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Huang et al.

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[54] **ELECTROSTATIC PRECIPITATING METHOD**

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Related U.S. Application Data

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[52] **U.S. Cl.** ..... **55/4;** 21/DIG. 2; 23/260; 23/277 C; 23/284; 55/5; 55/11; 55/13; 55/114; 55/117; 55/121; 55/129; 55/131; 55/135; 55/138; 55/146; 55/155; 55/DIG. 38; 204/157.1 R; 250/527; 250/432; 423/52; 423/155; 423/224; 423/242; 423/545; 423/554

[51] **Int. Cl.**[2] **B03C 3/74;** B03C 3/88

[58] **Field of Search** ..... 55/2, 4, 11, 12, 13, 101, 55/108, 113, 114, 120, 121, 131, 136, 137, 138, 154, 155, 5, 117, 129, 135, 146, DIG. 38; 423/52, 155, 224, 242, 454, 554, 210, 220, 222, 235, 246, 247, 215.5; 204/157.1 R, 157.1 HE, 158, 158 HE; 250/527, 428, 432, 435, 436, 437, 438, 493, 503, 504; 21/53, 54 R, 55, 74 R, 74 A, 102, DIG. 2

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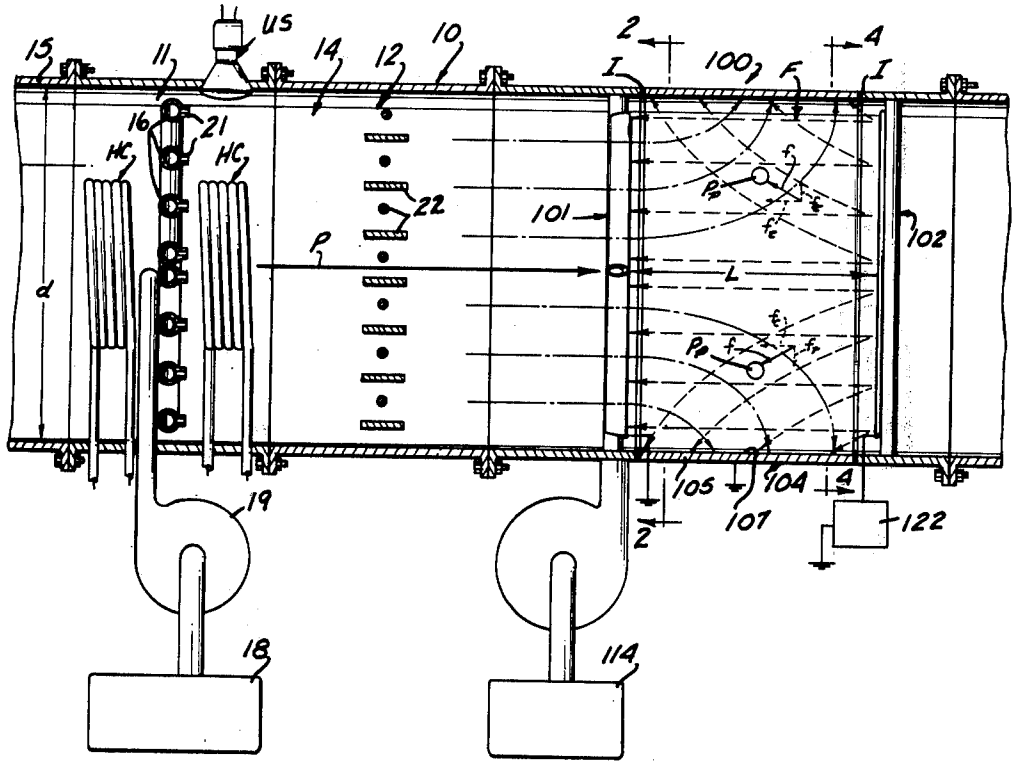
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Attorney, Agent, or Firm—B. J. Powell

[57] **ABSTRACT**

An electrostatic precipitating method which includes moving a gas stream with charged particles entrained therein along a prescribed path and imposing an electrostatic force field on the charged particles with a first component of force exerted on the particles opposite to the direction of movement of the particles to slow the particles down and a second component of force exerted on the particles generally normal to the path of movement of the particles to separate the particles from the gas stream.

