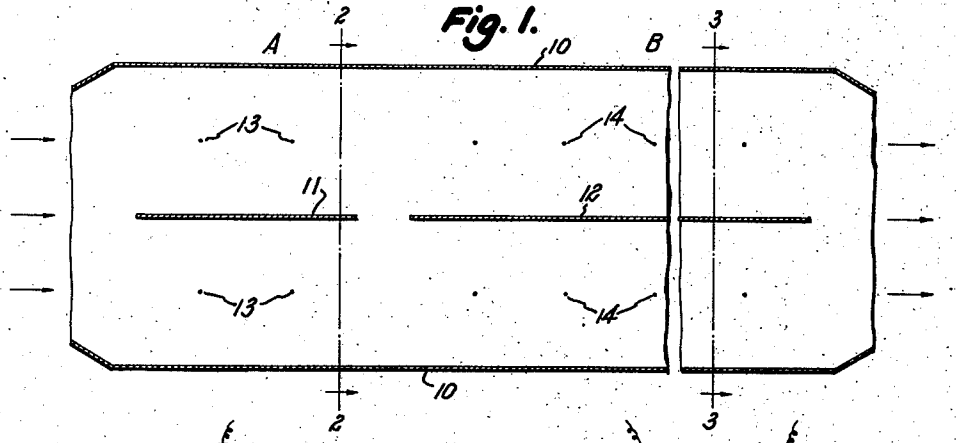
April 27, 1948. H. J. WHITE 2,440,455

CHARGING SUSPENDED PARTICLES

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Fig. 1.



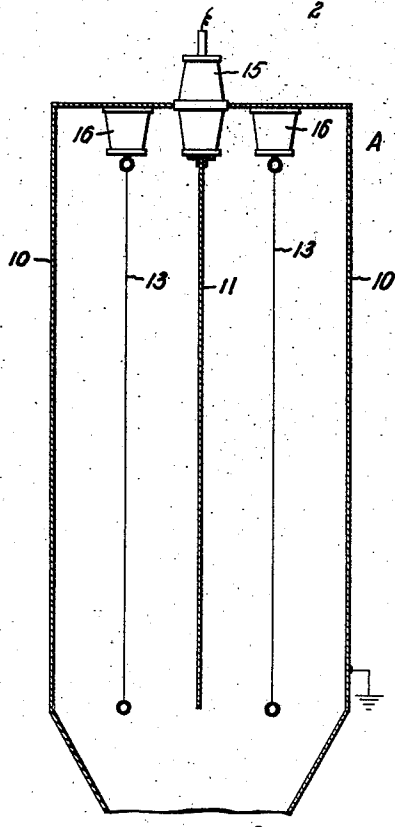


Fig. 2.

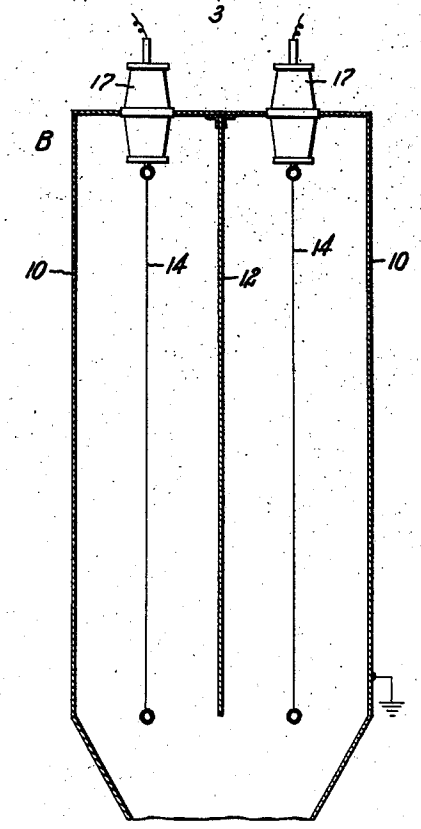


Fig. 3.

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CHARGING SUSPENDED PARTICLES

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Fig. 4.

