

June 23, 1964

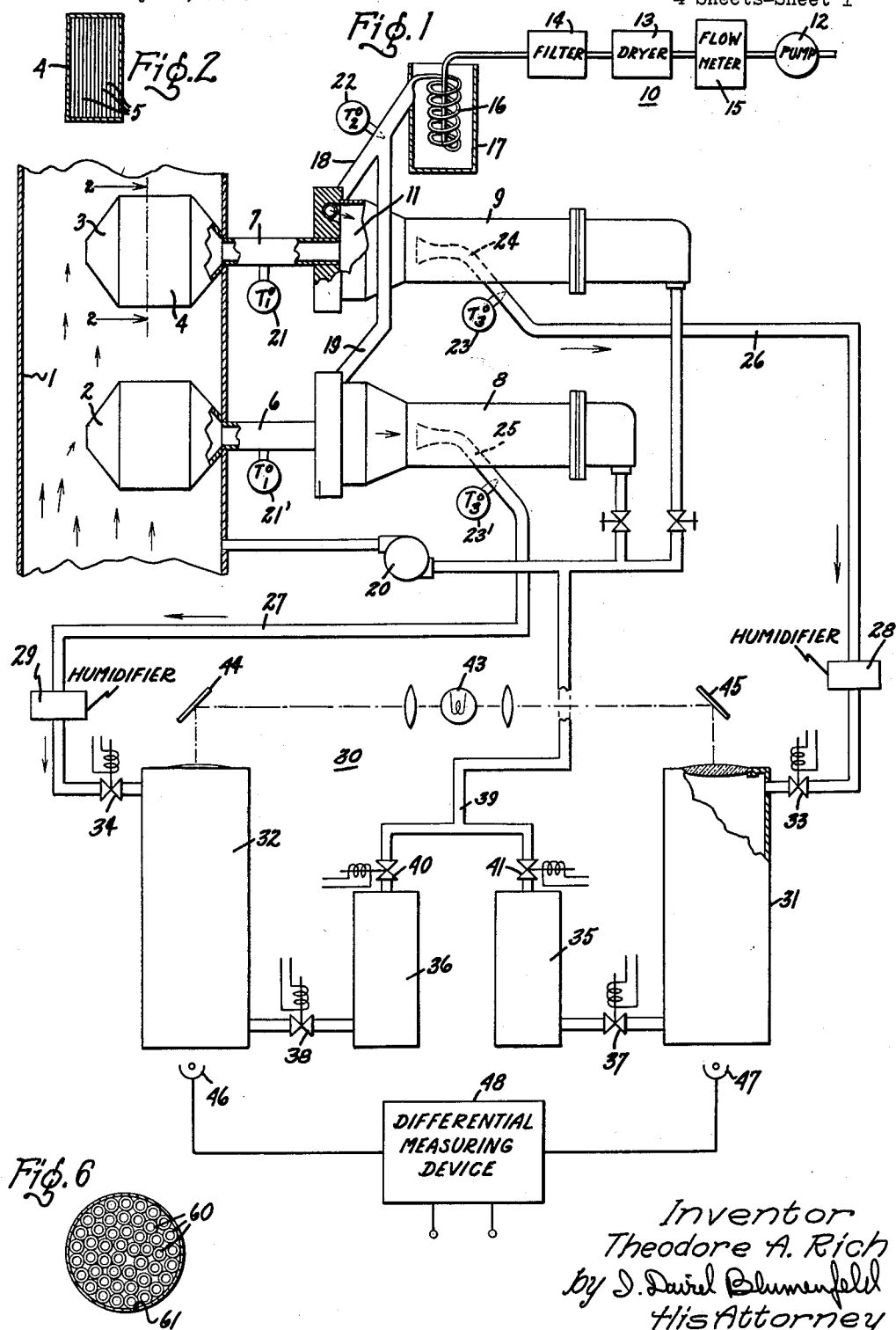
T. A. RICH

3,138,029

PARTICLE SIZE MEASUREMENT

Filed May 29, 1959

4 Sheets-Sheet 1