7 Claims, 13 Drawing Figures



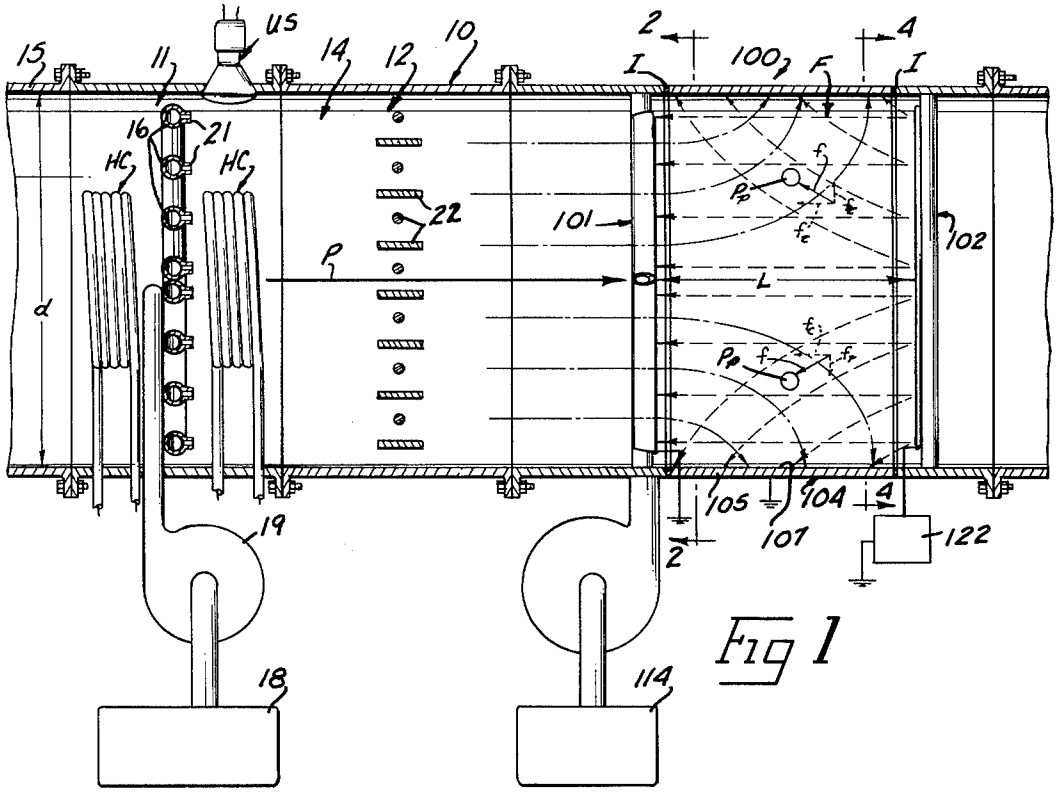


Fig 1

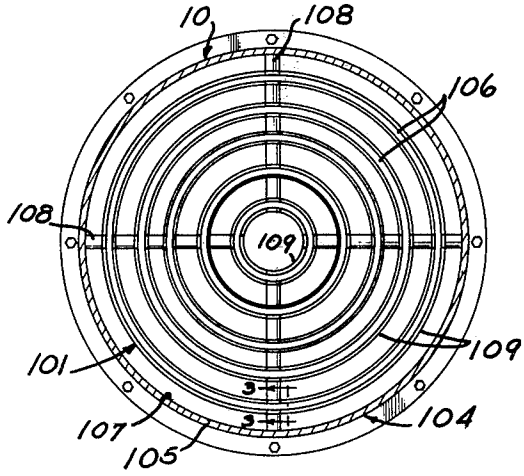


Fig 2

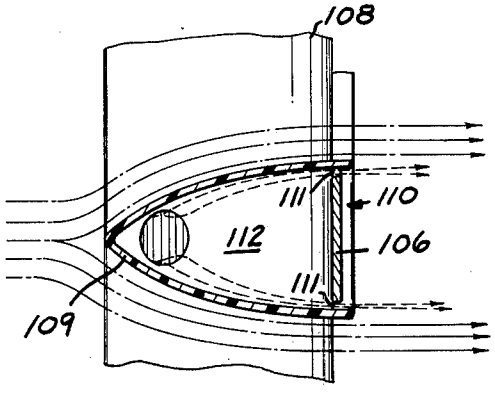


Fig 3

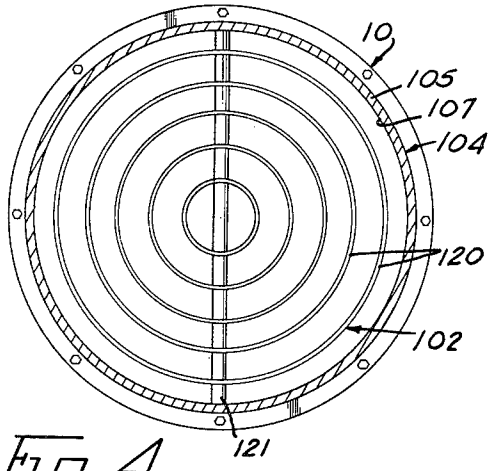


Fig 4

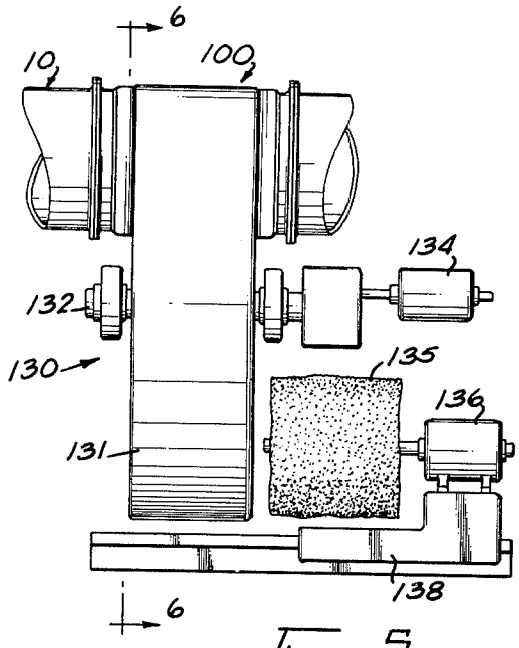


Fig 5

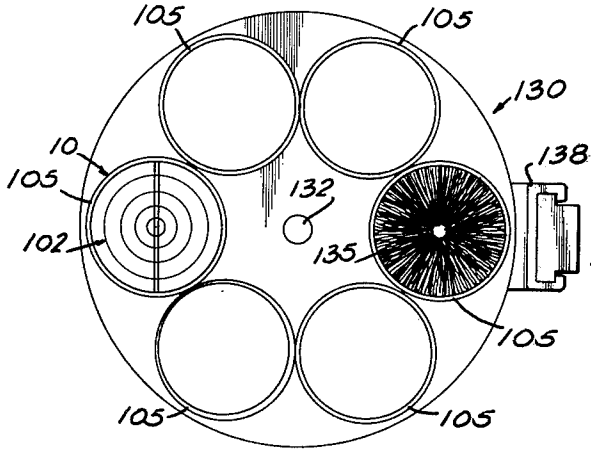


Fig 6

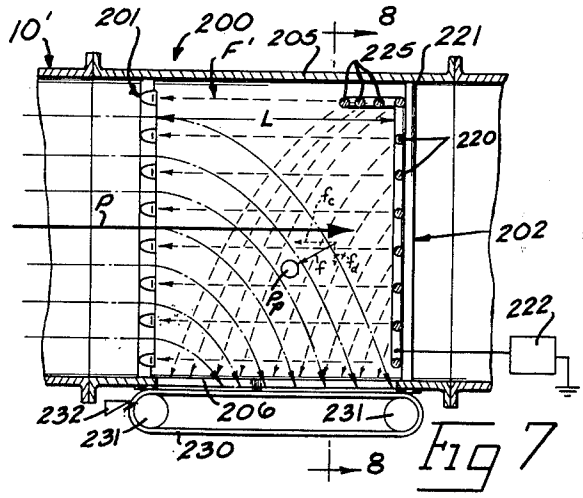


Fig 7

Fig 8

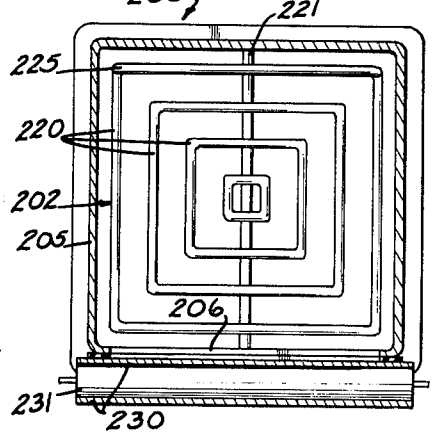
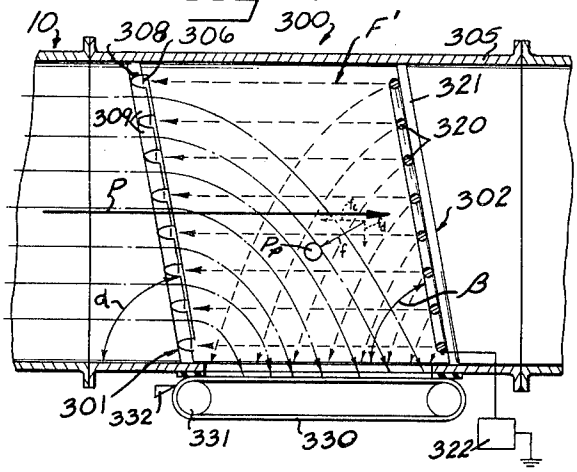


