

12

EUROPEAN PATENT APPLICATION

21 Application number: 79300858.2

51 Int. Cl.³: **B 03 C 3/01**
 B 03 C 3/12, B 03 C 3/88
 C 21 B 7/00

22 Date of filing: 17.05.79

30 Priority: 15.09.78 US 942582

43 Date of publication of application:
 16.04.80 Bulletin 80/8

84 Designated Contracting States:
 CH DE FR GB IT SE

71 Applicant: **ELECTRIC POWER RESEARCH INSTITUTE, INC**
 3412 Hillview, Avenue
 Palo Alto, California(US)

72 Inventor: **Tassicker, Owen James**
 10467 Mary Avenue
 Cupertino California(US)

72 Inventor: **Mitchner, Morton**
 44 Palm Court
 Menlo Park, California(US)

72 Inventor: **Collins, Leland Frederick**
 33871 Mello Way
 Fremont, California(US)

72 Inventor: **Self, Sidney Albert**
 241 Floresta Way
 Menlo Park, California(US)

72 Inventor: **Kobashi, Masaaki**
 84C Escondido Village
 Stanford, California(US)

74 Representative: **Beresford, Keith Denis Lewis et al,**
 R G C Jenkins & Co 53-64 Chancery Lane
 London WC2A 1QU(GB)

54 Fly ash agglomerator, flue equipped with this agglomerator and process for removing suspended charged particles of mixed size from a volume of gas.

57 A fly ash agglomerator for improving the efficiency of the electrostatic precipitators. Contaminated gas is passed through a charger wherein suspended particles become electrically charged, and thence past a plurality of parallel plates aligned with the flow direction. An AC voltage source applied to the plates subjects the charged particles to a high voltage AC field, which causes the larger-sized particles to sweep past the smaller-sized particles. The smaller particles adhere to the larger particles, thereby increasing the mean particle size. The gas stream is then passed through a collector to remove the particles from the gas stream.

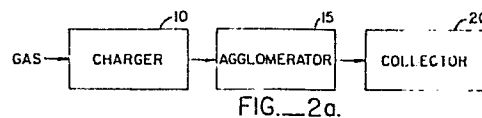


FIG. 2a.

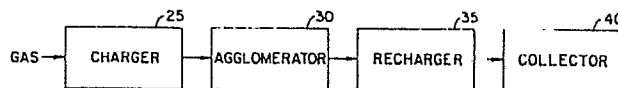


FIG. 2b.

TITLE MODIFIED
see front page

6092-57

>
FLY ASH AGGLOMERATOR

ACKNOWLEDGEMENT

This invention was made under contract with or supported by the Electric Power Research Institute, Inc. of Palo Alto, California.

BACKGROUND OF THE INVENTION

5
10
15
20
The problem of removing suspended particulate matter from a gas stream is present in a variety of industrial and utility applications. For example, coal often contains inorganic minerals such as silica and alumina to the extent of up to 10% of its weight. When this coal is burned in furnaces in either a pulverized or coarsely crushed form, the residual ash from the coal becomes entrained in the furnace gas in the form of finely divided particles, referred to as fly ash. When pulverized coal is used, substantially all of the ash is emitted, but even with coarsely crushed coal, approximately 20% of the ash present is emitted from the furnace. Thus, the exhaust gases from a coal-fired central station electrical plant contain large amounts of fly ash. Fly ash particles range down in size to the sub-micron region.

25
>
As emission standards for particulates in flue gases have become increasingly stringent, it has become increasingly important to efficiently remove the suspended particulate matter. Moreover, it is highly desirable that improvements in the technology be adaptable

>
> to existing pollution control apparatus, to minimize the
cost of conformance to the increasingly strict
requirements.

