It was determined that this apparatus by itself had an efficiency of 86% on 0.4 to

0.75 micron particles, 94% on 0.75 to 1.2 micron
particles, 98.2% on 1.2 to 2.0 micron particles, and
99.8% on 2.0 to 3.5 micron particles. It should be noted
5 at the ionizer exit in this example was over 900
micro-C/gm. These results, when compared with those
achieved with the ionizer alone, show the substantial
increase in the particle charging resulting when dis-
charge electrode 21 is used in combination with deflector
10 electrode 23.

In view of the above, it will be seen that the
several objects of the invention are achieved and other
advantageous results attained.

As various changes could be made in the above
15 constructions and methods without departing from the
scope of the invention, it is intended that all matter
contained in the above description or shown in the
accompanying drawings shall be interpreted as illustra-
tive and not in a limiting sense.

WE CLAIM:

1. A method for charging submicron and larger particles in a gas stream, characterized by:

generating an electrostatic field having a high voltage gradient of at least 6 KV/cm and extending along a path of the gas stream for a predetermined distance;

generating a first spatially discontinuous corona generally towards the upstream end of the electrostatic field to create a first band of ionization in said path and extending transversely thereacross, said band containing regions of relatively low ionization bordered by regions of relatively high ionization, said low ionization regions being substantially evenly spaced along said band transverse to the path of the gas stream;

generating a second spatially discontinuous corona downstream of the first corona in the electrostatic field to create a second band of ionization in said path and extending transversely thereacross, said second band containing regions of relatively low ionization bordered by regions of relatively high ionization, the regions of relatively high ionization of the second band being aligned along the path of the gas stream with the regions of relatively low ionization of the first band and the regions of relatively low ionization of the second band being aligned along the path of the

gas stream with the regions of relatively high ionization of the first band, the total corona current density of the discontinuous coronas being at least approximately 4 ma/m^2 ; and

40
45
passing the gas stream containing particles to be charged along the path through said electrostatic field and said bands of ionization to highly charge substantially all the submicron and larger particles in the gas stream.

2. A method as set forth in Claim 1 characterized in that the predetermined distance is at least 2.5 cm.

3. The method as set forth in Claim 1 characterized in that the total corona current density of the discontinuous coronas is in the range of from approximately 10.8 ma/m^2 to approximately 20 ma/m^2 .

4. The method as set forth in Claim 1 characterized in that the voltage gradient of the electrostatic field is in the range of from approximately 7.9 KV/cm to approximately 8.7 KV/cm.

5. The method as set forth in Claim 1 characterized in that the gas stream passes through the electrostatic field at a velocity of at least approximately 2.6 m/sec.

6. An apparatus for charging submicron and larger particles in a gas stream characterized by at least one substantially planar plate constituting a plate electrode for connection to one terminal of a
5 high voltage, unidirectional-current source; a plurality of substantially evenly spaced-apart needles forming a corona discharge electrode for connection to

the other terminal of said source thereby to form an electrostatic field between said needles and said
10 plate and to cause a corona current to flow therebetween; and a passage defined by said plate and said needles for flow therethrough from an inlet to an outlet thereof of a gas stream containing particles to be charged; said needles being disposed substantially parallel to said plate and spaced from said
15 plate a distance such that the voltage gradient of the electrostatic field during operation is at least 6 KV/cm, said needles being arranged in at least first and second groups, the needles of the first group
20 being offset with respect to the needles of the second group transversely to the direction of flow of the gas stream, the effective area of the plate and the spacing between adjacent needles being such that the corona current has a current density of at least 4 ma/m^2 ,
25 whereby during operation high corona current density and high voltage gradient of the electrostatic field are achieved, corona suppression is reduced, and high particle charges are achieved.

7. The apparatus as set forth in Claim 6 further characterized by a high voltage unidirectional-current power supply for connection to said corona discharge electrode and said plate electrode to impress a
5 high operating voltage thereacross to form an electrostatic field and to cause a corona current to flow between the corona discharge electrode and the plate electrode, said power supply including protective circuitry for automatically opening the circuit between
10 the power supply and the electrodes during arcing and sparkover conditions to quench any arcs and sparkovers and then automatically closing said circuit, and means for maintaining the voltage across the discharge and plate electrodes above some predetermined level for a

15 predetermined length of time but without supplying
sufficient current to the electrodes to maintain an
arc or sparkover for the predetermined length of time,
whereby the voltage across the discharge and plate
electrodes quickly recovers to the operating voltage
20 once any arcs and sparkovers are quenched and the
circuit between the ionizer and the power supply is
reclosed.