Fig 9



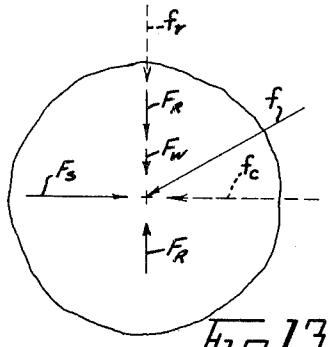


Fig 13

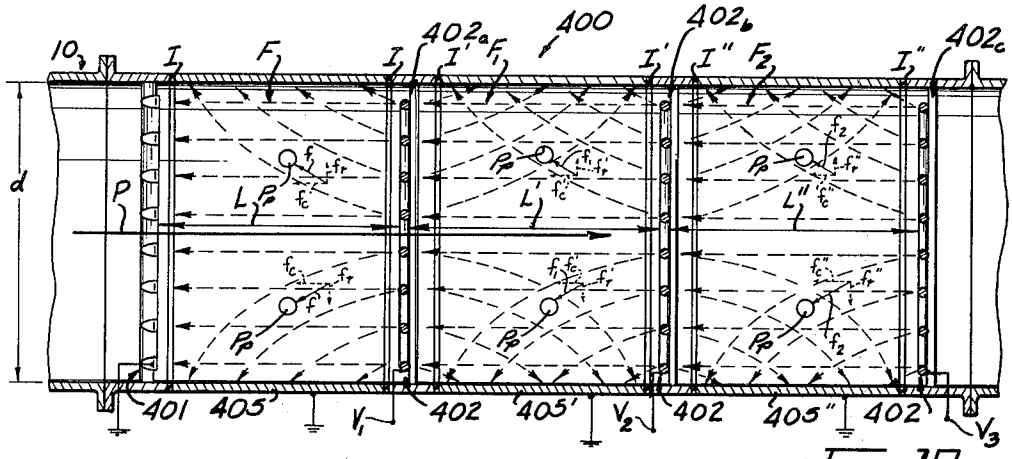


Fig 10

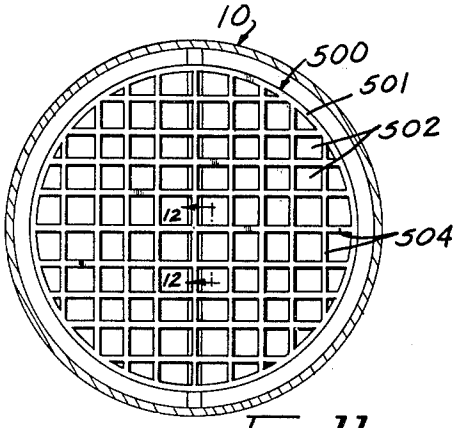


Fig 11

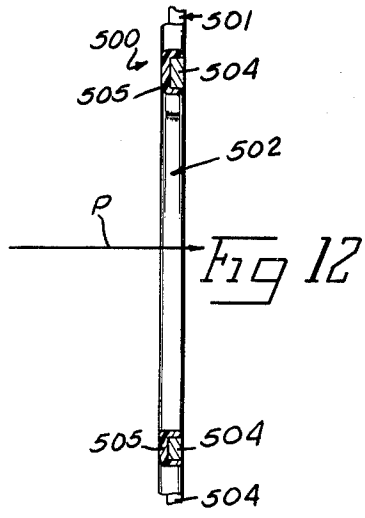


Fig 12

ELECTROSTATIC PRECIPITATING METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a division of our copending application Ser. No. 249,167, filed May 1, 1972 entitled "Electrostatic Precipitating Apparatus and Method", now U.S. Pat. No. 3,782,905.

BACKGROUND OF THE INVENTION

Electrostatic precipitators are available on the market today. These prior art precipitators first charge the entrained particulate matter in a gas stream and then separate the thusly charged particles by passing the gas stream with the charged particles therein through a series of charged members or grids imposed in the stream path. All of these precipitators collect the separated particles on the oppositely charged members or grids. This causes the collecting efficiency of the grids to quickly lose their collecting ability due to the insulation formed by the collected particles and requires a greater grid potential to maintain operation. Attempts have been made to solve this problem by intermittently preventing the gas stream from flowing across the grid and rapping the grid to dislodge the particles therefrom so that gravity will cause the particles to fall from the grid to be collected. This not only prevents the desirable continuous full operation of the precipitator but also does not completely clean the grid, thus reducing the effective operational time before the grids must be again rapped.

Because of the inefficiency of such prior art precipitators, attempts have been made to mechanically slow down the movement of the particles within the precipitator by creating highly turbulent zones in the gas stream within the precipitator to form eddies which entrap the particles. In order to create sufficient turbulency to significantly increase the particle collection capability of the precipitator, a back pressure is created requiring more power to force the gas stream through the precipitator and thus increase the cost of operating same.

SUMMARY OF THE INVENTION

These and other problems and disadvantages associated with the prior art are overcome by the invention disclosed herein by providing an electrostatic precipitating apparatus and method which separates the particles from a gas stream without collecting the particles on the primary field producing grids within the stream path so that operation is continuous. Moreover, the invention creates minimum back pressure in the stream to minimize the power required to force the gas stream through the invention. Also, because the particles are not collected on the grids within the gas stream the electrical field generating power is maintained at a minimum. Moreover, the apparatus of the invention is extremely simple thereby minimizing the construction and installation cost thereof.

The apparatus of the invention includes a duct through which the gas stream is forced, charging means for charging the particulate matter in the gas stream, and separating means for separating the charged particulate matter from the gas stream. Converter means may be provided for converting gaseous pollutants into particulate pollutants for separation.

One embodiment of the separating means includes an entry grid with a charge of opposite polarity to the charge on the particulate matter and an exit grid downstream of the entry grid with a charge of like polarity to the charge on the particulate matter. At least a portion of the duct wall between the entry and exit grids is charged like the entry grid to provide a collecting surface onto which the particulate matter is deposited. This is because an electrostatic field is generated between the entry and exit grids and the portion of the duct wall with a charge thereon which exerts a resultant force on the charged particles which has a major component of force contra to the direction of gas flow and a minor component of force normal to the direction of gas flow and toward the charged portion of the duct wall.

Additional exit grids may be spaced from each other downstream of the entry grid. The first downstream exit grid is charged to a first potential of like polarity to the charged particles, the second downstream grid is charrged to a second potential of like polarity to charged particles but higher than the first potential, the third grid is charged to a third potential of like polarity to the charged particles but higher than the second potential, etc. Thus, each exit grid has a higher potential than the next upstream exit grid to generate an electrostatic force field between each pair of adjacent grids that imposes a force on the charged particles contra to the direction of gas flow.

These and other features and advantages of the invention will become more apparent upon consideration of the following specification and accompanying drawings wherein like characters of reference designate corresponding parts throughout the several views and in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a longitudinal cross-sectional view of one embodiment of the invention;

FIG. **2** is a cross-sectional view taken along line **2—2** in FIG. **1**;

FIG. **3** is an enlarged cross-sectional view taken along line **3—3** in FIG. **2**;

FIG. **4** is a cross-sectional view taken along line **4—4** in FIG. **1**;

FIG. **5** is a top view of the invention of FIG. **1** showing a wall cleaning mechanism.