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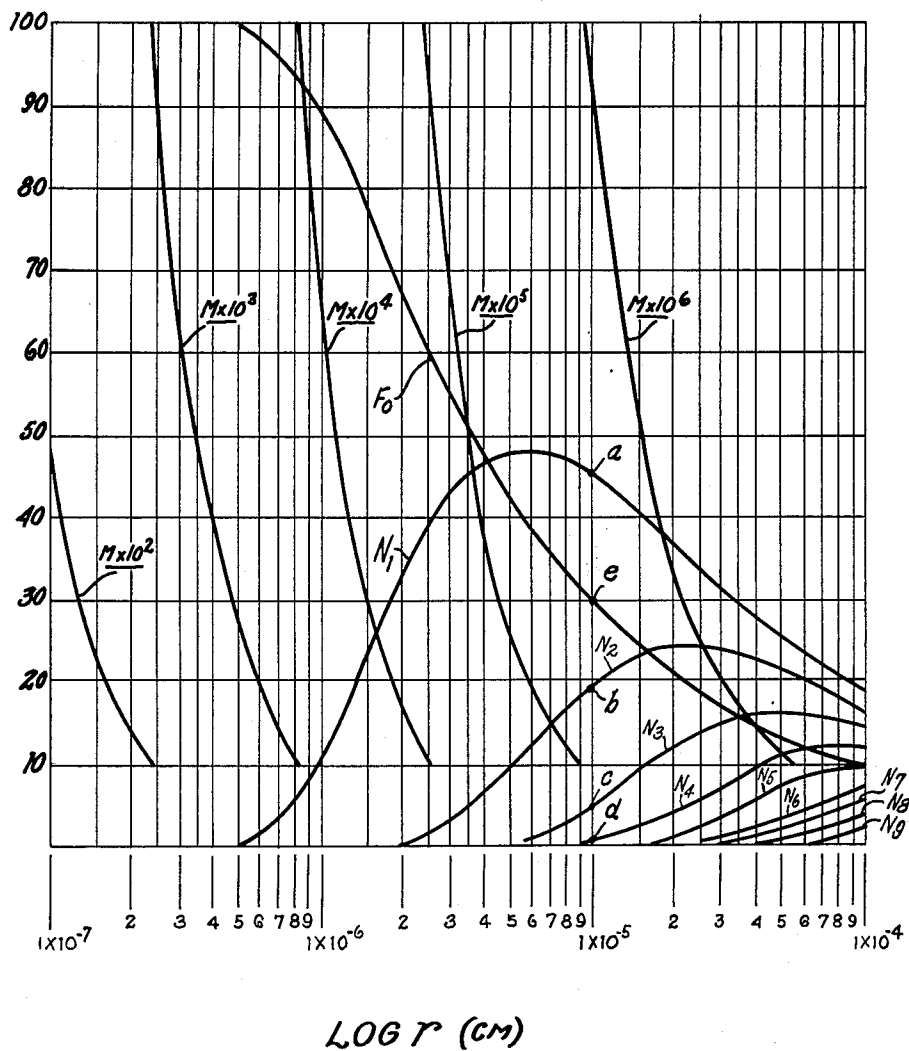
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Fig. 3