8. The apparatus of Claim 6 further charac-
terized in that a non-corona deflector electrode is
positioned downstream from said collector plate and
said corona discharge electrode for connection to a
5 first terminal of said high voltage, unipolar source,
said first terminal having the same polarity as the
charges on the particles, and at least one collecting
plate disposed substantially parallel to the deflector
electrode for connection to the other terminal of said
10 source, said collecting plate and said deflector
electrode having an air gap therebetween for passage
of the gas stream in which the charged particles are
entrained, whereby when said collecting plate and
said deflector electrode are connected to said
15 terminals they create an electrostatic field across
said air gap for deflecting the charged particles in
the air gap toward said collecting plate, said
deflector electrode including at least one conductor
for connection to said first terminal and separated
20 from the air gap by a layer of dielectric material
having a dielectric constant greater than that of air,
whereby sparkover between the deflector electrode and
the collecting plate is suppressed and high electro-
static fields therebetween are achieved.

9. An apparatus as set forth in Claim 8 further characterized by a second collector plate disposed generally parallel to the first collector plate for connection to said other terminal of the high voltage source, said deflector electrode being generally planar and disposed intermediate said first and second collector plates with generally equal sized air gaps between the deflector electrode and each plate for passage of the gas stream therethrough, the conductor of the deflector electrode being generally planar and embedded in the dielectric material, whereby sparkover between the deflector electrode and the collecting plates is suppressed and high electrostatic fields for deflection of the charged particles are achieved between the deflector electrode and each of said plates.

10. An apparatus for collecting submicron and larger particles in a gas stream, characterized by:

an ionizer having at least one substantially planar plate constituting a plate electrode for connection to one terminal of a high voltage, unidirectional-current source; a plurality of spaced-apart needles constituting a corona discharge electrode for connection to the other terminal of said source thereby to form an electrostatic field between said needles and said plate electrode and to cause a corona current to flow therebetween; and a passage defined by said plate electrode and said needles for flow therethrough of a gas stream containing particles to be charged,

said passage having an inlet end and an outlet end;

25 the direction of flow of the gas stream during operation being substantially from the inlet end to the outlet end of said passage;

30 the needles of the ionizer being disposed substantially parallel to said plate electrode and spaced from said plate electrode a distance such that the voltage gradient of the electrostatic field during operation is at least 6 KV/cm, said needles being arranged in at least first and 35 second groups, the needles of the first group being offset with respect to the needles of the second group transversely to the direction of flow of the gas stream, the effective area 40 of the plate electrode and the spacing between adjacent needles being such that the corona current has a current density of at least 4 ma/m^2 , whereby during operation high corona current density and high voltage gradient of 45 the electrostatic field are achieved, corona suppression is reduced, high particle charges of substantially a single polarity are achieved, and a 50 minimal amount of electrical power is consumed;

55 a non-corona deflector electrode disposed generally downstream of the ionizer for connection to a first high voltage terminal of said source,

said terminal having the same polarity
as the charges on the particles; and
at least one collecting plate
disposed substantially parallel to
the deflector electrode for connection
to said one terminal of said source,
said collecting plate and said deflector
electrode having an air gap therebetween
for passage of the gas stream in which
the particles charged by the ionizer
are entrained, whereby when said
collecting plate and said deflector
electrode are connected to said termi-
nals they create an electrostatic field
across said air gap for deflecting the
charged particles in the air gap toward
said collecting plate; said deflector
electrode including at least one con-
ductor for connection to said first
terminal and separated from the air
gap by a layer of dielectric material
having a dielectric constant greater
than that of air, whereby sparkover
between the deflector electrode and
the collecting plate is suppressed
and high electrostatic fields there-
between are achieved.

11. The apparatus as set forth in Claim 10
characterized in that the collecting plate and the
plate electrode of the ionizer are one substantially
continuous plate.