5 The most commonly used device for the removal
of particulate matter from power plant stack gases is the
electrostatic precipitator. The theory of operation and
typical design considerations are extensively set forth
in H.J. White, "Industrial Electrostatic Precipitation"
(Addison-Wesley 1963), hereinafter referred to as White.
10 Broadly, an electrostatic precipitator removes suspended
particulate matter from a gas stream by causing the
particles to become electrically charged, and sweeping
them out of the gas stream by means of an electrostatic
field, normally transverse to the flow direction.

15 Of the several possible charging methods, the
high voltage DC corona is almost universally used in
electrostatic precipitators. The corona is most often
established between one or more fine wires, normally at a
large negative voltage, and a grounded smooth electrode.
20 The particles passing through the corona field are
charged according to two mechanisms, bombardment (or
field) charging and diffusion charging. Both of the
charging mechanisms take place at the same time, but,
theoretically, diffusion charging is predominant for
25 particles smaller than 0.2 microns in diameter, while
bombardment charging is predominant for particles larger
than 0.5 microns in diameter. If all the corona wires
are operated at the same polarity, the charging is said
to be unipolar. Under such conditions, it still may be
30 very difficult to convert all the particles to the same
polarity, especially when the dust loading is high.

35 The charged particles then start to move toward
collector plates according to a high voltage DC field.
In most industrial clean-up applications, the electrodes
for providing the collection field are the same as the

>

corona electrodes. Such precipitators are called single stage precipitators. Most precipitators used for air cleaning applications are two-stage precipitators in which the contaminated gas stream is first passed through a charger, such as a high intensity ionizer, and then passed through a separate collector in which the collecting field is maintained. In either type of precipitator, the charged particles drift towards an electrode of the opposite sign and out of the gas stream.

Unfortunately, while electrostatic precipitators are highly efficient in removing the larger particles having diameters above about 1 micron, and the very small particles having diameters below about 0.1 microns, they are considerably less efficient in the removal of particles in the 0.1-1.0 micron range. The problem is compounded by the fact that efforts to reduce the emission of certain gaseous pollutants by using low sulphur coal have led to highly resistive fly ash. It has been found that the efficiency of a given electrostatic precipitator decreases as the electrical resistivity of the fly ash increases.

One of the main approaches to the problem of increasing the efficiency of the electrostatic precipitator, especially for particles in the sub-micron region, is to increase the size of the electrostatic precipitator itself. Precipitators are already very large devices, typically requiring between 100 and 500 square feet of collection plate area per 1,000 cubic feet per minute throughput. Given that a big power plant typically has a throughput in the range of several million cubic feet per minute, it can be seen that acres of plate are required. Therefore, an improvement along this line is relatively expensive. Additionally, an increase in size is not the kind of change that is readily made to an existing system.

>
>
Another approach to removing sub-micron sized fly ash is the use of cloth filtration in a so-called "bag house". This method suffers from the disadvantage that the insertion of cloth filters in the gas stream causes a pressure drop which must be made up by additional fans. This adds to the cost and may be impossible in some existing facilities.

5
10 It has been further suggested that precipitator efficiency could be improved by first subjecting the entrained particles to so-called bipolar charging wherein some of the particles become charged positively and others negatively. The amounts of positive and negative charge would be equal. Then, coulomb attraction between oppositely charged particles would tend to cause agglomeration, thereby resulting in fewer submicron particles. Since a lot of neutralization of charge could occur, the particles might have to be recharged before collection. A description of this process is found in J.F. Melcher and K.S. Sachar, "Electrical Induction of Particulate Agglomeration", Final Report to Air Pollution Control Office, APTD-0869, National Technical Information Services PB-205188 (August 1971).
15
20
25
30
35
>

SUMMARY OF THE INVENTION

The present invention provides a method and apparatus for improving the efficiency of electrostatic precipitators, to allow a reduction in the size and cost of the units. The invention can be added to many existing electrostatic precipitator facilities to comply with increasingly stringent regulations with a minimum of disruption. Further, the invention does not result in any significant pressure drop, thereby avoiding the need for additional fans, and it achieves the increased efficiency without a substantial increase in energy expenditure.