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Fig. 4

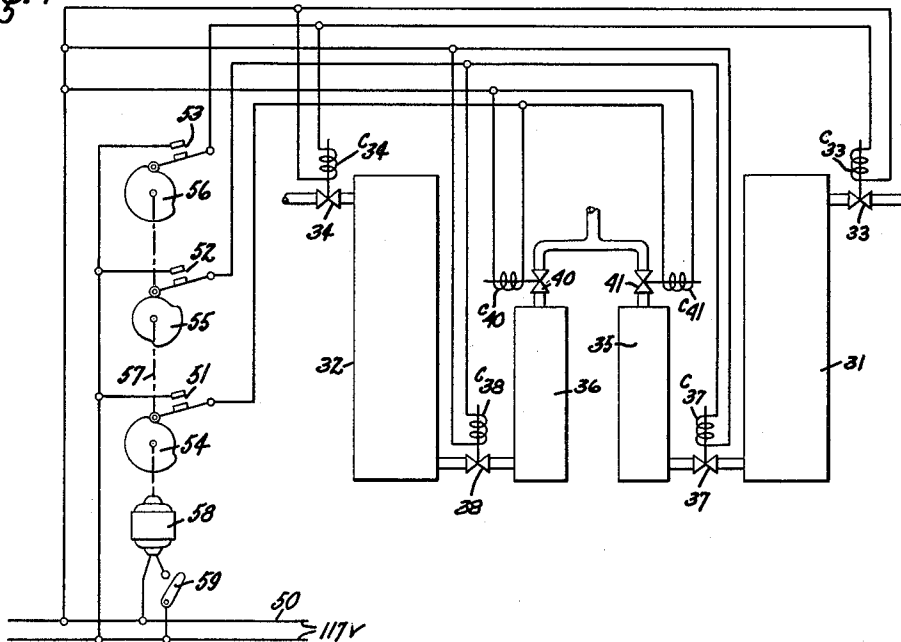
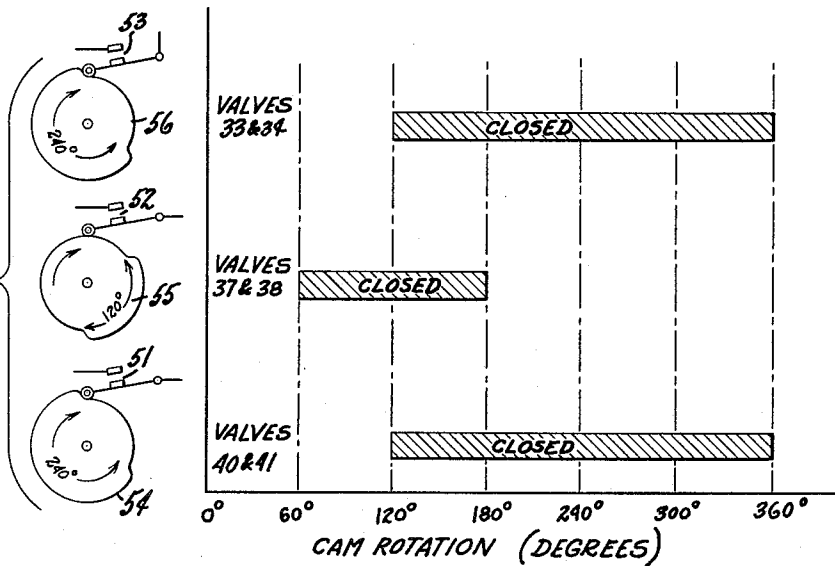