FIG. **6** is a cross-sectional view taken along line **6—6** in FIG. **5**;

FIG. **7** is a cross-sectional view showing a second embodiment of the separating means of the invention;

FIG. **8** is a cross-sectional view taken along line **8—8** in FIG. **7**;

FIG. **9** is a longitudinal cross-sectional view of a modified form of the separating means shown in FIG. **7**;

FIG. **10** is a longitudinal cross-sectional view showing a third embodiment of the separating means of the invention;

FIG. **11** is a front elevational view showing an alternate form of the grid construction;

FIG. **12** is a cross-sectional view taken along line **12—12** in FIG. **11** showing modification of the grid shown in FIG. **11**; and,

FIG. **13** is a free body diagram illustrating the forces on one of the entrained charged particles in the gas stream as it passes through the separating means.

These figures and the following detailed description disclose specific embodiments of the invention, however, the inventive concept is not limited thereto since it may be embodied in other forms.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Referring to the figures, the apparatus of the invention includes generally a duct **10,** a converter **11** for converting gaseous pollutants in a gas stream passing through the duct **10** into particulate matter, a corona discharge unit **12** downstream of the converter **11** for charging the particulate matter entrained in the gas stream, and a separating section downstream of the corona discharge unit for separating the charged particulate matter from the gas stream. The first embodiment of the separating section is designated **100,** the second embodiment is designated **200,** the modification of the second embodiment is designated **300,** and the third embodiment is designated **400.**

Referring to FIG. **1,** the duct **10** is illustrated with a circular cross-section but may have other configurations such as the square cross-section illustrated in FIGS. **7–9.** The gas stream is forced or drawn through duct **10** by an external pumping means (not shown) as is well known in the art.

The converter **11** is placed within the passage **14** through duct **10** adjacent the entry end **15** thereof which receives the gas stream containing pollutants therein. The pollutants in the gas stream are usually in both gaseous form and in particulate form. The converter **11** converts the gaseous pollutants into a particulate form. Particulate as used herein means both solids and liquid droplets since both may be electrostatically charged for separation. While it is understood that many pollutants may be found, normally sulfur dioxide, carbon monoxide, and nitrogen oxides are found in exhaust gases in a gaseous form while carbon particles are normally found in particulate form. The converter **11** is used to convert the pollutants in gaseous form into particulate form by injecting a converting medium into the gas stream.

The converter **11** may have several configurations but is shown in FIG. **1** as a series of concentrically arranged pipes **16** located in passage **14** of duct **10** connected to a medium source **18** through a pump **19** and manifold **20.** A plurality of nozzles **21** are provided on each pipe **16** for injecting the converting medium from source **18** into the gas stream entering the duct **10.** While the nozzles **21** are illustrated as facing downstream, it is to be understood that they may be made to face upstream. It is also to be understood that the converting medium may be different for each gaseous pollutant to be converted and there may be a set of pipes **16** for each converting medium to be used or the converting mediums may be injected from a single set of pipes **16.** Various converting mediums may be used, however, a list of possible mediums to be used are set forth in Table I hereinafter. The list of mediums shown in Table I is in no way meant to be all inclusive. Thus, the gas stream issues from the converter with all of the pollutants to be separated entrained in the gas stream as particulate matter ready for ionization.

The gas stream then passes through the corona discharge unit **12** of conventional construction. While various configurations may be used, a conventional plate-wire arrangement **22** is illustrated. The unit **12** may charge the particulate matter in the gas stream either positively or negatively, however, it has been found that a sufficient charge will be imposed on the particulate matter when a voltage of 20,000 volts is imposed on the plate-wire arrangement **22.** Thus, the gas stream exits the corona discharge unit **12** with the particulate matter entrained therein charged.

The first embodiment **100** of the separating section is shown in FIGS. **1–4,** and includes an entry grid **101** and an exit grid **102** spaced a prescribed distance L apart. The entry grid **101** is oppositely charged with respect to the charge on the particulate matter, here shown as grounded, while the exit grid **102** is charged the same as the charge on the particulate matter. Oppositely charged or opposite polarity as used herein includes a charge with unlike polarity or grounded. Thus, while the entry grids and duct walls are illustrated herein as grounded, they could have a high voltage of unlike polarity imposed thereon. The section **104** of duct **10** between the grids **101** and **102** has its side wall **105** oppositely charged like entry grid **101** or grounded as seen in the figures. Thus, when the grids **101** and **102** and side wall **105** are powered, an electrostatic force field will be established between the grids **101** and **102** and side wall **105** that will exert a force on the charged particulate matter entrained in the gas stream opposite to the direction of gas flow and normal to the direction of gas flow to separate the charged particulate matter from the gas stream and deposit same on the inside surface **107** of the side wall **105.**

Referring now more specifically to FIGS. **2** and **3,** the entry grid **101** includes a plurality of concentric conductor rings **106** carried on the downstream side of a plurality of radially extending circumferentially spaced support ducts **108** made of an insulating material. The rings **106** are arranged in a plane perpendicular to the path P of gas flow through the duct **10.** A plurality of concentrically arranged annular ducts **109** also made of an insulating material extend between and are connected to the radial ducts **108** on the upstream side of the conductor rings **106.** The annular ducts are hollow and are provided with an open mouth **110** on the downstream side thereof which is wider than the rings **106** and within which the rings **106** are positioned as seen in FIG. **3** to provide an annular opening **111** on both sides of the rings **106** which communicates with the cavity **112** within the annular duct **109.** Thus, the annular ducts **109** completely cover the upstream side of the conductor rings **106** as well as the edges thereof. The rings **106** may be recessed within the annular ducts **109** to insure passage of the charged particulate matter past the conductor rings **106** before they are attracted toward the rings **106** as will become more apparent.

The internal passage in the radial ducts **108** is connected to a pressurized clean air source **114** and communicates with the cavities **112** in the annular ducts **109** so that the clean air enters through the passage in the ducts **108,** passes through the cavities **112** and is discharged around the conductor rings **106** through the annular openings **111.** This further insures passage of the charged particulate matter downstream of grid **101** before they are attracted toward rings **106** as will become more apparent. The rings **106** are grounded so as to be oppositely charged with respect to the charge on the particulate matter.

As best seen in FIGS. **1** and **4,** the exit grid **102** includes a plurality of annular wire rings **120** mounted on

a diametrically extending insulated support **121** so that rings **120** are concentric and lie in a plane perpendicular to the path P of the gas flow. The rings **120** are connected to a voltage source **122** so that the rings have a potential imposed thereon of the same polarity as the charge on the particulate matter. Because the side wall **105** is grounded like the rings **106**, an electrostatic force field F is set up between the grids **101** and **102** and between the grid **102** and side wall **105** which exerts a resultant force *f* on each particle of the charged particulate matter which has a first major component f_c directed oppositely to the direction of gas flow to retard the downstream movement of the particle and a second component of force f_r which is directed radially outwardly with respect to the duct **10** to direct the particle toward the nearest portion of the side wall **105** as will become more apparent.