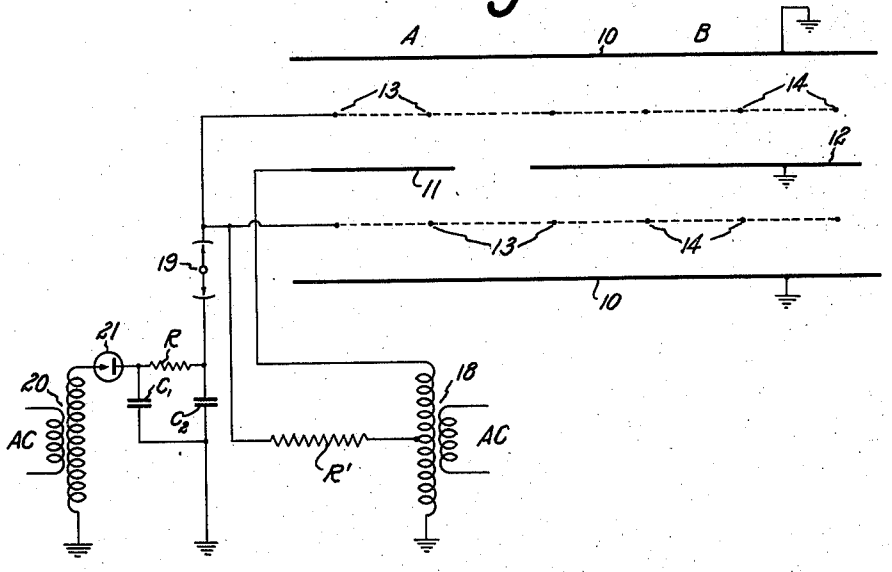
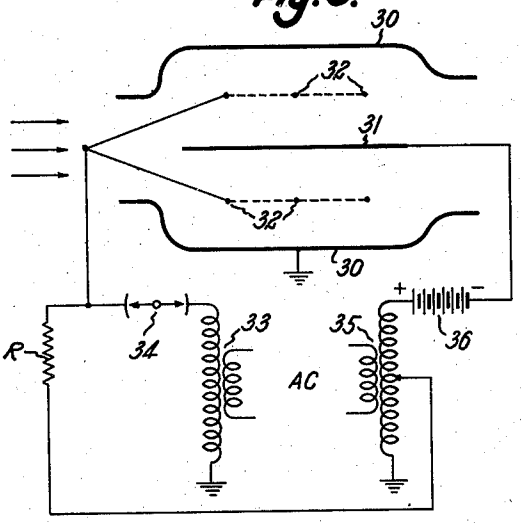


Fig. 5.



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CHARGING SUSPENDED PARTICLES

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Fig. 6.

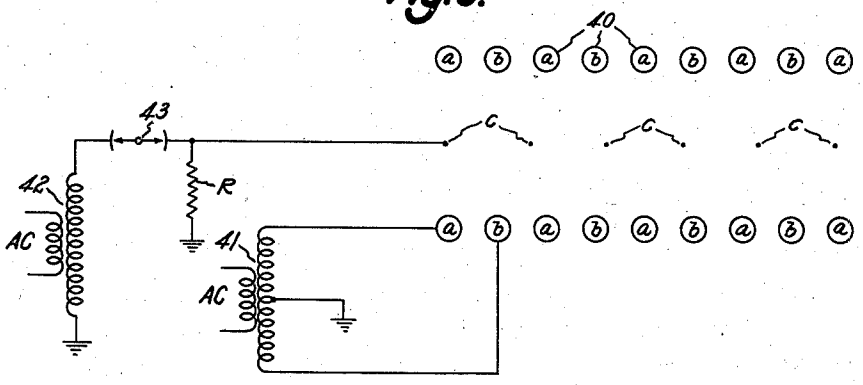


Fig. 7.

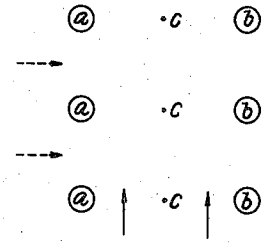


Fig. 8.

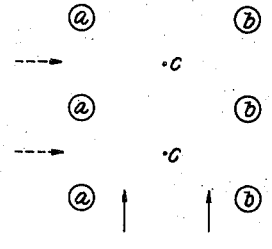
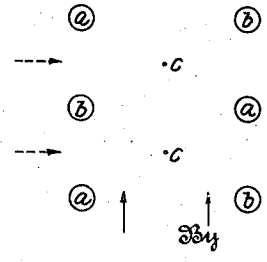


Fig. 9.