12. The apparatus as set forth in Claim 11 further characterized by including a housing for flow therethrough of the gas stream, said housing having a top, bottom, sides and inlet and outlet ends, and
5 further including a second substantially continuous plate substantially parallel to the first continuous plate, both plates extending generally in the direction of flow of the gas stream and from top to bottom of the housing, said plates defining a collecting section
10 having inlet and outlet ends, the corona discharge electrode of the ionizer being disposed downstream of the inlet end of the collecting section between and generally equidistant from said parallel plates, said deflector electrode being generally planar and having
15 equal sized air gaps between itself and each collecting plate for passage of the gas stream therethrough, said deflector electrode including at least one conductor for connection to said first terminal and embedded in a dielectric material having a dielectric constant
20 and a volume resistivity greater than those of air, thereby to limit the current that can flow from said conductor through the air gaps to the collecting plates to a magnitude less than would flow therebetween if air alone were disposed between the conductor
25 and the collecting plate, whereby sparkover between the deflector electrode and the collecting plate is suppressed and high electrostatic fields therebetween are achieved.

13. The apparatus as set forth in Claim 12 further characterized by a set of irrigated baffles disposed generally downstream of the deflector electrode for collecting the charged submicron particles
5 remaining entrained in the gas stream, said set of baffles having:

10 a first row of generally vertical
irrigated strips of generally equal
width, each extending transversely of
the direction of flow of the gas stream
generally from the top to the bottom of
the housing, said row being disposed
generally downstream of said ionizer
and extending from side to side of the
15 housing with the strips spaced equally
apart across the housing to form a
plurality of slots having a predeter-
mined slot width equal to the width
of the individual strips;

20 a second row of generally vertical
irrigated strips having widths
generally equal to the predetermined
slot width, said second row being
disposed generally downstream from
25 the first row toward the outlet end
of the housing, each strip extending
transversely of the direction of the
gas stream and generally from the top
to the bottom of the housing, the
30 second row being spaced from the first
row a distance in the range of from
approximately 0.8 times to approxi-
mately 3 times the predetermined slot
width, the strips of the second row
35 being aligned with the slots in the
first row along the direction of flow
of the gas stream to form a plurality
of targets for the charged submicron
particles passing through the slots
40 in the first row, said strips of the

second row forming a plurality of slots of the predetermined slot width aligned with the strips of the first row along the direction of flow of the gas stream; and

45

a third row of generally vertical, irrigated strips substantially identical to the first row disposed downstream of the second row a distance in the range of from approximately 0.8 times to approximately 3 times the predetermined slot width, the strips of the third row being aligned with the slots in the second row along the direction of flow of the gas stream to form a plurality of targets for the charged submicron particles passing through the slots in the second row.

50

55

14. The apparatus of Claim 12 further characterized in that:

the first and second substantially continuous plates are spaced apart a first distance to form a passage therebetween; and

5

said deflector electrode has a width measured perpendicular to the plates in the range of from approximately one-twentieth the first distance to approximately one-half the first distance, the distance between the discharge electrode and the deflector electrode being in the range of from approximately one-fourth the first distance to approximately the first distance,

10

15

20 whereby during operation a decel-
erating electric field is generated
in the vicinity of the deflector
electrode, and the space charge and
precipitating fields in the region
along the gas stream between the
discharge and deflector electrodes
25 are increased.

15. The apparatus of Claim 13 further
characterized in that said predetermined slot width
being no more than 2.5 cm.

16. The apparatus of Claim 10 further
characterized by means for irrigating the surface
of said collecting plate.

17. The apparatus of Claim 16 further
characterized in that said means for irrigating the
surface is an apparatus having a closed low pressure
chamber disposed generally at the upper reach of a
5 surface to be irrigated and extending horizontally
along its length, said chamber having a plurality of
relatively large apertures spaced along the length of
the surface to allow liquid in the chamber to drain
down uniformly and at relatively low pressure over the
10 surface to be irrigated; and a high pressure line for
carrying the irrigating liquid at relatively high
pressure to the low pressure chamber, said high
pressure line extending generally along the length of
the low pressure chamber and having a plurality of
15 means for discharging irrigating liquid into the low
pressure chamber, whereby the pressure of the irri-
gating liquid in the low pressure chamber is maintained
substantially even over the length of the surface to be
irrigated so that irrigating liquid continuously flows
20 evenly and uniformly out of said apertures and down
over the surface to be irrigated without splashing or
squirting.

