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(54) IMPROVED ELECTROSTATIC PRECIPITATION SYSTEMS

(71) We, HIGH VOLTAGE ENGINEERING CORPORATION, a Corportion organised and existing under the laws of the Commonwealth of Massachusetts, United States of America, having a principal place of business in Burlington, Massachusetts, United States of America do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The present invention relates to improved electrostatic precipitation systems and is an improvement of the strcuture in our patent specifications 1445361, 1445362 and 1468457.

In our patent specification 1445361 we have disclosed a procedure for the electrostatic precipitation of particulates entrained in a stream of gas between corona electrodes and collecting electrodes in which an underlying unidirectional field which serves to charge the particulates and transport them out of the stream is made relatively uniform, thereby allowing the creation of relatively high electric field intensities, while the corona which is required to yeild ions to charge the entrained particulates is provided by a high, repetitvely pulsed, electric field between the corona electrodes and the collecting electrodes. Such a system separates the charge and transport function from the function of production of charge carriers by corona discharge.

A number of other advantages are also comprehended by such systems:

1) Presently existing electrostatic precipitators can be adapted to such systems without the necessity of major changes in the installation since the electrical circuitry may be quite simple.

2) The wire breakage rates of such systems may be smaller than those of presently exizsting electrostatic precipitators since such systems allow corona electrodes of greater cross-sectional area than that acceptable in presently existing precipitators to be used.

3) In such systems the pulsed field can be chosen sufficiently high that corona current is assured under vitually all operating conditions, thereby alleviating the very sensitive nature of conventional system electrodes to contamination, and the operative range of the dc field is greatly increased.

4) Such systems also allow the average value of the corona current to be closely regulated independently of the dc field by adjusting the superimposed pulse voltage, pulse width, or pulse repetition rate. Thus, "back corona" can be controlled, and the minimum level adequate to charge the particulates close to their equilibrium state need not be significantly exceeded.

We have found, however, that such systems, especially converted conventional precipitators, may be costly to operate. A typical electric utility system with which the precipitator of the present invention might be used might be one with an electric power output of 7 megawatts. Assuming, for example, that the power is generated by burning coal, the products of combustion might result in a typical case in a gas flow of 50,000 cubic feet per minute. In order to clean this gas flow a typical total anode collecting area would be 20,000 square feet, and with typical wire-to-plate spacing the capacitance of the precipitator would be 100 nanofarads. A conventional rectified unfiltered dc system would have a total current of 1 ampere and a dc voltage of 70 kilovolts, thus resulting in a total power consumption of about 70 kilowatts. If the improvement described in patent 1445361 were used for the conversion of such a conventional system to a pulsed system, the delivery of a pulse amplitude of 70 kilovolts thereto would require an energy of 735 joules per pulse to superimpose a single pulse onto a dc level. If one further assumes a pulse width of 100 nanoseconds, which we have suggested as typical for such systems, and ionisation parameters such that a repetition frequency on the order of 10^4 pulses per second is required to produce the necessary corona current, a total power consumption on the order of 7.35 MW is the result. Even 10^3 pulses per second yields power consumption figures of 735 KW.

It will be noted that this power consumption has nothing to do with the useful power consumed in particulate removal, but is solely the reactive power required to charge the capacitance of the precipitator for purposes of the pulse. If sharp pulses are to be produced, as is necessary in the above improvement, it is necessary that the charge applied to the capacitance for purposes of the pulse must somehow be dissipated between pulses, and this is where the power loss occurs. It will be noted that in the above example at a repetition frequency of 10^4 pulses per second the reactive power consumption exceeds that of the utility plant itself, and even at 10^3 pulses per second the reactive power loss is over 10 percent.

The power discrepancy is clear. At present rates, the energy costs alone for a system such as the one described above would be around $160,000 per year. This figure is comparable to the present cost of the electrical portion of a conventional precipitator, and electric rates are rising steadily. Clearly, means are needed to reduce power requirements of improved systems if they are ever to be practical alternatives to conventional models, much less improvements thereon.

A reduction of pulse amplitude is one possible approach to this problem. This approach is unattractive however, since it leads to a configuration and operation only slightly different from conventional dc charged precipitators and it significantly reduces the usefulness and availability of the beneficial factor of controllable corona current. A reduction of pulse repetition frequency is also unattractive. It is possible to vary this parameter somewhat, but it will be desirable to provide sufficient charge carriers to charge the particulates close to their equilibrium value in a time which is short in comparison with the particle crossing time. Thus, given a representative drift velocity of 70 cm/sec. CF. J. W. Parkington, M. S. Lawrie-Walker, "Attainment of High Precipitation Efficiencies on Fine and Sub-Micron Dusts and Fumes", LA PHYSIQUE DES FORCES ELECTROSTATIQUE ET LEURS APPLICATIONS, pp 351-362, Grenable (1960), and an average perpendicular travel distance of 7 cm, for example, a repetition frequency far in excess of 10 pulses per second (pps) is indicated. One hundred pulses per particle crossing time, which would not be unusual, suggests 1000 pulses per second as a typical value for this parameter. Experiments with each specific system and particulate are necessary to determine optimal repetition frequency.