Broadly, the invention provides a fly ash agglomerator through which the contaminated gas is passed after passage through the charger and before passage through the collector. The agglomerator includes a plurality of parallel plates aligned with the flow direction and connected to an AC voltage source to subject the charged particles to a high voltage AC field. This AC field causes the larger-sized particles to sweep past the smaller-sized particles.

The invention can be used with unipolar or bipolar charging. For like-charged particles the AC field tends to overcome the long-range coulomb repulsion and produces large short-range attractive forces which help the smaller particles adhere to the larger particles. For oppositely-charged particles, the AC field promotes mixing and enhances the short-range attractive forces. By thus removing a significant fraction of the smaller particles from the stream, the overall collection efficiency is improved.

While the above discussion of the background of the invention emphasized fly ash removal, the invention could have other applications, such as in the carbon black industry. Additionally, the agglomerator of the

>
> present invention need not be used with an electrostatic precipitator, but could be used to increase the efficiency of cyclone collectors.

5 Other objects, features, and advantages of the present invention will become apparent after a reading of the remainder of this specification and the attached drawings.

10

15

20

25

30

35

>



BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graph showing the general relation between collector efficiency and particle diameter.

Fig. 2a is a block diagram of the apparatus and method for unipolar charging.

Fig. 2b is a block diagram of the apparatus and method for bipolar charging.

Fig. 3 is a perspective, schematic view of an agglomerator.



THEORETICAL OVERVIEW OF AC FIELD AGGLOMERATION

Under certain ideal conditions the collection efficiency of an electrostatic precipitator is given by the Deutsch equation:

$$\text{efficiency} = 1 - e^{-(wA/Q)}$$

where

w is the average migration velocity toward the plate of the entrained articles,

Q is the volume throughput, and

A is the collection surface area.

Thus, collection efficiency could be improved by providing more plate area, slowing the gas stream down (i.e., lowering the volume throughput), or somehow increasing the average migration velocity of the suspended particles.

The present invention is directed to increasing the particles' average migration velocity. The migration velocity depends on many variables, including the properties of the particles and the gas. However, the relation can be simplified and still remain illuminating. For a spherical charged particle in the size range where Stokes' law is valid, the migration velocity w is given by:

$$w = \frac{q E_p}{6 \pi a \eta}$$

where

q is the particle charge,

E_p is the collecting field,

a is the particle radius, and

η is the gas viscosity.

For conductive particles, the charge of accumulated during the charging step due to bombardment charging is given by:

$$q = 3 E_0 a^2$$

where

E_0 is the charging field, and

a is as defined in Equation 2.

5 Therefore, the migration velocity w is given by:

$$w = \frac{E_0 E_p a}{2 \pi \eta}$$

where E_0 , E_p , a , and η are as defined in Equations 2 and 3.

10 The above discussion assumes that bombardment charging is the predominant mechanism, and that the Stoke's law is valid. However, at small particle diameters comparable to or less than the mean free path λ of the gas molecules (roughly 0.1 microns for air at STP), the migration
15 velocity must be corrected by a factor of about $[1 + A(\lambda/a)]$ (Cunningham correction) where A is a dimensionless constant approximately equal to 1. Additionally, diffusion charging, which is roughly proportional to the
20 particle radius a (as opposed to a^2 as in bombardment charging), becomes dominant in this size range. The combined effect is an increase in the migration velocity and a corresponding increase in collection efficiency.

In spite of the increased efficiency at very
25 small particle sizes, the overall efficiency (corresponding to the mean migration velocity) could be increased by increasing either the charging field, the collecting field or the mean particle radius, as suggested by Equation 4.

30 The present invention increases the average migration velocity by causing the smaller particles to adhere to the larger ones, thereby effectively increasing the mean particle radius. This is done by subjecting the particles to an AC electric field E given by:

35

$$E = E_a \cos \omega t$$

where

E_a is the AC electric field amplitude, and ω is the angular frequency.