FIG. 1

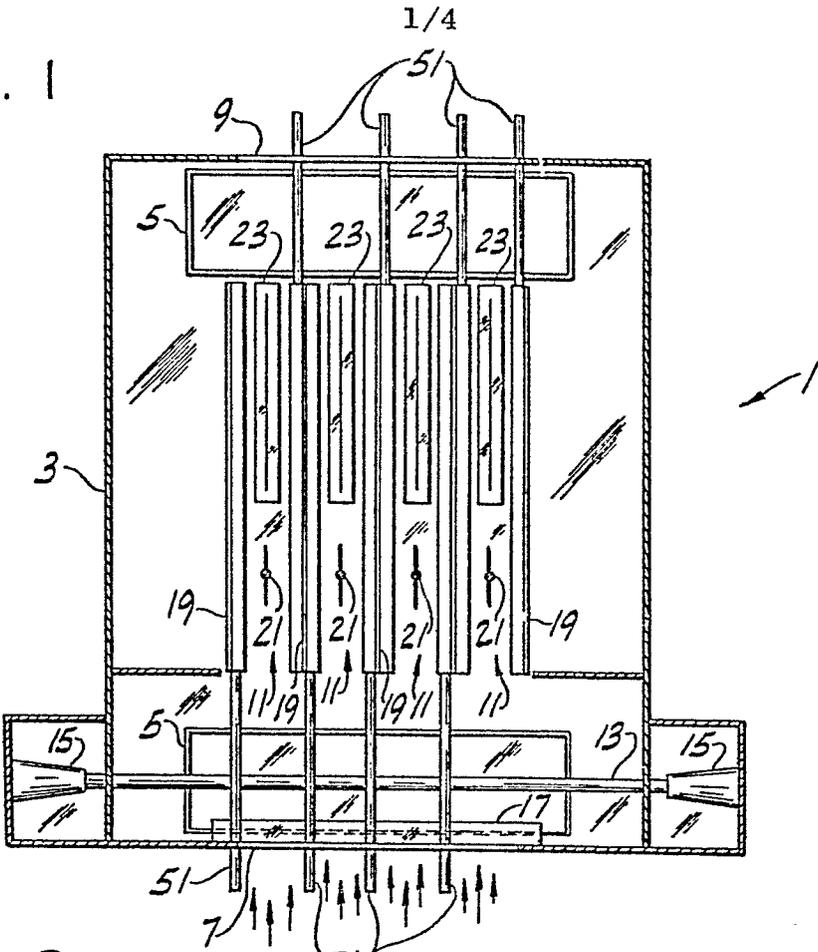
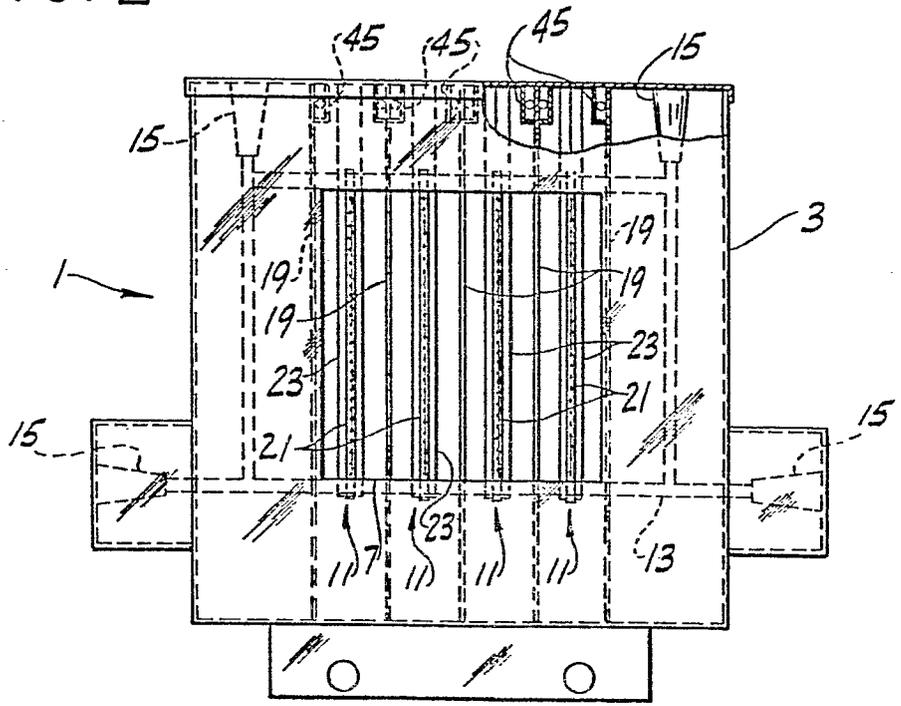