Fig. 5



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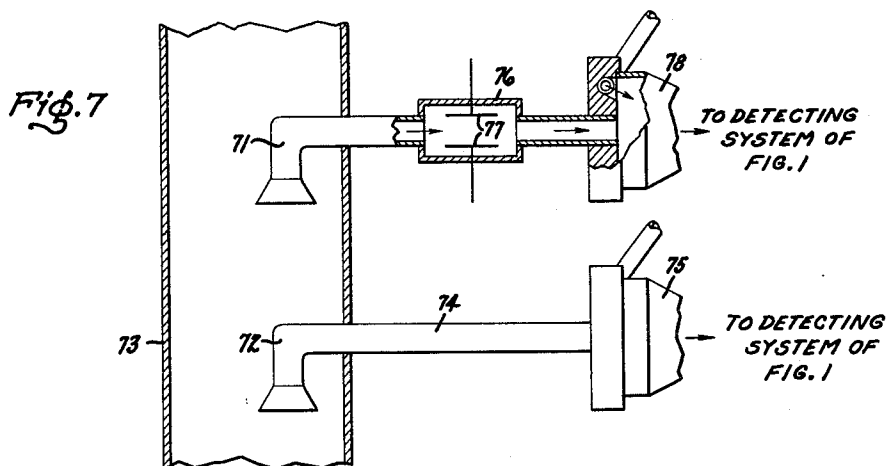
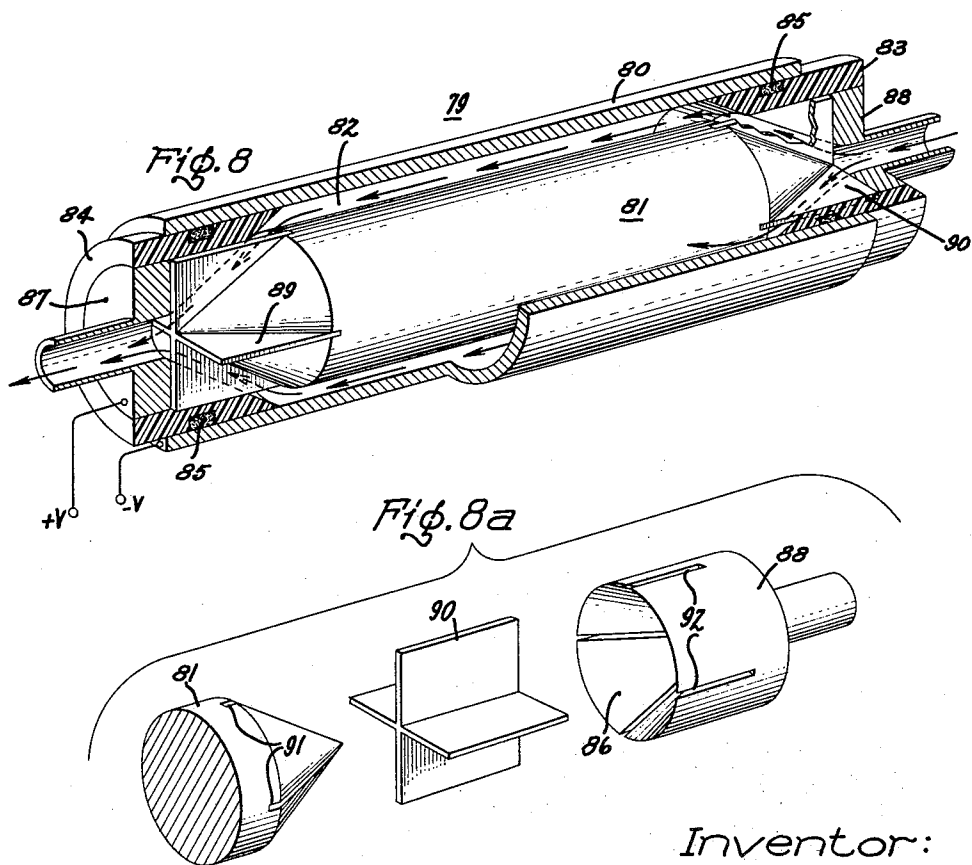
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PARTICLE SIZE MEASUREMENT

Filed May 29, 1959

4 Sheets-Sheet 4



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3,138,029

PARTICLE SIZE MEASUREMENT

Theodore A. Rich, Scotia, N.Y., assignor to General Electric Company, a corporation of New York
Filed May 29, 1959, Ser. No. 816,943
8 Claims. (Cl. 73-432)

This invention relates to a method and apparatus for determining particle size, and more particularly, for determining the "average size" of particles suspended in a gaseous medium.

Particle size information is often desirable because of the relationship that size bears to the properties of particles. In most practical circumstances, however, the particle population is actually a mixture of sizes and actually no one number can describe this mixture. Fortunately, it has been found that an average value for the particle size, in terms of an average diameter or radius, is often more valuable than a complete particle size distribution, particularly when primary concern is with those particle properties such as rates of chemical reaction, absorptency, solubility, health effects, etc.

Certain parameters such as the diffusion characteristics, and the fraction of the particles which become charged in natural conditions, for example, are so related to the size of the particle that they may be utilized to define any given mixture of particle sizes in terms of an equivalent mono-disperse (single size) particle. Thus, for example, any mixture of particle sizes which has a certain fraction thereof charged due to naturally occurring ionizing events, may be defined by saying that its "average size" is that of a mono-disperse particle concentration which would have the same fraction of particles charged. Similarly, a mixture which has a certain diffusion characteristic may be defined as having an "average size" which is that of a mono-disperse particle mixture which would have the same diffusion characteristic.

By manipulating a particle bearing gaseous sample to change the concentration as a function of existing size by removing the charged fraction of the particles, or by removing a portion through diffusion, it is possible to determine the "average size" of the particles in terms of an equivalent mono-disperse particle concentration.