In addition to the excessive power requirements of pulsing a precipitator in the manner described above, in which the pulse voltage is applied to all the precipitator's wires simultaneously, a further problem is the difficulty in producing a short-rise time of the pulse. A typical inductance between the pulser and the cathode structure would be of the order of 1 microhenry. If one assumes, therefore, an inductance of 1 microhenry and if one considers a precipitator capacitance of 100 nf per pulser one arrives at a pulse rise time of approximately one-half microsecond. This time is already too long to take advantage of the increased hold-off strength of gases for short pulses. Differently stated, the excessive time required to reach the peak of the pulse effectively increases the pulse length obtainable.

The present invention provides apparatus for electrifying and collecting particles entrained in gases comprising an array of generally parallel spaced collector electrodes of large surface area, at least one wire forming a group of corona electrodes of relatively small surface area, each corona electrode being arranged in an interplate gap between opposing collector electrodes and the corona electrodes forming the or each group being connected in series so as to form with said collector electrodes a transmission line, said wire extending through adjacent interplate gaps and sequentially from one interplate gap to the next, passing alternately above and below successive collector plates, a dc potential source means for applying a dc potential to said corona electrodes, and means for delivering pulses to said transmission line comprising a pulse source adapted to produce, in use, pulses of corona producing voltage of sufficiently short duration as to charge to corona producing voltage only a small proportion of the transmission line at any given instant of time.

Thus the present invention connects the corona electrodes in series in such a way that, in combination with the collector electrodes and support structure, a transmission line is formed to which the pulses are applied. The width of the pulse must be less than the length of the transmission line. As each pulse travels along the transmission line the corona electrodes are sequentially charged, but only a small proportion of the precipitator is charged at any given instant of time. In this way the necessary corona current is produced without the necessity of pulse charging all corona electrodes simultaneously.

The benefits of the proposed system are strongly enhanced by experimentally established facts which demonstrated that the emitted charge per pulse is only slightly determined by pulse width, indicating that the charge is emitted during the very early part of the pulse when the shielding effects of the space charge cloud are absent. This fact allows use of very short pulses, on the order of 10nsec, which reduces power requirements as well as reducing the probability of an unwanted breakdown between the corona (cathode) wires and the collecting (anode) plates.

Since the power reduction achieved by the propagation system is proportional to the ratio of the pulse transit time through the series over the pulse width, such short pulses lead to total power consumption figures comparable to or less than present day requirements for dc systems.

A preferred embodiment of the invention will now be described by way of example only and with reference to the accompanying drawing which is a three dimensional view of an electrostatic precipitator showing the electrode configuration and transmission-line circuitry.

The Figure shows an arrangement which may be operated in a similar way to that described in our patent 1466457, that is, at similar potentials and frequencies.

Referring to the Figure, collecting plates 30 are arranged in a parallel array similar to that of the collecting plates 2 shown in Figures 1-4 of our patent specification 1466457. However, whereas the corona electrodes of each section of those Figures 1-4 are essentially in parallel, in the present embodiment the corona electrodes are connected in series to form one or more transmission lines represented schematically as long wires 31*a* - 31*r* each of which lies approximately in a plane perpendicular to the planes in which the collecting plates 30 are disposed, to form each such wire extending between adjacent collecting plates corona electrodes and sequentially from one interplate gap to the next, passing alternatively above and below successive collecting plates 30. The wires 31 are supported upon an upper array 32 and a lower array 33 of beam members. The upper array of beam members 32 comprises a series of rows 32*a* - 32*f*, and in each such row the beam members thereof are arranged longitudinally of one another approximately midway between neighbouring collecting plates 30 but spaced above them.

Similarly, the lower array of beam members 33 comprises a series of rows 33*a*-33*f* in each of which the beam members belonging to that row are arranged longitudinally of one another approximately half-way between adjacent collecting plates 30 but spaced below them. Thus each elongated wire 31*a* - 31*r* proceeds sequentially from beam member 33*a* to beam member 32*a* and so on sequentially through beam members 32*b*, 33*b*, 33*c*, 32*c*, 32*d*, 33*d*, 33*e*, 32*e*, 32*f*. 33*f* as shown. The elongated wires 31 are driven by pulsers 34, 35 and a single pulser can drive a number of parallel wires.