FIG. 2



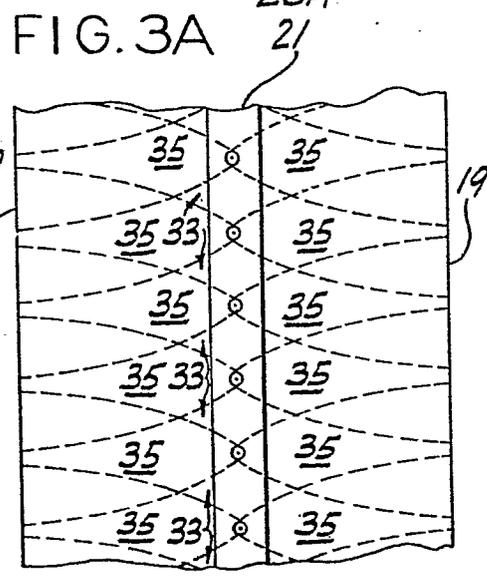
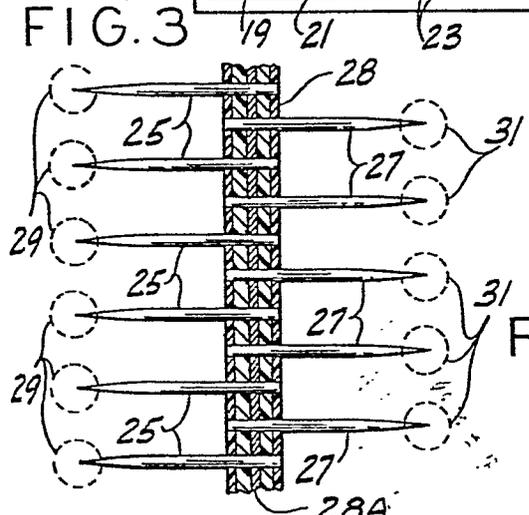