It is possible, and sometimes convenient, to subject the particles to an alternating field that is not purely sinusoidal, but rather comprises voltage excitation terms of the Fourier expansion form. Such a field E' is given by:

$$E' = \sum_{n=1}^{\infty} E_n \cos (n\omega t + \phi_n)$$

where

n characterizes the harmonic,

E is the amplitude of the n^{th} harmonic,

ϕ is the phase of the n^{th} harmonic, and

ω is the fundamental angular frequency.

However, much of the discussion below will assume a purely sinusoidal field.

Under certain simplifying, but not invalidating assumptions, each charged particle subjected to the field of Equation 5 undergoes oscillatory motion characterized by a displacement x given by:

$$x = \frac{q E_a \sin \omega t}{6 \pi a \eta \omega}$$

where q , E , a , η and ω are as defined in Equations 2 and 5.

Recalling Equation 3, the particle displacement x is given by:

$$x = \frac{E_0 E_a a \sin \omega t}{2 \pi \eta \omega}$$

where E_0 , E_a , a , η and ω are as defined in Equations 2, 3 and 5. Thus the larger charged particles will sweep back and forth over a greater distance than

>
> the smaller charged particles, and therefore sweep past
them repeatedly. This overcomes long-range coulomb
repulsion for like-charged particles, and causes the
smaller particles to stick to the larger ones. The
5 effect may be enhanced by providing as high as AC field
as possible.

For unlike-charged particles, the AC field
promotes mixing and increases the short-range force of
attraction.

10 While Equation 8 shows the amplitude of oscil-
lation to be inversely proportional to frequency, it must
be noted that the number of oscillations undergone is
proportional to frequency. Thus, the total path length
swept out by a particle in a given time is independent of
15 frequency, subject to the underlying simplifying
assumptions.

20

25

30

35
>

DESCRIPTION OF THE PREFERRED EMBODIMENT

Fig. 1 is a typical plot of precipitator collection efficiency as a function of particle diameter. It can be seen that the efficiency drops dramatically for particles having diameters in the range of 0.1-1.0 microns. This general behavior is consistent with the theoretical discussion above.

Figs. 2a and 2b are block diagrams for electrostatic precipitation using agglomeration, wherein the contaminated gas stream has been subjected to unipolar and bipolar charging respectively.

With reference to Fig. 2a, the particulate laden gas first passes through a charger 10, in which the suspended particles become charged, the particles being charged generally with the same polarity. The gas then passes through an agglomerator 15 which subjects the gas stream and suspended charged particles to a high voltage AC field aligned transverse to the direction of gas flow. The larger charged particles sweep back and forth past the smaller ones, thereby overcoming the long range coulomb repulsion and causing the smaller particles to adhere to the larger ones. The gas then passes through a collector 20 in which the gas stream is subjected to a transverse high voltage DC field which causes the charged particles to be swept out of the gas stream.

Referring to Fig. 2b, in another embodiment the gas stream is first passed through a bipolar charger 25 under the influence of which the suspended particles become charged, some negatively and some positively. Some processes give rise to particles that are naturally bipolarly charged, as for example grinding or dispersion processes which charge the particles triboelectrically. If such is the case, no charger is required. The gas stream then passes to an agglomerator 30 where it is subjected to a transverse AC field. The AC field causes

> the larger particles to sweep by the smaller ones,
> thereby enhancing attractive coulomb forces and over-
coming repulsive coulomb forces. Thus agglomeration is
achieved. Since substantial charge neutralization often
5 tends to occur, the gas stream may then be passed through
a recharger 35 and thereafter through collector 40.
Recharger 35 may be of a similar design to that of
charger 10, or it can be incorporated with collector 40
as a single stage precipitator. Recharger 35 is prefer-
ably unipolar since some charge neutralization occurs
10 when bipolar charging is used, and this could signifi-
cantly impair collection efficiency.