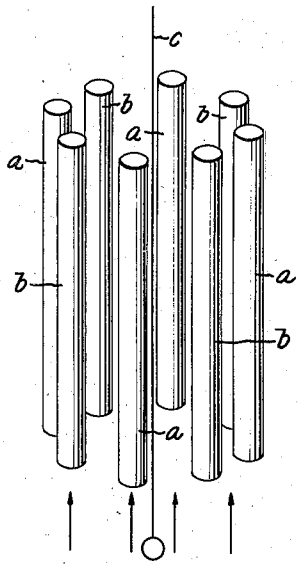


Fig. 10.

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Patented Apr. 27, 1948 2,440,455

UNITED STATES PATENT OFFICE

2,440,455

CHARGING SUSPENDED PARTICLES

Harry J. White, Cambridge, Mass., assignor, by direct and mesne assignments, of one-half to Research Corporation, New York, N. Y., a corporation of New York, and one-half to Western Precipitation Corporation, Los Angeles, Calif., a corporation of California

Application June 11, 1945, Serial No. 598,732

12 Claims. (Cl. 183—7)

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The invention relates to methods and apparatus for the charging of solid and liquid particles suspended in a gas. The invention is useful in the charging of suspended particles for the purpose of removing them from the gas by means of an electric field and the invention will be particularly described with reference to such use, but the invention is generally useful for the charging of suspended particles.

Typically, suspended particles are charged, for example, in the operation of electrical precipitation, by passing the gas containing the suspended particles through a high potential electric field maintained between an attenuated or discharge electrode and an extended surface or non-discharge electrode. Ionization of the gas by the action of corona or silent discharge from the attenuated electrode brings about the charging of the particles. The charged particles are transported by the action of the electric field in which the charging is effected, or in a subsequent electric field through which the gas is passed, upon an extended surface electrode or collecting electrode. Because the conditions for most effective collection of the charged particles are not always identical with the conditions for the most effective charging, the carrying out of the operations of charging and collecting in separate successive stages is advantageous in many applications of the process of electrical precipitation.

It has been found that the charging of suspended particles by corona discharge in a gas depends for its effectiveness on three principal factors: (1) the presence of an adequate density of unipolar ions, typically of the order of 10^8 to 10^9 ions/cm.^{3}; (2) a strong electric field, typically of the order of 5 to 10 kv./cm.; and (3) an adequate charging time, typically of the order of 10^{-2} seconds. However, it has been found in the past that attempts to increase the efficiency of the charging operation by increasing ion density or field strength or both have encountered serious difficulties.

Particularly disastrous in its ultimate effect on the efficiency of charging is the phenomenon of "back corona," which is a reverse discharge usually arising from particles deposited on the surface of the extended surface electrode. The conditions under which back corona arises vary greatly with the character of the deposited material and the chemical composition and physical state of the suspending gas, but whenever back corona appears a great reduction in the charging efficiency results, due to the formation of ions of opposite polarity to those formed in the discharge

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from the attenuated electrode, to localization of the corona discharge, and to other factors.

Various means for overcoming back corona have been used or suggested. These include conditioning of the gas, conditioning of the extended surface electrode as by water flushing, provision of mechanical means for cleaning or preventing the deposit of material on the extended surface electrodes, and reducing the corona current density as by the use of impulse voltages.

I have now found that the efficiency of the charging process can be greatly improved by subjecting the suspended particles to unipolar corona discharge in an alternating field. The striking advantages of an alternating field in conjunction with the unipolar discharge may be attributed principally to several effects. First, by alternating the polarity of the field at a period substantially less than the transport time between the discharge electrode and the extended surface electrodes, the ions for the most part are caused to oscillate in the field without striking the extended surface electrode, thus building up and maintaining a high ion density with relatively small net current flow; second, in such an alternating field even fewer of the much less mobile charged particles will be transported to the extended surface electrode to form a basis for conditions leading to back corona; third, the alternating field tends to suppress the formation of back corona even under conditions which would otherwise lead to substantial and highly deleterious back discharge, because the alternation of the field has the effect of "quenching" the points of back corona discharge during every other half cycle, and, fourth, the maximum electric field which can be maintained between the non-discharging alternating potential electrodes is about double that which can be maintained with the customary electrode arrangement in which one electrode is of attenuated or discharging form, so that the maximum possible particle charge is approximately doubled since the particle charge is proportional to the maximum field strength.