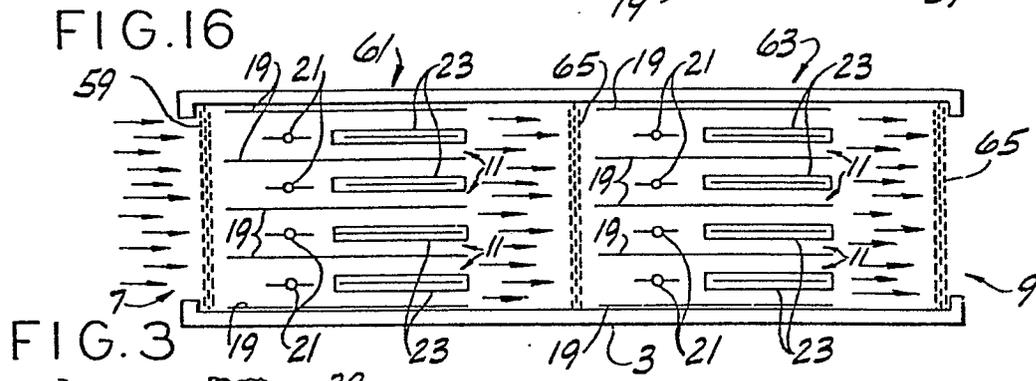
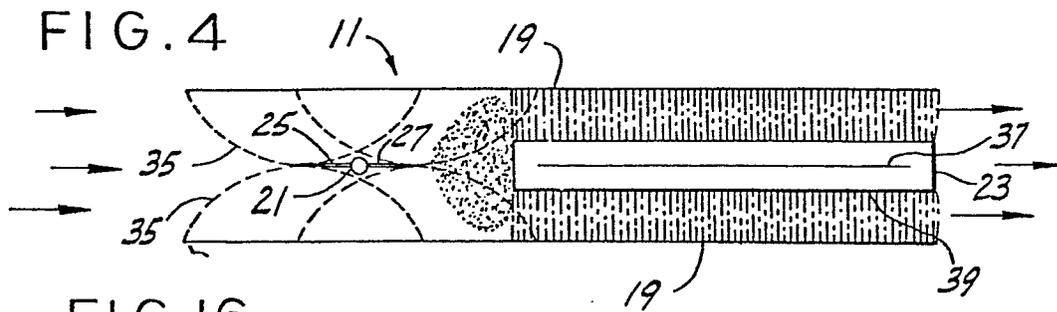
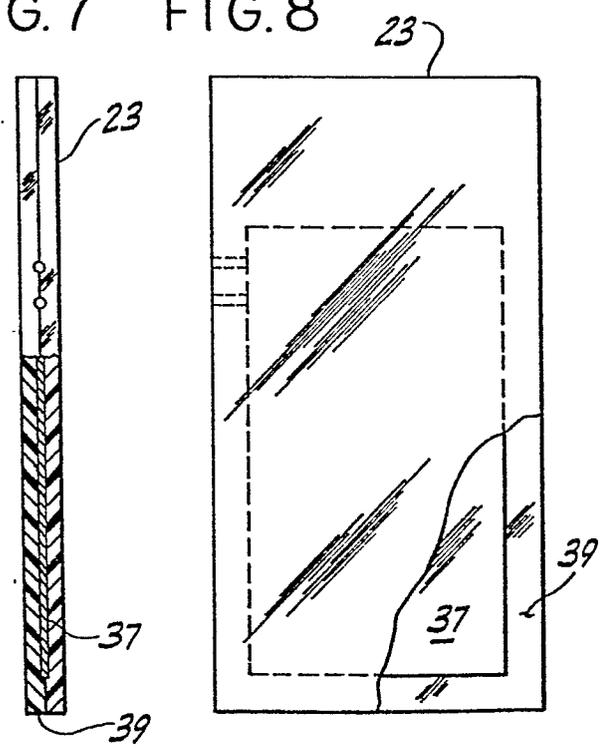