Because the charged particles are deposited on the side wall **105**, means may be provided for cleaning the inside surface **107** of the side wall **105** without interrupting the gas flow through the separating section **100**. One specific embodiment of such a cleaning mechanism is shown in FIGS. **5** and **6** and is designated **130**. Since many embodiments may be devised, this mechanism **130** is shown for illustrative purposes only. The cleaning mechanism **130** is shown in FIGS. **5** and **6** and includes a cylinder **131** which has a plurality of side walls **105** equally spaced about the center of rotation of cylinder **131** so that any one of the side walls **105** may be pivoted into registration with the rest of duct **10**. The cylinder **131** is rotatably mounted by a shaft **132** adjacent the duct **10** so as to allow the side walls **105** to be selectively moved into alignment with the rest of the duct **10**. An indexing motor **134** is connected to shaft **132** so as to allow the side walls **105** to be placed in registration with the duct **10**. A cleaning brush **135** driven by motor **136** is mounted on a carriage **138** diametrically opposite the duct **10** so that when the duct **10** is in registration with one of the side walls **105**, the brush **135** will be in registration with another of the side walls **105**. Brush **135** can be rotated by motor **136** and traversed along the carriage **138** so as to be inserted within the side wall **105** in registration therewith to clean same. Appropriate washing means (not shown) may be provided for insuring that the particulate pollutants on the inside surface of the side wall **105** will be removed as a result of the brushing action. It will also be noted that the side walls **105** are arranged closely adjacent to each other so that when the cylinder **131** is indexed by the motor **134**, gas flow through the duct **10** will not be appreciably interrupted to provide for continuous operation in section **100**.

FIGS. **7** and **8** illustrate the second embodiment **200** of the separating section. It will be understood that the second embodiment **200** will be used to replace the first embodiment **100** in the duct **10** and since the converter **11**, and the corona discharge unit **12** remain the seame, they are omitted from these views for sake of simplicity. It will be noted that the duct **10** illustrated in the second embodiment **200** of the separating section has a square cross-section rather than a circular cross-section as illustrated for the first embodiment of the separating section.

The separating section **200** includes an entry grid **201** and an exit grid **202** spaced a prescribed distance L apart. The entry grid **201** is the same as the entry grid **101** for the first embodiment **100** of the separating section and is oppositely charged with respect to the charge on the particulate matter or grounded as shown herein since the particulate matter has a charge of a prescribed voltage thereon. It will be noted, however, that the grid **201** has a square configuration rather than a circular configuration like the grid **101**, but, the functional arrangement of the grid **201** is the same as the grid **101**.

The exit grid **202** is similar to the grid **102** with a plurality of annular wire rings **220** mounted on a diametrically extending insulated support **221** so that the rings **220** are concentric with each other and lie in a plane perpendicular to the path of the gas flow. It will be noted that the rings **221** are arranged in a configuration like the cross-section of the duct **10** and are thus in the shape of a square as illustrated in FIGS. **7** and **8**. In addition, a plurality of secondary conducting members **225** are provided along the upper edge of the grid **202** and are equally spaced from each other and from the rings **220**. The members **225** are positioned on that side of the exit grid **202** toward the entry grid **201** as will become more apparent. The rings **220** and the members **225** are connected to a voltage source **222** so that the rings and members have a potential imposed thereon of the same polarity as the charge on the particulate matter.

The section **200** has a side wall **205** extending between the grids **201** and **202** with a generally square tubular cross-section. The side wall **205** has an opening **206** in the bottom portion thereof under which is positioned a grounded collector member **230** which is insulated from side wall **205**. While the collector member **230** may have any of a number of different configurations, the member **230** illustrated is a flexible conductive belt mounted on rolls **231** closely adjacent the opening **206** and lying outside of the side wall **205**. A cleaning member **232** is positioned at one end of the member **230** so as to clean the deposited particulate matter therefrom as the flexible member is indexed on the rolls **231**. An appropriate mechanism (not shown) is provided for indexing the member **230** periodically to selectively clean the deposited particulate matter therefrom. It is to be further understood that the side wall **205** may be insulated from the rest of the duct **10** and grounded similarly to that of section **100**.

Since the member **230** is grounded, it will be seen that when the voltage of the same polarity as that on the particulate matter is imposed on the rings **220** and members **225** of the exit grid **202**, an electrostatic force field F′ is set up between the grids **201** and **202** and between the grid **202** and the grounded collecting member **230**. The force field F′ exerts a resultant force *f* on each particle of the particulate matter which has a first major component f_c directed oppositely to the gas flow to retard the downstream movement of the particle and a second component of force f_d directed downwardly perpendicular to the direction of gas flow to force the charged particle toward the collection member **230**. Thus, it will be seen that the particulate matter in the gas stream will be collected on the collection member **230** and then the collection member **230** can be selectively indexed when the particulate matter collected thereon has built up to a prescribed amount. Because the particulate matter is collected on one side of the side wall **205**, it will be seen that the collected particulate matter can be easily disposed of.

Referring now to FIG. **9**, the modification designated **300** of the second embodiment of the separating section is illustrated. Since the converter **11** and discharge corona unit **12** remain the same, they are omitted, however, it is to be understood that they could be used in combination with this embodiment of the separating section **300**. The section **300** includes generally an entry grid **301** and an exit grid **302** mounted within the side wall **305** of duct **10**. It will be noted that the plane of the entry grid **301** is arranged at an angle α with respect to the path P of the gas flow in the vertical direction and perpendicular to the path P in the other direction. The exit grid **302** is arranged at an angle β with respect to the path P of the gas flow in the vertical direction and perpendicular to the path P in the other direction. The angles α and β may be varied to meet the particular requirements of each individual application.

The entry grid **301** is of the same construction as the entry grid **101** in the section **100** except that the arrangement of the insulating ducts **309** and conductor rings **306** are revised to a generally square configuration to match the square configuration of the duct **10** illustrated and modified so that the vertical spacing between the rings **106** is equal. Likewise, the exit grid **302** is similar to the exit grid **102** of the section **100** except that the rings **302** are arranged to conform to the square configuration of the side wall **305** and that the spacing between the rings **320** are equal in a vertical plane. The bottom portion of the side wall **305** is provided with an opening **306** like the opening **206** and a collection member **330** is positioned thereunder like the member **230** so that the charged particulate matter can be collected thereon.

The entry grid **301** and the collection member **330** are connected to ground and the exit grid **302** is connected to the voltage source **332** to charge the exit grid with a potential of the same polarity as the charge on the particulate matter. Thus, it will be seen that an electrostatic force field F′ is established between the entry grid **301** and the exit grid **302** and the exit grid **302** and the collection member **330** so that a resultant force f is imposed on the charged particles of the particulate matter within the section **300** which has a first component f_c directed oppositely to the direction of gas flow and a second component f_d which is directed downwardly toward the collection member **330** normal to the path P of the gas flow. Therefore, the charged particles of the particulate matter entering the section **300** will be displaced downwardly and onto the collection member **330** to separate the particulate matter from the gas stream. The collection member **330** may be indexed as specified for the separating section **200** to remove the collected particulate matter therefrom.