The principles of the invention may be applied in practice in a number of ways and various modifications and variations of the method and apparatus of the invention may be utilized. In general, the method of the invention comprises passing a gas containing suspended particles through an electric field alternating between spaced non-discharge electrodes at a period less than half the transport time of gaseous ions between said electrodes and subjecting the gas

while passing through the alternating field to ionizing discharge impulses between a discharge electrode and at least one of the non-discharge electrodes, the ionizing impulses preferably having an impulse duration substantially less than half the period of the alternating field.

The maximum period or minimum frequency which will just prevent ions in a uniform alternating field from reaching the boundary electrodes can be calculated from the following equation:

$$f_c=\frac{2kV_0}{\pi d^2} \quad (1)$$

where f_c is the "critical" frequency, d is the distance between the electrodes forming the boundaries of the alternating field, V_0 is the maximum or peak value of the potential between the electrodes, and k is the mobility of the gas ions.

As an example, k may be taken as 2 cm./sec./volt/cm. for air. Then with an interelectrode distance of 10 cm. and a peak voltage of 70 kv., f_c would be 890 cycles per sec. However, the "critical" frequency is not at all sharp because of the effect of such factors as space charge and diffusion, and the value of the frequency as determined by Equation 1 is to be taken as a guide to the proper order of magnitude. The advantages of the alternating current field by no means cease at the "critical" frequency as even at lower frequencies the formation of back corona is substantially decreased, but, in general, it is desirable to operate at frequencies substantially above the critical range. In practice, the range of useful frequencies will usually be found within the "sonic" or "audio" range, that is, within the range of frequencies of audible sound although supersonic frequencies will sometimes be preferred. Alternating electric potentials within this range are readily produced by a number of different known devices such as mechanical alternators, vacuum tube oscillators and the like.

The electrodes forming the boundaries of the alternating field may consist of plates or other extended surface members free from surface elements of small radius of curvature such as rods. When the electrodes are formed of rods or are otherwise readily permeable to the gas, the gas flow may be either parallel to the electrodes or normal to and through the electrodes. The discharge electrodes, which are, in general, symmetrically positioned between the non-discharge electrodes forming the boundaries of the alternating field, may be of any form providing surface elements of small radius of curvature which induce the emission of corona discharge under the conditions of operation.

As was stated above, one of the principal applications of the invention is in the charging of suspended particles as the first stage of a two-stage precipitator. Since one of the advantages of the invention is that it permits the charging of the suspended particles at a high rate of flow, it is desirable to provide a second or collecting stage which can efficiently operate at a high gas velocity. This may be effectively accomplished by collecting the charged particles by means of a unipolar corona discharge instead of the unipolar non-discharge electric field typically used in the second stage of two-stage precipitators.

The alternating electric field of the invention is not necessarily symmetrical. It may advantageously be "biased" at one polarity so that the repelling force for the ions produced by the corona discharge is higher at one of the boundary electrodes. In this form of the invention, it is particularly advantageous to confine the gas flow substantially to the region having the higher potential in order to take advantage of the more effective charging rate in that region, or, if the gas is passed transversely through the electrodes, to pass the gas last through this region where the charging conditions are best.

The alternating electric field of the invention need not be "bilaterally" oriented with respect to the discharge electrode structure, but may comprise a series of alternating fields of successively reversed polarity along or around the discharge electrode structure.

The ionizing discharge impulses to which the gas containing suspended particles is subjected are produced by impressing between the discharge electrode and at least one of the extended surface electrodes a succession of unipolar high potential impulses preferably of short duration relative to the period of the alternating field and preferably of a form having a relatively steep wave front. Circuits for the production of such impulses of any desired frequency and duration are well known in the electrical art. Suitable combinations of a condenser and a spark gap provide a simple means of producing high voltage impulses, which may be modified in various known ways to produce impulses of the desired wave form. The impulses may be synchronized with the alternating field by suitable connection of the impulse generating circuit with the alternating field circuit, for example, by operating a mechanical spark gap by means of the alternating current of the alternating field circuit at the frequency or a submultiple of the frequency of the alternating field.