Charger 10 (or 25) may be of any conventional
design. Since migration velocity and hence collection
15 efficiency are improved through using as high a charging
field as practical, as discussed in Equations 1 and 4,
any improvements allowing the use of a high field are
preferably incorporated into charger 10 (or 25). In-
creasing the charging field also increases the agglom-
eration, as indicated by Equation 7. One example of such
20 an improvement relating to chargers is set forth in the
copending commonly owned United States Patent Application
Serial No. 784,196, filed April 18, 1977, and entitled
"Resistive Anode for Electrostatic Precipitation".

25 The design of collector 20 (or 40) will not be
described herein in detail. However, for the purpose of
describing the relevant parameters for the agglomerator,
it is helpful to note some basic parameters and design
considerations for collectors more generally.

30 The collector typically consists of a series of
grounded parallel plates and an interleaving series of
electrodes at high voltage. In single stage precipi-
tators the high voltage electrodes are the same wires
that provide the corona field; in two-stage precipitators
35 the high voltage electrodes may be wires or plates. The

>

>
> grounded electrode plates are where the collection occurs, and a dust layer having a thickness of a centimeter or more can be expected to form. The plates are typically designed with the collecting surface shielded from
5 the gas flow to prevent the once collected particles from becoming re-entrained in the gas stream.

Since collection efficiency is enhanced by increasing the collection field (see Equations 1-3), it is a general rule to use as high a field as is practical.
10 The breakdown field in air at STP is 30 kv/cm and represents an upper limit. As a practical matter, electric fields in the range of 10 kv/cm are more common.

The preferred spacing between electrodes results from a compromise. A smaller spacing would require
15 a lower voltage for the same field and provide a larger plate area for a given overall width. However, too small a spacing leads to problems with collected dust layers bridging the gap and causing a short circuit. Expense is also a problem with smaller spacing, since more material
20 is required. For a duct precipitator having a given total width, the optimum duct spacing (the distance between adjacent ground plates, there being a high voltage wire plane therebetween) can be shown to be in the range of 10 inches. See White at pp. 177-180.

25 Referring to Fig. 3, the mechanical structure of agglomerator 15 (30) typically resembles that of plate type collectors. Thus, the agglomerator includes an outer grounded shell 50 which extends along the direction of gas flow 60 and defines a transverse cross sectional
30 area of gas flow. Shell 50 is provided with a plurality of high voltage electrode plates 70 aligned parallel to the direction of gas flow, and an interleaved plurality of grounded plates 75. Thus, a high voltage AC field is set up between adjacent electrode pairs, each such pair
35 having a grounded electrode and a high voltage electrode.

>

The considerations for choosing an electric field amplitude E_a differ depending on whether the collisions are between like-charged or unlike-charged particles. For like-charged particles one should choose as high a field E_a as possible so as to overcome coulomb repulsion. For collisions between unlike-charged particles, there is a trade-off between higher fields E_a that promote both a larger relative velocity (and hence collision frequency) between particles as well as an enhanced short-range attraction and mixing, and lower fields E_a that better allow for the beneficial effects of long-range coulomb attraction. Again, there is the static breakdown field limit on E_a , with practical considerations dictating a lower peak amplitude in the range of 5-15 kv/cm.

Since the agglomerator is not a collecting stage, plate spacing and design may be varied in order to optimize other considerations. In contrast to the situation in the collection stage, agglomeration efficiency is not increased by increasing the plate area (for a given plate length). Thus, the main advantage of using a smaller plate spacing is the feasibility of using a lower voltage source for a given field. This can be directly balanced against the cost of an increased number of plates. The plates need not be designed to avoid re-entrainment, since collection is undesirable. Thus, flat plates are suitable. However, the edges should be rounded to avoid local field enhancement and resultant corona emission which can reduce the charge on the particles. A "Rogowski" shape is preferred.