The third embodiment **400** of the separating section is illustrated in FIG. **10**. In this embodiment, an entry grid **401** is provided and a plurality of exit grids **402** are also provided. While any number of exit grids may be used in the section **400**, three are illustrated and are designated 402_a, 402_b and 402_c. The grids **401** and **402** are arranged so as to lie in a plane perpendicular to the direction of the gas flow with the entry grid **401** having the same configuration as the entry grid **101** because the side wall **405** is of a circular cross-section. Likewise, each of the exit grids 402_a–402_c have a configuration similar to the configuration of the exit grid **102** of the first embodiment **100** of the separating section. The exit grid 402_a is spaced a prescribed distance L from the entry grid **401**, the exit grid 402_b is spaced a prescribed distance L′ from the exit grid 402_a and the exit grid 402_c is spaced a prescribed distance L″ from the exit grid 402_b. While various distances L, L′ or L″ may be used, they are illustrated as equal in FIG. **10**, it being understood that these distnaces are dependent upon the diameter d of the duct **10**. The entry grid **401** is grounded as with the other embodiments of the invention, the exit grid 402_a is charged to a first potential V_1 of the same polarity as the charge on the particulate matter, the second exit grid 402_b is charged to a second potential V_2 which is greater than the potential V_1 on the grid 402_a. The next exit grid 402_c is charged to a potential V_3 which is greater than the potential V_2 on the grid 402_b. Thus, there will be a first force field F set up between the entry grid **401** and the first exit grid 402_a which exerts a resultant component of force f on each particle of the charged particulate matter which is directed oppositely to the direction of the gas flow. Likewise, a second electrostatic force field F_1 will be set up between the grids 402_a and 402_b which also exerts a component force f_1 on the particles of the particulate matter which is opposite to the direction of the gas flow. Also, an electrostatic force field F_2 will be set up between the grids 402_b and 402_c that exerts a component of force f_2 on the particles of the particulate matter which is directed oppositely to the direction of the gas flow. Thus, as the particulate matter progresses through the section **400**, the particles have a force exerted thereon which is constantly and oppositely directed to the direction of the gas flow. Because there is a natural self-repulsoin force between the particles of the particulate matter as a result of all of the particles having like charges thereon, this self-repulsion force will tend to displace the particles toward the side walls within the section **400** thus separating them on the side wall **405** as the particles move through the section **400**. To further enhance the separation of the particles from the gas stream, the side wall **405** may be grounded as illustrated for the other embodiments of the separating section to cause the particles to be deposited thereon. Likewise, the grids **401** and **402** may be arranged to cause the particles to be separated in a single downwardly direction as illustrated in FIGS. **7–9**.

Referring to FIGS. **11** and **12**, an alternate embodiment of the entry and exit grids is illustrated and designated **500**. The grid **500** is a plate **501** having a configuration corresponding to the cross-sectional configuration of duct **10** having a plurality of punched openings **502** therethrough to leave narrow ribs **504** in place **501**. To allow use of the grid **500** as an entry grid a thin insulating coating **505** of known material may be used to cover the upstream facing side of plate **501** and the edges of the openings **502** as seen in FIG. **1**. To make an exit grid, the coating **505** is omitted. The grid **500** is substituted for the grids described hereinbefore and serves the same function.

OPERATION

In operation, it will be seen that the polluted gas stream is forced or drawn through the duct **10** along the path P. If the polluted gas stream contains gaseous pollutants as is generally the case with exhaust gases, the stream first passes through the converter **11**. The converting medium is injected into the gas stream whereupon the medium reacts with the gaseeous pollutants to form particles. Because different mediums may be used

for each type of gaseous pollutant or for different pollutants, it is to be understood that more than one injection unit, here shown as pipes **16** and nozzles **21**, may be necessary to obtain conversion of all of the gaseous pollutants. Also because the converting medium itself may be in a gaseous, liquid or solid state, it may be necessary to modify the converter to inject the particular medium. However, it is to be understood that such modification is within the scope of the invention.

When the gas stream is exhaust gases from a power source such as factory or electrical power plants or internal combustion engines, the converting medium may be selected from those identified in Table I attached hereinafter.

For example, sulfur dioxide (SO_2) may be converted into solid particulate matter by injecting ammonia (NH_3) from nozzles **21** or injecting calcium oxide (CaO) or maganese dioxide (MnO_2) in powder form through nozzles **21.** Heating coils HC may be placed in duct **10** to assist in heating the gas stream for better reaction. The nitrogen dioxide (NO_2) may be converted into an aerosol containing both liquids and solids by injecting one of the cyclic olefin compounds such as ethylene from nozzles **21.** An ultraviolet source US, here shown as a sun lamp but may be a mercury arc, may be provided for enhancing the reaction speed. The nitric oxide (NO) can first be converted to nitrogen dioxide by the injection or air or oxygen (O_2) and then converted as above described.

Carbon monoxide, on the other hand, can be converted into harmless carbon dioxide (CO_2) by the injection of air or oxygen (O_2) as is well known especially if the gas stream is heated by coils HC. Also, the carbon monoxide can be converted by injecting lead chloride combined with water $PbCl_2 \cdot H_2O$ with the lead being removed by the separating sections. It must also be noted that converter **11** may not be necessary if only particulate matter already in the gas stream is to be removed.

After the gas stream exits the converter **11** it enters the corona discharge unit **12** as it moves along path P in duct **10.** The unit **12** operates in known manner to charge the particles in the gas stream to a predetermined level with a particular polarity. The plate-wire arrangement **22** has either the plate or wire grounded in conventional manner with either a positive or negative polarity potential imposed on the ungrounded plate or wire. Thus if a positive polarity potential is imposed thereon, it will be seen that the particles passing therethrough while entrained in the gas stream will have a resulting positive charge imposed thereon while a negative polarity potential will impose a negative charge on the particles.

It is also to be understood that some of the particles within the gas stream may more readily accept a charge thereon of either a positive polarity or negative polarity. If such is the case, it may be necessary to have a first corona discharge unit **12** for imposing a charge on the particles of one polarity and the gas stream passed through the separating section **100, 200, 300** or **400** to separate those particles which have accepted a charge. The gas stream can thereafter be passed through a second corona discharge unit **12** to impose a charge on the remaining particles of the other polarity and the gas stream passed through a second separating section **100,** 200, 300 or **400** to separate the remaining particles.