In general, the peak potential of the corona discharge impulses may be from about 10 to 100 kv. The peak potential may be higher the shorter the duration of the impulse.

The duration of the corona discharge pulses is preferably considerably shorter than the half period of the alternating field. For example, when using an alternating field having a frequency of say 1,000 cycles per sec., the pulse duration may advantageously be of the order of 10 to 100 microseconds and the pulse frequency may be the same as the alternating field frequency or a sub-multiple of it.

The invention will be more particularly described for the purpose of illustration with reference to the accompanying drawings, in which:

Fig. 1 is a plan view of a two-stage electrical precipitator embodying the principles of the invention;

Figs. 2 and 3 are sectional elevations on lines 2—2 and 3—3 of Fig. 1;

Fig. 4 is a diagrammatic representation of electric circuits suitable for energizing the precipitator of Fig. 1 in accordance with the principles of the invention;

Fig. 5 is a diagrammatic plan view of a charging device embodying the biased alternating electric field of the invention;

Fig. 6 is a diagrammatic plan of view of a charging device embodying another form of the invention;

Figs. 7–9 are diagrammatic plan views of various electrode arrangements within the scope of the invention, and

Fig. 10 is a fragmentary perspective view of a further electrode arrangement embodying the principles of the invention.

The electrical precipitator shown in Figs. 1–4

comprises two stages, a charging stage A and a collecting stage B. The side walls 10 of the precipitator shell provide extended surface electrodes complementary to the extended surface plate electrode 11 in stage A and provide, with extended surface plate electrode 12, the collecting electrodes of stage B. 13 are the discharge electrodes of stage A and 14 are the precipitating electrodes, in this embodiment of the invention shown as discharge electrodes of stage B.

Plate electrode 11 and discharge electrodes 13 and 14 are suspended in the precipitator chamber from insulators 15, 16 and 17, respectively, through which the leads from the energizing circuits may be brought. The precipitator shell and plate electrode 12 are grounded.

As shown more particularly in Fig. 4, a high potential field of alternating polarity is provided between plate 11 and the side walls 10 by means of high potential alternating current from transformer 18, the midpoint of the high potential winding of the transformer being connected to the discharge electrodes 13, 14 through resistance R'. High potential unipolar impulses are supplied to discharge electrodes 13 and 14 by means of condensers C_1 and C_2, resistance R and rotary interrupter 19 which are supplied with high potential unidirectional current from transformer 20 and rectifier 21. If desired, unidirectional current either continuous or discontinuous may be supplied to discharge electrodes 14 by a separate source.

Because of the alternating electric field in stage A, a strong electric field and a high ion density are maintained in this stage with substantially no back corona from the extended surface electrodes, so that a high particle charge is produced on the suspended particles in the gas passing this charge even at relatively high gas velocities. These charged particles are deposited on the extended surfaces of side walls 10 and plate 12 in stage B. The corona discharge from discharge electrodes 14 in stage B tends to cause reprecipitation of deposited material which may be eroded from the collecting electrode surfaces due to the high gas velocity. Other means of reducing the loss of efficiency due to erosion, such as pocket-type collecting electrodes, may be provided in stage B in addition to or instead of the use of corona-forming precipitating electrodes.

In the charging device shown in Fig. 5, extended surface electrodes are provided by the side walls 30 of the grounded shell of the device, and by plate 31 which is insulated from the shell. High potential unipolar impulses are supplied to discharge electrodes 32 by means of transformer 33 and rectifying switch 34. A high potential alternating current field is supplied between plate electrode 31 and the shell 30 by means of transformer 35. This field is biased by increasing the negative potential of plate 31 (when the impulses supplied to the discharge electrodes are negative, as is preferred), as diagrammatically indicated by battery 36. This negative bias tends to repel negative ions which would otherwise strike plate 31 because of space charge and diffusion effects. In this form of the invention, it is desirable to substantially confine the gas flow to the region adjacent plate 31, for example, by suitably arranging the gas inlet and outlet conduits as indicated diagrammatically in Fig. 5. The phase relation of the current supply to transformers 33 and 35 is preferably regulated so that the voltage across one transformer is at its maximum when the voltage across the other is zero.