FIG. 7

FIG. 8



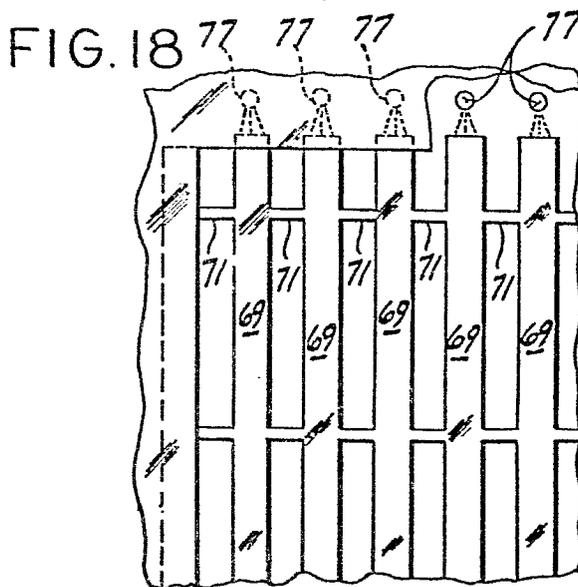
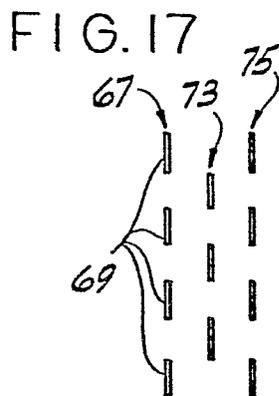
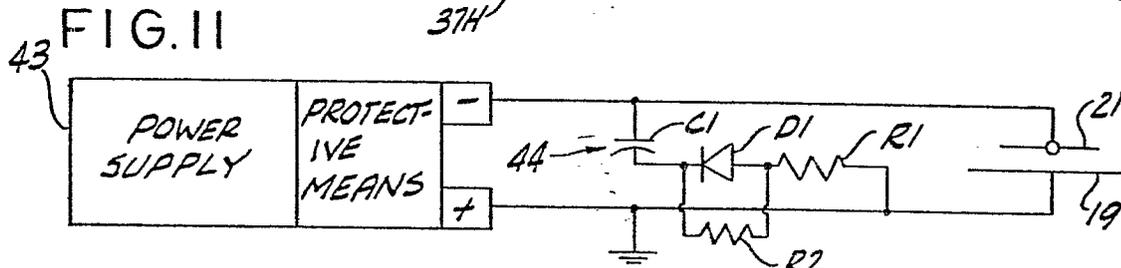
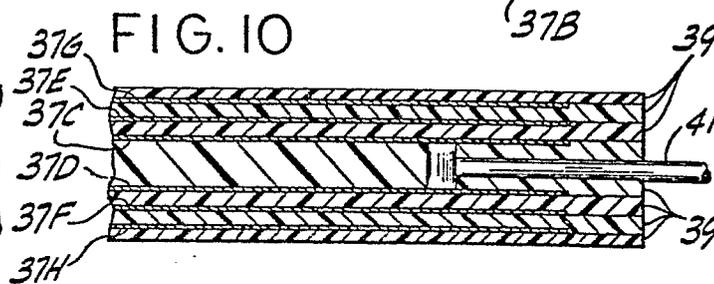
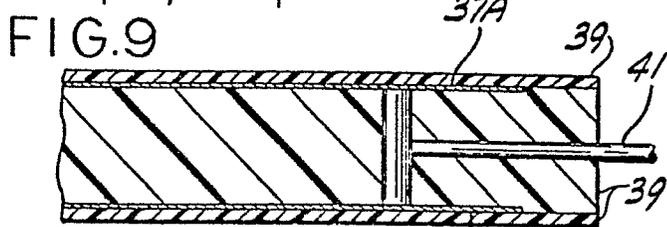
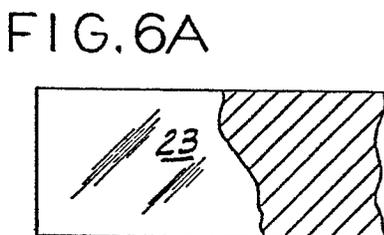
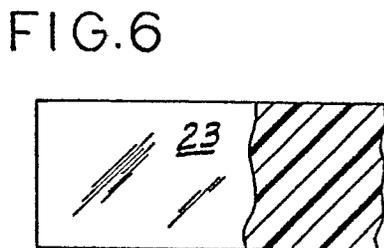
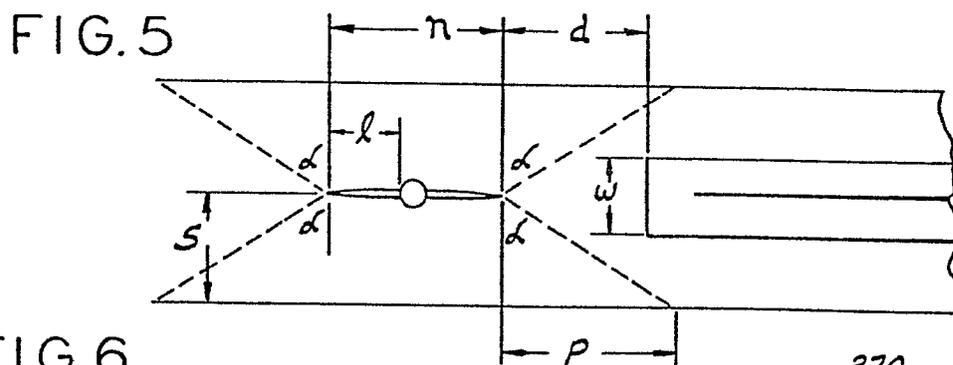