Referring to the free body diagram as best seen in FIG. **13** of a particular charged particle P_P of the particulate pollutant matter in the gas stream as it issues from the corona discharge unit **12,** it will be seen that the gas stream exerts a force F_S on the particle P_P due to its entrainment generally parallel to the path P of movement of the gas stream through the duct **10.** This path P is horizontal as seen in the figures, however, it is to be understood that path P could be at other positions such as vertical. Also forces F_R will be exerted on the particle P_P by the self-repulsion between particles due to their charges of like polarity. Because the outside layer of particles P_P adjacent the side wall of the duct **10** has no repulsion with respect to the side wall, there will tend to be a general drift of the particles P_P toward the side wall. There will also be a gravitational force F_W acting on the particle P_P, however, such force is generally insignificant in the operation of the invention.

When the particle P_P passes within the first embodiment **100** of the separating section, it passes between the annular ducts **109** as indicated by phantom lines in FIG. **3** and is deflected past the grounded conductor rings **106** by the clean air shown in dashed lines in FIG. **3** issusing through the openings **111** on both sides of the rings **106.** The particle P_P is now located within the side wall **105** and is acted on by the electrostatic force field F between the grids **101** and **102** and side wall **105.** It will be noted in FIG. **1** that side wall **105** is insulated from the rest of the duct **10** at I. Thus, as seen in FIG. **13,** the force field F will exert a resultant force f on the particle P_P. The force f has one component f_c which is diametrically opposite to the force F_S of the gas stream on the particle. The component f_c serves to retard the movement of the particle P_P along the path of movement P. The force f also has a component f_r generally perpendicular to the path of movement P. The component f_r is directed radially outward from the path of movement P so that the particle P_P will be deflected outwardly toward the nearest portion of side wall **105.** This deflection is seen by the phantom lines in FIG. **1.** Thus, the particles P_P will be deflected toward and collected on the inside surface **107** of side wall **105** in an outwardly flaring funnel shaped pattern. It will also be noted that the contra component f_c is the major component of force f and the radial component f_r is the minor component since the major part of the electrostatic force is used to slow down the particle so that it can be easily separated.

The distance L between the entry grid **101** and exit grid **102** may be varied for the optimum separating efficiency. The distance L will depend on the diameter d of duct **10.** Also, the potential difference between the entry and exit grids **101** and **102** and between the exit grid **102** and side wall **105** may be varied to obtain maximum separation. It has been found, however, that a potential difference of 10,000 to 40,000 volts between grids **101** and **102** and between grid **102** and side wall **105** is sufficient. In practice, the potential difference is maintained as high as possible without arcing. Of course it is to be understood that additional sections **100** may be placed downstream of the section **100** illustrated to remove any particles from the gas stream that were not removed in the first section **100.** Also, it will be noted that the electrostatic field F acts as a means for charging the particles P_P. Thus, in some cases, the corona discharge unit **12** may not be necessary where

the particles will be both charged with a charge of a polarity like grid **102,** especially if the grid **101** is grounded, and separated from the gas stream after the charge is imposed thereon.

When the cleaning mechanism **130** is used, the cylinder **131** is positioned to align one of the side walls **105** in the duct **10** so that the particulate matter will be collected on the inside surface **107** of the aligned wall **105.** When the surface **107** of the aligned side wall **105** becomes coated with particulate matter to such an extent to affect the collecting efficiency thereof, the cylinder **131** is indexed by motor **134** until the next side wall **105** is aligned with the duct **10** without interrupting the operating of the section **100.** When the coated side wall **105** is indexed to the cleaning brush **135,** it is rotated by motor **136** and moved along carriage **138** to clean the side wall **105.** Thus, it will be seen that the operation is continuous.

In the operation of the second embodiment **200** of the separating section, the particles P_P pass the grid **201** in the same manner as described for grid **101.** The electrostatic force field F' will exert the force *f* on the particle P_P with the component f_c diametrically opposite the force F_S thereon in the same manner as the force f_c of field F to retard the movement of the particle along path P. The component f_d of force *f* as seen in FIG. **7** corresponds to force f_r of field F in that it is directed normal to path P, however, it is different in that it is directed only toward the collection member **230** completely across the cross-section of the side wall **205.** Thus, the particles within section **200** will be deflected toward the collection member **230** across the entire cross section of side wall **205** as indicated by phantom lines in FIG. **7.**

When the collection member **230** has been sufficiently coated with the collected particulate matter to lose its collecting efficiency, the member **230** is indexed to place a clean portion thereof in registration with the opening **206** in the side wall **205** to provide for continuous operation while the cleaning member **232** cleans the coated portion of member **230.** While only one member **230** is illustrated, it is to be understood that additional members **230** may be positioned around the side wall **205** and in combination with additional members **225** on exit grid **202** on that side of the passage **214** of side wall **205** opposite the additional collection members **230** to also separate the particles from the gas stream. It is also to be understood that different types of cleaning mechanisms and collection members may be used in lieu of those illustrated.

The operation of the modification **300** of the second embodiment of the invention is virtually the same as the second embodiment thereof. Because the angles α and β for grids **301** and **302** are selected in the range of 45° to 90°, the component f_c of force *f* retards movement of the particles P_P while the component f_d of force *f* deflects all of the particles toward the collecting member **330** as indicated by phantom lines in FIG. **9.** It will be noted that the plane of the charged surfaces of grids **301** and **302** define the included acute angles α and β with the plane of the surface of the collection member **330** exposed to the gas stream and intersect the plane of the collection member along a line normal to the longitudinal centerline of the member **330** which is parallel to the path P along which the gas stream passes. Also, the exit grid **302** extends over the member **330** from the downstream end thereof.

As seen in FIG. **10,** the particle P_P passes through the entry grid **401** of the third embodiment **400** of the separating section in the same manner as it passes grid **101** in the first embodiment **100.** Because the side wall **405** is grounded, the particles are subjected to the same forces f_c and f_r as they move between grids **401** and 402_a as described for the first embodiment **100** of the separating section to be collected on side wall **405** between grids **401** and 402_a, the side wall **405** being insulated from the rest of the duct **10** at I.

If the particle P_P is not separated in the field F between grids **401** and 402_a, it passes downstream of grid 402_a. Unlike the first embodiment **100** wherein the charged particle would be speeded up when it passed downstream of the exit grid **102,** however, it encounters the electrostatic field F_1 to exert the force f_1 thereon with the contra component f_c' and the radial component f_r' seen in FIG. **10** which causes the particle to continue to slow down while at the same time continue to be deflected outwardly toward the grounded side wall **405'** between grids 402_a and 402_b. It will be noted that side wall **405'** is also insulated from the rest of duct **10** at the insulators I'. The electrostatic field F_1 will be generated as long as the potential on grid 402_b is greater than that on grid 402_a and of the same polarity as grid 402_a and the charge on the particles. The side wall **405'** is charged with a polarity opposite to that of grid 402_b, here shown as grounded, to continue to attract the particle theretoward and collect same thereon.

Likewise, if the particle P_P is not separated from the gas stream in the field F_1 between grids 402_a and 402_b, it passes downstream of grid 402_b to be subjected to the electrostatic field F_2 between grids 402_b and 402_c. Because the potential imposed on grid 402_c is always greater than that on grid 402_b and of the same polarity as the potential on grid 402_b and the particles P_P, the force f_2 exerted on the particle P_P has a component f_c'' contra to the flow of the gas stream and a component f_4'' in a radial direction with respect to the side wall **405''** and normal to the path P. The side wall **405''** is also grounded and insulated from the rest of duct **10** at I''. This insures that the particles will continue to be attracted toward the side wall **405''**.