Therefore, it is an object of this invention to provide a method and apparatus for measuring the average size of airborne particles by utilizing those characteristic properties of the particles which are related to their size;

A further object of this invention is to provide a method and apparatus for determining the average size of airborne particles by changing the concentration of the particles as a function of existing size;

Another object of this invention is to provide a method and apparatus for determining the "average" equivalent size of an airborne particle concentration by utilizing the diffusion characteristics of the particles;

A still further object of this invention is to provide a method and apparatus for determining the average size of airborne particles wherein the rate at which the naturally charged particles become removed provides a measure of their average size;

Other objects and advantages of this invention will become apparent as the description thereof proceeds.

In one of its aspects this invention contemplates determining average particle size by manipulating the particle concentration as a function of existing size either by removing all naturally charged particles, or by producing a diffusion loss. Since both the fraction of the particles which are naturally charged and the diffusion loss is a function of the particle size it is possible by measuring the original and manipulated samples to determine the magnitude of these losses and, hence, the average size.

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The novel features which are believed to be characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings in which:

FIGURE 1 is a schematic illustration of an instrument for determining average size by diffusion loss;

FIGURE 2 is a sectional view of the diffuser taken along the lines 2-2 of FIGURE 1;

FIGURE 3 is a graph of the various properties of airborne particles and is useful in understanding the operation of the instrument;

FIGURE 4 is a wiring diagram illustrating the manner in which the solenoid valves of the instrument of FIGURE 1 are controlled;

FIGURE 5 is a graphical illustration of the operational cycle of the valves of FIGURE 4;

FIGURE 6 is an alternative construction of a diffusing mechanism which may be used with the instrumentality of FIGURE 1;

FIGURE 7 is a fragmentary showing of an alternative embodiment of the size measuring instrumentality, and

FIGURES 8 and 8a show a portion of the instrumentality of FIGURE 7 in perspective.

Referring now to the drawing, FIGURE 1 shows an instrument for measuring and determining the average size of airborne particles in a smoke stack 1 or some similar area which is being monitored. Positioned in the stack 1 are a pair of sampling probes 2 and 3 which remove gaseous samples having the particles entrained therein for measurement. Sampling probe 3, unlike probe 2, contains a diffusion chamber 4, seen most clearly in FIGURE 2, formed of a plurality of parallel plates 5 which provide uniform channels open at each end. When the particle bearing gaseous sample passes through these channels, many of the particles diffuse to the walls and are retained there so that a fraction $E < 1$ of the particles appears at the output of the diffuser. The number of particles lost by diffusion under given operating conditions of temperature, size of diffuser channel, etc., is determined, inter alia, by the diffusion constant of the particles which in turn is a function of the radius r of the particle. Hence, the gaseous sample appearing at the output of the diffusion chamber 4 has its particle concentration manipulated as a function of the particle size in the sample.

The samples emanating from the probe 2 and the diffusion chamber 4 are brought by conduits 6 and 7 to a pair of chambers 8 and 9 where they are diluted with cold, clean, dry gas brought into the chamber from a source 10 through a circular distributor 11. The samples are diluted in order to reduce the particle density and minimize errors due to particle coagulation, which varies as the square of the particle concentration. Furthermore, dilution of the samples reduces the temperature from that of the stack 1 to that of the instrument measuring the particle concentration whereby the ease of measurement is facilitated.

The source 10 which supplies the diluting gas includes a pump 12 which directs a stream of gas through a dryer 13 and a filter 14 to remove excess moisture and any ambient particles from the diluent gas while a flowmeter 15 is provided to obtain an indication of the velocity of the gas. The dried and filtered gas is passed through a cooling coil 16 immersed in a coolant bath 17 to reduce the temperature of diluent gas to a desired value and the gas is supplied through a pair of conduits 18 and 19 to the respective dilution chambers. The gaseous samples in the chambers 8 and 9 are recirculated by means of a pump 20 and returned to the stack 1 from which they were taken.