In view of the typical range of field strength, and since it is generally impractical to use high voltage supplies about about 100 kv, a plate spacing of about 6-20 cm or 2-8 inches is preferred.

The choice of agglomerator field frequency is relatively simple. As was discussed in connection with Equation 8, the path length swept out to produce agglomeration is independent of frequency. Thus, there is great freedom on the choice of frequency at which the agglomerator can be operated. Since nearly all power is distributed at 60 cycles (cps) per second, most agglomerators will operate at that frequency. Other frequencies, such as the 400 cps frequency encountered on aircraft and the like, can be employed when practicing the present invention. A preferred frequency range is 30-500 cps, since inertial effects could become significant at higher frequencies. At frequencies much lower, the agglomerator could act as a collector, especially with respect to the larger particles. This would undercut the agglomerator function.

The length of a typical agglomerator stage depends on the length of time it takes for agglomeration to occur. This characteristic time, referred to as residence time, can be shown to be inversely proportional to the charging field E_0 , the agglomerator (AC) field E_a , the collision cross section or efficiency, and the dust loading. Assuming that the charging field has been maximized, and furthermore recognizing that the dust loading is likely to be a given quantity in a specific application, it becomes an object to increase the product of E_a and collision efficiency which depends on E_a . Whether this is necessary clearly depends on a given situation, for example, the properties of the suspended particles in question. Bipolar charging improves collision efficiency since positive and negative particles are attracted to one another, thereby enhancing the agglomeration. Bipolar charging is not without its detrimental characteristics since it may become necessary to recharge the suspended particles if considerable

>
> charge neutralization occurs. This would require
additional precipitator length, and could undercut some
of the advantage to be gained by agglomeration. Addi-
tionally, it is more of a routine procedure to run
5 ionizers with negative polarity than it is to run them
with positive polarity. Thus the choice between unipolar
and bipolar charging will depend on the particular
application.

10

15

20

25

30

35

>

CLAIMS

1. An apparatus for removing suspended charged particles of mixed size from a stream of gas, for example for removing particulate combustion products from gases in a flue, comprising an electrostatic precipitator system having collecting means (20,40) for causing the suspended charged particles to be removed from the stream of gas, characterised by means (15,30) interposed in the gas stream upstream of the collecting means (20,40) for subjecting the suspended charged particles to an AC electric field wherein some of the smaller suspended particles become attached to some of the larger suspended particles causing an overall increase in the median size of the suspended particles, whereby the efficiency of the collecting means (20,40) is improved.

2. The apparatus of claim 1 wherein the means (15,30) for subjecting the particles to an AC electric field comprises:

two plates (70,75) aligned along the direction of the gas flow; and

voltage means (80) for applying an AC voltage between the plates (70,75) thereby setting up an AC electric field in the region between the two plates (70,75).

3. The apparatus of claim 2 wherein the two plates (70,75) are separated by a distance in the range 2-8 inches.
4. The apparatus of claim 2 wherein one of the plates (70,75) has a rounded edge having a Rogowski shape to avoid corona emission.
5. The apparatus of claim 1 wherein the AC electric field has a peak magnitude in the range of 5-15 kv/cm, and a frequency in the range of 30-500 cps.
6. The apparatus of claim 1 further comprising first charging means (25) for causing the suspended particles to become charged including positive charging means and negative charging means such that some of the suspended particles are charged positively and some negatively, the total amounts of positive and negative charge being substantially equal.
7. The apparatus of claim 6 also including second charging means (35) interposed in the gas stream downstream of the means (30) for subjecting the suspended particles to an AC electric field and upstream of the collecting (40), the second charging means (35) causing the suspended

particles to become electrically charged with substantially all the particles having the same polarity charge.

8. The apparatus of claim 1 wherein the collecting
5 means (20,40) includes means for subjecting the suspended particles to a transverse DC electric field.