It is to be fuurther understood that while only three grids **402** are illustrated in FIG. **10,** additional grids **402** may be placed downstream of those illustrated with each having a higher potential imposed thereon than the adjacent upstream grid **402** with the same polarity as the adjacent upstream grid **402** to generate a repulsive force field. While different voltages V_1, V_2 and V_3 may be used depending on the particular kind of particles to be separated and the desired separating efficiency, one set of suggested voltages is 10,000 volts fo voltage V_1, 20,000 volts for voltage V_2, and 30,000 volts for voltage V_3. As discussed with the first embodiment **100** of the separating section, the distances L, L' and L'' between grids **401** and 402_a–402_c may be varied for maximum separating efficiency and will depend on the diameter *d* of the passage defined by side walls **405, 405'** and **405''**.

In some applications, the grid **401** may not be necessary with all of the separation taking place between the grids 402_a–402_c. If such is the case, grid **401** can be eliminated and the side wall **405** need not be grounded.

It is also to be understood that in some instances the side walls **405, 405'** and **405''** may not need be oppo-

sitely charged or grounded. This is because the self repulsion forces between the particles will cause them to drift toward the side walls as they are slowed down by the contra forces from force fields F, F_1 and F_2.

The difference between the operation of a precipitator using a series of separating sections **100** and the separating section **400** is that each time a particle moves downstream of an exit grid **102,** it is accelerated until it passes the next downstream entry grid **101** whereas a retarding force is constantly exerted on the particle from the time it enters the section **400** until the time it leaves the section. This results in reducing the section **400** to a minimum by maximizing the separating efficiency thereof.

With the invention disclosed herein, the less turbulent the flow of the gas stream through the duct **10** the better the separating efficiency. Thus, the sections of the invention are designed to introduce a minimum of turbulence into the gas stream unlike those prior art precipitators which use turbulence to mechanically slow down the particles. This results in maintaining the pumping power necessary to force the gas stream through the precipitator at a minimum.

The use of grid **500** in lieu of the grids previously illustrated does not materially change the operation as above described. It will be noted that the coating **505** may be necessary when grid **500** is used in lieu of the entry grids **101, 201, 301** or **401** to prevent collection of the particles thereon.

While specific embodiments of the invention have been disclosed herein, it is to be understood that full use may be made of modifications, substitutions and equivalents without departing from the scope of the inventive concept.

TABLE I

GASEOUS POLLUTANT TO BE CONVERTED	CONVERTING MEDIUM	MEDIUM STATE	PARTICULATE PRODUCT	PRODUCT STATE
Sulfur Dioxide (SO_2)	Ammonia (NH_3)	Gas	Ammonium Sulfate [$(NH_4)_2SO_4$]	Solid
Sulfur Dioxide (SO_2)	Calcium Oxide (CaO)	Solid	Calcium Sulfate ($CaSO_4$)	Solid
Sulfur Dioxide (SO_2)	Manganese Dioxide (MnO_2)	Solid	Manganese Sulfate ($MnSO_4$)	Solid
Nitrogen Dioxide (NO_2)	Cyclic Olefin Group	Gas	Aerosol	Liquid/Gas
Nitric Oxide (NO)	Air/Oxygen (O_2)	Gas	Nitrogen Dioxide (NO_2)	Gas
Carbon Monoxide (CO)	Air/Oxygen (O_2)	Gas	None	
Carbon Monoxide (CO)	Lead Chloride ($PbCl_2 \cdot H_2O$)	Solid	Lead	Solid

We claim:

1. A method of separating charged particles from a gas stream including the steps of:

moving the gas stream with the charged particles entrained therein along a prescribed path through a tubular duct;

positioning a first open grid within the tubular duct so that the first grid extends generally transversely across the prescribed path;

positioning a second open grid within the tubular duct a prescribed distance downstream of the first grid so that the second grid extends generally transversely across the prescribed path;

electrically grounding the first grid and that portion of the duct wall between the first and second grids;

imposing an electrical potential of a prescribed value on the second grid with the same polarity as that on the particles to generate an electrostatic repulsive force field between the second grid, the first grid and the duct wall which exerts a first component of force on the particles as they pass between the first and second grids opposite to the direction of movement of the gas stream along the prescribed path and exerts a second component of force on the particles generally toward the duct wall and normal to the movement of the gas stream to slow the movement of the particles with the gas stream and deflect the particles to the duct wall for collection; and,

preventing the collection of the charged particles on the upstream side of the grounded first grid so that the particles are collected only on the duct wall.

2. The method of claim **1** wherein the step of preventing the collection of the charged particles on the upstream side of the grounded first grid includes electrically shielding the upstream side of the first grid.

3. The method of claim **2** wherein the step of preventing the collection of charged particles on the upstream side of the grounded first grid further includes directing a secondary stream of a gaseous medium without charged particles therein around the peripheral edges of the first grid to cause the gas stream with the charged particles therein to bypass the grounded first grid without the charged particles being collected on the first grid.

4. A method of separating charged particles from a gas stream including the steps of:

moving the gas stream with the charged particles entrained therein along a prescribed path within a tubular duct;

positioning a plurality of first open grids so as to intersect said prescribed path spaced from each other by a prescribed distance;

imposing an electrical potential of a prescribed value on said most upstream first open grid with the same polarity as that of the charge on said particles;

imposing an electrical potential on the remaining first grids of the same polarity as the charge on said particles, the charge on each of said remaining first grids having a value a predetermined amount greater than the charge on the next adjacent upstream first grid;

positioning an additional second open grid so as to intersect said prescribed path and spaced upstream from said most upstream first open grid,

electrically grounding said additional second open grid and said tubular duct between adjacent open grids; and,

electrically shielding the upstream side of said second open grid to prevent the collection of the charged particles thereon so that an electrostatic repulsive force field is generated between adjacent grids and the duct wall therebetween which exerts a first component of force on the particles as they pass between adjacent grids opposite to the direction of movement of the gas stream along the prescribed path and exerts a second component of force on the particles generally toward the duct wall and normal to the prescribed path to slow the movement of the particles with the gas stream and deflect the particles to the duct wall for collection.

5. The method of claim **4** further including the step of directing a flow of a gaseous medium without charged particles therein about the peripheral surfaces of said second open grid and generally parallel to the prescribed path to cause the gas stream with the charged particles entrained therein to pass by the second open grid without particles being collected thereon.

6. The method of claim **5** further including the step of imposing a charge on the particles entrained in the gas stream upstream of said second open grid of the same polarity as the charge on said first grids.

7. The method of claim **6** further including the step of injecting a converting medium into the gas stream upstream of the point at which the electrical charge is imposed on the particles therein to convert gaseous pollutants in the gas stream into particulate matter for acceptance of an electrical charge thereon.

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