Since it is important for the sake of accuracy of measurement that each sample is diluted by the same amount and the amount of dilution be known, the conditions are controlled by bringing the samples in the dilution chambers to the same temperature. To this end, temperature measuring and indication means 21, 21', 22, 23, and 23', which may be of any suitable type, are positioned in the conduits 6, 7 and 18 and in the sampling probes 24 and 25 located in the dilution chambers. By noting the temperatures at various stages of the apparatus and particularly the temperature in the sampling probes, the flow and temperature of the diluent gas from the source 10 may be adjusted to insure that successive samples in the sampling probes are always at the same temperature and, hence, the amount of dilution of the particle concentration remains constant.

The sampling probes 24 and 25 supply samples of the treated and untreated gas from the dilution chambers through conduits 26 and 27 to a pair of humidifying elements 28 and 29 where they are brought to 100 percent relative humidity. In order to measure the particle concentration, the humidified samples are brought to a measuring device indicated generally at 30 wherein both samples are acted upon simultaneously to determine the fraction of the particle concentration lost by diffusion. The device 30 is of the class usually referred to as a condensation nuclei meter and is characterized by the fact that the particle concentration is measured by subjecting the humidified particle bearing gaseous samples to an adiabatic expansion which produces a condensation effect to form droplet clouds about the particles. The density of the droplet clouds is measured optically as an indication of the particle concentration. Thus, a pair of expansion chambers 31 and 32 into which the samples are admitted are connected to the conduits 26 and 27 through a pair of solenoid control valves 33 and 34. The expansion chambers 31 and 32 are in turn connected, through solenoid control valves 37 and 38, to vacuum chambers 35 and 36 into which the samples expand to form the droplet clouds. The vacuum chambers 35 and 36 are periodically evacuated by the pump 20 connected to these chambers through a branch conduit 39 and a third pair of solenoid valves 40 and 41.

The solenoid valve pairs 33 and 34, 37 and 38, and 40 and 41 are operated in a predetermined sequence so that the respective particle bearing samples in the conduits 26 and 27 are brought into the expansion chambers 31 and 32 and then expanded into the vacuum chambers 35 and 36 to form droplet clouds about the particles, the density of which may be measured optically to determine the particle concentration in the respective samples.

The density of the droplet clouds is measured by an electro-optical measuring system including radiant energy beams which traverse the chambers 31 and 32 and are attenuated by the droplets so that the degree of attenuation is a measure of the particle concentration. To this end, a single light source shown as an incandescent bulb 43 projects two light beams onto a pair of inclined mirrors 44 and 45 so that the beams are reflected and pass through the expansion chambers 31 and 32 and onto a pair of photosensitive devices 46 and 47 to produce electrical output signals proportional to the intensity of the respective beams traversing chambers 31 and 32. These output signals representative of the particle concentrations in the two samples are applied to a differential measuring device 48 which produces an output signal representative of the difference in particle concentration. It will be immediately apparent that the appearance of droplet clouds in the chambers 31 and 32 attenuates the light beams to a degree determined by the density of the droplet clouds and, hence, the particle concentrations in the respective samples. Therefore, the output of the differential measuring device 48 is representative of the difference in the concentration in the respective samples due to the loss in the diffusion chamber 4.

The condensation nuclei measuring device 30, which is described and claimed in an application Serial No. 816,947, filed May 29, 1959, concurrently with the instant application in the name of T. A. Rich, now Patent No. 3,102,200 entitled "Radiation Measurement" and is assigned to the assignee of the present invention, functions as follows: The valves 33 and 34, 37, 38, 40 and 41 are opened and the pump 20 flushes out the chambers and fresh humidified samples are admitted into the chambers. The valves 37 and 38 then close, isolating the vacuum chambers 35 and 36 from their respective expansion chambers so that continued operation of the pump 20 evacuates the chambers. The valves 33, 34, 40 and 41 then close and the entire system is permitted to come into thermal equilibrium. Next the valves 37 and 38 open and the pressure in chambers 31 and 32 falls very rapidly since the gaseous samples in these chambers must occupy the combined volumes of the expansion and vacuum chambers. The sudden expansion of the humidified gaseous samples in the chambers 31 and 32 produce a supersaturated condition, i.e., an instantaneous humidity larger than 100 percent, and water vapor begins to condense about the particles forming a cloud of droplets in both chambers. The formation of these droplet clouds attenuates the light beams traversing the chambers 31 and 32 by an amount proportional to the density of the droplet clouds and the photosensitive devices 46 and 47, which may be photoemissive devices for example, produce an output signal which is proportional to the density of this cloud. These signals are measured in the differential measuring device 48 to produce an output which is proportional to the difference in the droplet cloud densities and hence to the difference in the particle concentrations.