In the charging device diagrammatically shown in Fig. 6, the alternating field is not bilaterally oriented with respect to the discharge electrodes *c*, but the field periodically reverses in orientation along the discharge electrode structure. In this form of the invention extended surface electrodes 40, which may be smooth-surfaced rods, are electrically connected in alternate sets, *a* and *b*, respectively, along the length of the discharge electrode structure to the opposite terminals of the high potential side of transformer 41. High potential unipolar impulses are supplied to discharge electrodes *c* by means of transformer 42 and rectifier 43. The relative phases of transformers 41 and 42 may be advantageously adjusted as described in connection with Fig. 5.

The gas containing suspended particles to be charged may be passed through the interelectrode space parallel to the electrode systems (either in or normal to the plane of the drawing), or the gas may be passed transversely through the electrode systems.

Arrangements of the type shown in Fig. 6 are effective in largely eliminating back corona even when treating suspended materials which, because of their poor conductivity, tend to cause the formation of back corona very readily. During the periods when one of the electrode sets, for example, the *a* electrodes are positive, practically all of the corona current from the discharge electrode will come to it (assuming the usual negative polarity of the discharge electrode energization). As the material which deposits on the electrodes is poorly conducting, local sparks may pass through the deposited material forming craters which, in the usual arrangement, would constitute points from which back corona would emanate. But, with the arrangement of the invention in which the electric field at the electrode surfaces is rapidly alternating, before positive ions can travel an appreciable distance into the gas stream they are forced back to the electrode from which they originate by the reversal of the field. The shutting off of the corona current together with the elimination of positive ions during the reverse field periods effectively quenches the back corona points and prevents positive ions from passing into the main gas stream. Hence, the gas stream remains free of positive ions and the charging action of the unipolar corona discharge is maintained at high effectiveness despite the poorly conducting character of the suspensoid. The advantageous effect of the rapidly reversing field is further enhanced by the fact that it greatly reduces the amount of suspended material which is deposited on the extended surface electrodes.

Figs. 7 to 9 are diagrammatic representations of several modified electrode arrangements in which the significance of the letter designations is the same as in Fig. 6. In any of these arrangements, the gas flow may be either parallel to or transversely through the rod electrode systems, as indicated by the full line and dotted arrows, respectively, or it may be parallel to the electrode systems in a direction normal to the plane of the drawing.

When the flow of gases is transversely through the rod electrode systems of Figs. 7 and 8 as indicated by the dotted arrows, electrodes *b* may be given a biased potential with respect to electrodes *a*, as described in connection with electrode 31 of Fig. 5.

Fig. 10 illustrates an electrode arrangement (in which the letter designations likewise have

the same significance as in Fig. 6), particularly adapted for gas flow parallel to the electrodes, as indicated by the arrows. In this arrangement, the *a* and *b* rod electrodes, or equivalent shapes, are positioned in alternation in a circle about the discharge electrode wire *c*. The gas flow is largely confined to the cylindrical path defined by the rod electrodes.

In each of the forms of apparatus described above, the charging stage comprises two spaced insulated extended surface electrode systems and a discharge electrode system interspaced with and insulated from said extended surface electrode systems. The two extended surface electrode systems comprise electrodes 10 and electrode 11 in Figs. 1, 2 and 4, electrodes 30 and electrode 31 in Fig. 5, and the oppositely energized rod electrodes A and B respectively in the remaining figures, while the discharge electrode system comprises the electrodes 13 in Figs. 1, 2 and 4, electrodes 32 in Fig. 5, and electrode or electrodes C in the remaining figures.

It will be seen that the principles of the invention are susceptible of application to a wide variety of conditions and arrangements within the scope of the invention as defined by the claims hereof.

I claim:

1. A method of charging particles which comprises passing a gas containing suspended particles through an electric field alternating between spaced non-discharge electrodes at a period less than half the transport time of gaseous ions between said electrodes and subjecting the gas while passing through the alternating field to ionizing discharge impulses having an impulse duration substantially less than half the period of the alternating field.

2. A method of charging particles which comprises passing a gas containing suspended particles through an electric field alternating between spaced non-discharge electrodes at a period less than half the transport time of gaseous ions between said electrodes and subjecting the gas while passing through the alternating field to ionizing discharge impulses of negative polarity having an impulse duration substantially less than half the period of the alternating field.