FIG. 13

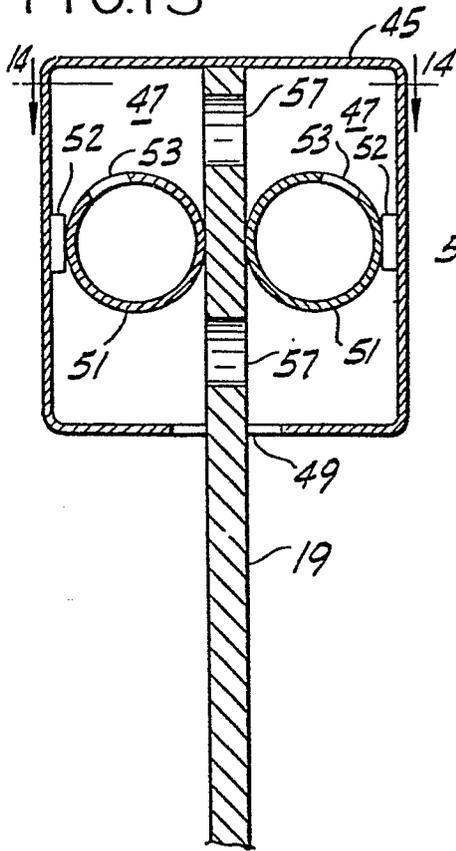


FIG. 12

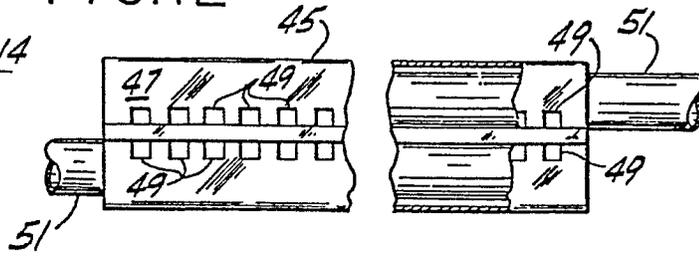


FIG. 15

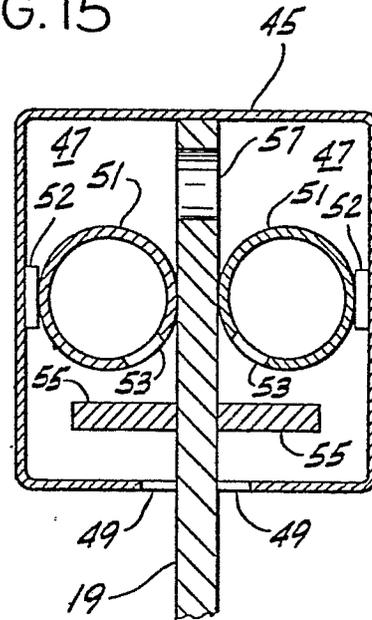
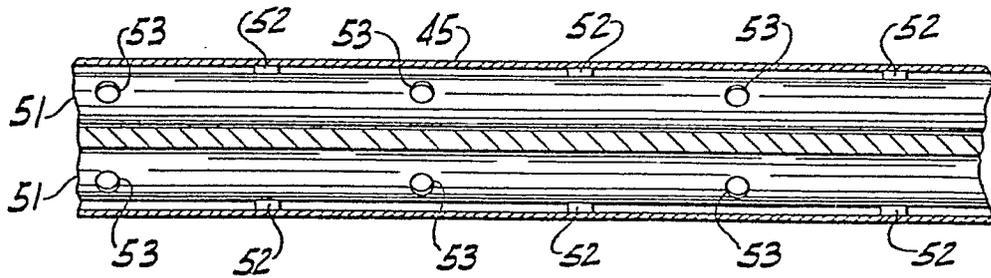


FIG. 14





DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	<p><u>US - A - 4 119 416</u> (K. HAYASHI et al.)</p> <p>* Claim 1; column 2, lines 23-41; figures 2,4 *</p> <p>--</p>	1,6,8, 9,10, 11,12, 14	B 03 C 3/38 3/40 3/68
	<p><u>US - A - 3 650 092</u> (M.C. GOURDINE et al.)</p> <p>* Column 4, line 20 - column 5, line 36; figure 1 *</p> <p>--</p>	1,6,8, 9,10, 11,12 14	
A	<p><u>DE - A - 2 601 358</u> (HARA, KEUCHI)</p> <p>* Claims 1,3; page 6, last paragraph - page 7, first paragraph; figures 1,3,4, *</p> <p>--</p>	6	TECHNICAL FIELDS SEARCHED (Int.Cl. 3)
A	<p><u>DE - A - 2 018 447</u> (METALLGESELLSCHAFT A.G.)</p> <p>* Claims 1,2 *</p> <p>--</p>	6	B 03 C 3/38 3/40 3/41 3/53 3/68 3/78 3/12 3/08
A	<p><u>US - A - 3 958 961</u> (E. BAKKE)</p> <p>* Column 4, line 20 - column 6, line 12; figures 2,3 *</p> <p>--</p>	13,16	
A	<p><u>FR - A - 2 314 766</u> (DART INDUSTRIES)</p> <p>* Page 5, lines 6-16; figure 3 *</p> <p>----</p>	16,17	CATEGORY OF CITED DOCUMENTS
			<p>X: particularly relevant</p> <p>A: technological background</p> <p>O: non-written disclosure</p> <p>P: intermediate document</p> <p>T: theory or principle underlying the invention</p> <p>E: conflicting application</p> <p>D: document cited in the application</p> <p>L: citation for other reasons</p>
<p><input checked="" type="checkbox"/> The present search report has been drawn up for all claims</p>			<p>&: member of the same patent family, corresponding document</p>
Place of search	Date of completion of the search	Examiner	
The Hague	21.08.1980	DECANNIERE	