9. A flue provided with apparatus according to any preceding claim for removing fly ash from exhaust gases passing therethrough.

10 10. A process for removing suspended charged particles of mixed size from a volume of gas , for example for removing particulate combustion products from gases in a flue, the process including the step of applying a DC electric field to the volume of gas whereby the charged
15 particulate matter is attracted out of the volume of gas, characterised by subjecting the volume of gas to an AC electric field before the step of applying the DC electric field, wherein some of the smaller suspended particles become attached to some of the larger suspended particles,
20 thereby increasing the median size of the suspended particles, whereby the removal efficiency of the step of applying the DC electric field is improved.

11. The process of claim 10 wherein some of the particles are positively charged and some negatively charged, with the total amounts of positive and negative charge being substantially equal, and including the step of causing the particles to become electrically charged such that substantially all the particles are charged to the same polarity, carried out after the step of applying the AC electric field and before the step of applying the DC electric field.
12. The process of claim 11, wherein the volume of gas containing suspended particulate matter is first put into motion and wherein the steps of causing the suspended particles to become charged, applying the AC electric field, and applying the DC electric field are carried out at separate locations.

1/1

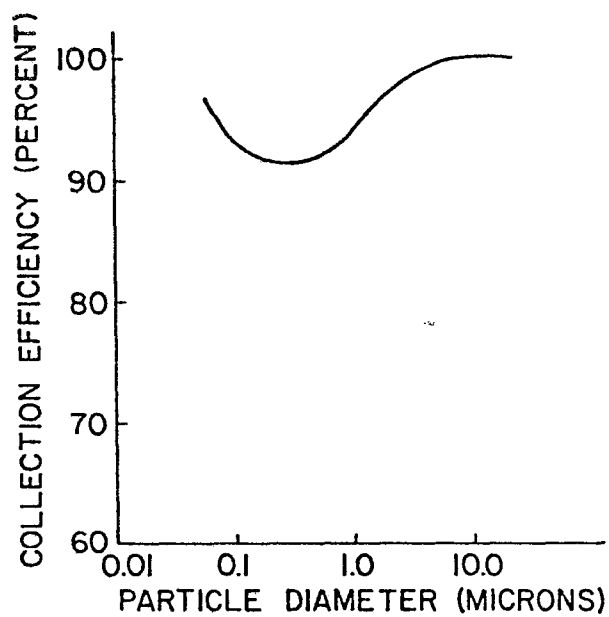


FIG. 1.

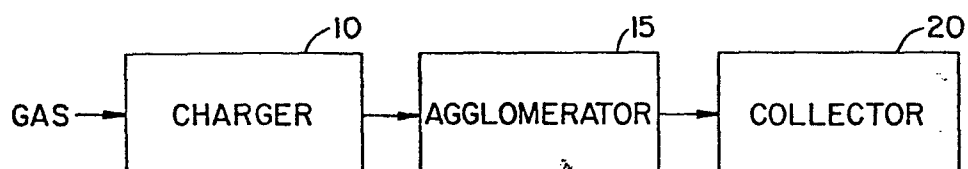


FIG. 2a.

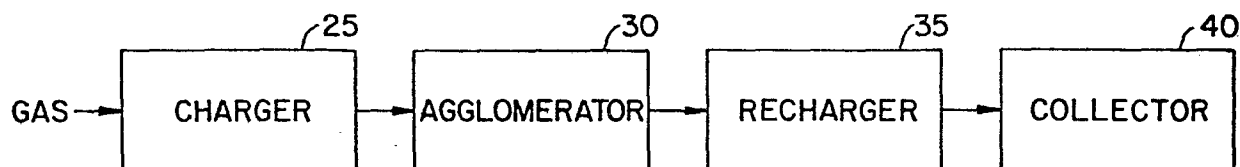


FIG. 2b.