One of the advantages of the embodiment shown in that the impedance of each elongate wire may easily be calculated. Each elongate wire is essentially a single wire between earthed parallel planes with an earth return. This is a simple configuration and the impedance of such a wire is given for example at page 22-23 item P of Reference Data for Radio Engineers (Fifth Edition), Howard W. Sama and Co.,Inc ITT. As therein shown, the characteristic impedance Z_0 in ohms of one wire between grounded plates spaced apart a distance h, where the diameter of the wire d is measured in the same units as h, is

$$\frac{138}{\sqrt{\varepsilon}} \log_{10} \frac{4h}{\pi.\varepsilon}$$

where ε is the dielectric constant of the medium in which the wire is placed relative to that in air. This equation gives the impedance presented to a pulse by the wire; it does not depend upon the length of the line. In a typical precipitator constructed in accordance with this invention the spacing between parallel plates would be 9 inches and a typical wire diameter would be 1/4 inch. Substituting these values in the above equation, the impedance of a typical wire would be 230 ohms. Six parallel cables of this nature would therefore have an impedance of 1/6 of 230 or 38.2 ohms. Consequently, 6 parallel wires of this nature could easily be driven by one pulser via a cable of an impedance which is close to the 38 ohms of the wire arrangement. For example, elongated wires 31*a*-31*f* might be driven by one pulser 34, while elongated wires 31*g*-31*L* might be driven by a second pulser 35. The invention comprehends the use of any number of pulsers, and indeed a single pulser may be used to drive an entire section of a precipitator.

A major feature of the embodiment shown is the ease with which impedance may be matched. For example, the pulsers can be located in a room several hundred feet from the plates and wires of the precipitator itself, and the pulses may be transmitted from the pulsers to the corona wire by a standard cable the impedance of which is simply L/C (where L is the inductance and C the capacitance of the cable). Such a cable will have a given inductance per unit length and a given capacitance per unit length, so that the impedance of the cable is easily calculated. Having done so, it is then a simple matter to match the impedance of the cable to that of the corona wires simply by appropriate selection of the number of wires to which each pulser is connected. This calculation is also simple since, as set forth above, the configuration of the Figure is simply a single wire between grounded parallel planes the impedance of which is well known and easily calculated.

Since a typical precipitator has approximately 30 to 40 ducts perpendicular to the gas flow, and since the length of one wire is of the order of 30 feet, one arrives at a continuous wire length of 900 to 1,800 feet for each of the elongated wires. Such an arrangement therefore arrives at a wire length which is longer than one obtains when making the connections of the corona electrodes in the manner shown in Figure 1 or Figure 2 of patent specification 1468457. Moreover, the present arrangement is more compatible with present feeding arrangements of the dc voltge than the arrangement shown in those Figures 1 and 2. For this reason the present arrangement is preferred.

It will be understood of course that the presently described precipitator is charged in a similar way to that in our patent specification 1468457. For example, a similar dc voltage is applied to the corona delectrodes and the pulsers are adapted to produce pulses of corona producing voltage of sufficiently short duration as to charge only a small proportion of the corona electrodes, at any given instant of time. By acting as a transmission line, for example, a single pulse may pass along each transmission line comprising the corona electrodes formed end to end, the length of the pulse being less than the length of the transmission line and may be of the order of the length of a single corona electrode.

It is to be understood that the embodiments of the improvement herein described are intended to be illustrative and exemplary and not limiting. It will be apparent to one skilled in the art that derivations may be made to adapt the improvement to particular circumstances and parameters and that such adaptations may be made without departing from the following claims. It is recommended, however, that in adapting the present improvement to a specific set of circumstances and parameters, care be taken to obtain optimal impedance matching conditions between the transmission cable and the wire cathode-anode geometry, preferably via experiments incorporating both time domain reflectrometry measurements and pulse amplitude decay along the path of propagation.

WHAT WE CLAIM IS:

1. Apparatus for electrifying and collecting particles entrained in gases comprising an array of generally parallel spaced collector electrodes of large surface area, at least one wire forming a group of corona electrodes of relatively small surface area, each corona electrode being arranged in an interplate gap between opposing collector electrodes and the corona electrodes forming the or each group being connected in series so as to form with said collector electrodes a transmission line, said wire extending through adjacent interplate gaps and sequentially from one interplate gap to the next, passing alternately above and below successive collector .plates, a dc potential source means for applying a dc potential to said corona electrodes, and means for delivering pulses to said transmission line comprising a pulse source adapted to produce, in use, pulses of corona producing voltage of sufficiently short duration as to charge to corona producing voltage only a small proportion of the transmission line at any given instant of time.

2. Apparatus as claimed in Claim 1 substantially as described with reference to the accompanying drawings.

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1563714 COMPLETE SPECIFICATION

1 SHEET

This drawing is a reproduction of the Original on a reduced scale