3. A method of charging particles which comprises establishing an alternating electric field between spaced non-discharge electrodes at a period less than half the transport time of gaseous ions between said electrodes, biasing the voltage of said field to produce a higher peak potential at one of said electrodes, passing a gas containing suspended particles through said field, and subjecting the gas while in said field to ionizing discharge impulses having an impulse duration substantially less than half the period of the alternating field.

4. A method of charging particles which comprises establishing an alternating electric field between spaced non-discharge electrodes at a period less than half the transport time of gaseous ions between said electrodes, biasing the voltage of said field to produce a higher peak potential at one of said electrodes, passing a gas containing suspended particles through said field adjacent the electrode of higher peak potential, and subjecting the gas while in said field to ionizing discharge impulses having an impulse duration substantially less than half the period of the alternating field.

5. A method of charging particles which comprises establishing an alternating electric field between spaced non-discharge electrodes at a period less than half the transport time of gaseous ions between said electrodes, biasing the voltage of said field to produce a higher negative peak potential at one of said electrodes, passing a gas containing suspended particles through said field, and subjecting the gas while in said field to ionizing discharge impulses of negative polarity having an impulse duration substantially less than half the period of the alternating field.

6. A method of electrical precipitation which comprises passing a gas containing suspended particles through an electric field alternating between spaced non-discharge electrodes at a period less than half the transport time of gaseous ions between said electrodes, subjecting the gas while passing through the alternating field to ionizing discharge impulses having an impulse duration substantially less than half the period of the alternating field, and thereafter passing the gas through a high potential unidirectional electric field.

7. A method of electrical precipitation which comprises passing a gas containing suspended particles through an electric field alternating between spaced non-discharge electrodes at a period less than half the transport time of gaseous ions between said electrodes, subjecting the gas while passing through the alternating field to ionizing discharge impulses having an impulse duration substantially less than half the period of the alternating field, and thereafter subjecting the gas to ionizing discharge impulses in a high potential unidirectional electric field.

8. A method of electrical precipitation which comprises passing a gas containing suspended particles through an electric field alternating between spaced non-discharge electrodes at a period less than half the transport time of gaseous ions between said electrodes, subjecting the gas while passing through the alternating field to ionizing discharge impulses of negative potential having an impulse duration substantially less than half the period of the alternating field, and thereafter subjecting the gas to ionizing discharge impulses of negative potential in a high potential unidirectional electric field.

9. An electrical precipitator comprising a charging stage including two spaced insulated extended surface electrode systems, a discharge electrode system interspaced with and insulated from said extended surface electrode systems, means for establishing an alternating electric field of sonic frequency between said extended surface electrode systems, and means for establishing unipolar high potential impulses between the discharge electrode system and at least one of the extended surface electrode systems; a collecting stage including an extended surface electrode, a precipitating electrode spaced and insulated therefrom, and means for establishing a high potential unidirectional field between said precipitating electrode and said extended surface electrode; and means for directing gas flow successively through said charging and said collecting stages.

10. An electrical precipitator comprising a charging stage including two spaced insulated extended surface electrode systems, a discharge electrode system interspaced with and insulated from said extended surface electrode systems, means for establishing an alternating electric field of sonic frequency between said extended surface electrode systems, and means for establishing unipolar high potential impulses between

the discharge electrode system and at least one of the extended surface electrode systems; a collecting stage including an extended surface electrode, a discharge electrode spaced and insulated therefrom, and means for establishing a high potential unidirectional field between said discharge electrode and said extended surface electrode; and means for directing gas flow successively through said charging and said collecting stages.

11. An electrical precipitator comprising a charging stage including two spaced insulated extended surface electrode systems, a discharge electrode system interspaced with and insulated from said extended surface electrode systems, means for establishing an alternating electric field of sonic frequency between said extended surface electrode systems, and means for establishing unipolar high potential impulses between the discharge electrode system and at least one of the extended surface electrode systems; a collecting stage including an extended surface electrode, a discharge electrode spaced and insulated therefrom, and means for establishing high potential unipolar electric impulses between said discharge electrode and said extended surface electrode; and means for directing gas flow successively through said charging and said collecting stages.

12. Apparatus as defined in claim 9 in which the extended surface electrode systems include substantially parallel plates.

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