Referring now to FIGURE 4 there is illustrated a valve control circuit diagram for the solenoid control valves of the instrumentality 30 of FIGURE 1. For the sake of simplicity of explanation those portions of FIGURE 4 which correspond to portions of FIGURE 1 have been indicated by the corresponding numerals. Thus the individual solenoid valves 33, 34, 37, 38, 40 and 41 which control communication between the various chambers and the pump are actuated by energizing their solenoid coils in proper sequence. Each solenoid coil C₃₃, C₃₄, C₃₇, C₃₈, C₄₀, and C₄₁ has one side thereof permanently connected to one side of a 117 volt line shown at 50 and the other side connected through cam operated snap switches 51, 52 and 53 to the other side of the line. The switches 51, 52 and 53 each control the energization of one solenoid coil pair in a predetermined operating sequence and are individually actuated by cams 54, 55, and 56 mounted on a common shaft 57. The shaft 57 is driven by a low speed motor 58, which may for example be a one r.p.m. KYC-23 Bodine motor manufactured by the Bodine Manufacturing Company, Chicago, Illinois, which motor is energized from the 117 volt line through the switch 59.

The cams 54, 55, and 56 are so constructed, as may be seen most clearly in FIGURE 5, that the switches 51, 52 and 53 are closed to energize the respective solenoid coils and actuate the valves in a sequence and for a duration which is exemplified by the graph of FIGURE 5. Thus in this figure the rotational cycle of the cam in degrees is illustrated along the abscissa and the closure of the switches, and the energization of their associated solenoid valves, is illustrated by means of the cross-hatched portion. Thus it can be seen that the cam surface on cam 54 extends for approximately 240 degrees of its circumference so that the coils C₄₀ and C₄₁ are energized from 120 degrees to 360 degrees during each operational cycle closing the valves 40 and 41. The cam 56 is identical to cam 54 in construction and operation so that the coils C₃₃ and C₃₄ switch, and the valves 33 and 40 have the same operational cycle as those associated with the cam 54. The cam surface on the cam 55, on the other hand, extends only for approximately 120 degrees and is so spaced with respect to the others that the sequence of

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energization of the solenoid valves is that shown graphically in FIGURE 5.

Since the diffusion loss as measured by the apparatus of FIGURE 1 is related to the particle size, an average size in terms of an equivalent mono-disperse (single-size) particles having the same diffusion loss may be obtained from this information.

That is, it can be shown that the diffusion loss is defined by the equation

$$L = \frac{100S}{V} \times \sqrt{Dt} \quad (1)$$

where:

L = the diffusion loss in percent

S = the surface of the diffuser in cm^2

V = the volume of the diffuser in cc.

D = the diffusion constant

t = the average residence time in the diffuser volume and can be expressed in terms of flow in cc./sec.

The diffusion constant (D) may be defined as the number of particles passing through a unit area $A=1$ due to unit number concentration gradient, or

$$\frac{dN}{dt} = D \frac{dn}{dx} \quad (2)$$

where:

N = the number of particles crossing a plane perpendicular to direction x

dN/dt = the rate at which particles pass through the unit area, i.e., particle velocity

n = concentration of particles, number per cm^3

dn/dx = concentration gradient along direction x

t = time

At one boundary (a) of the incremental length of channel dx there are n particles per cc. and due to concentration gradient there are $(n-dn)$ particles/cc. at the other boundary (b) of the incremental length. These particles may be considered as a very heavy gas and as a result the pressures exerted at the entrance and terminus of increment dx may be defined as

$$p_a = nKT \quad (3)$$

where:

K = Boltzmann's constant (1.37×10^{-16} erg/deg. K.)

T = absolute temperature in degrees K.

and

$$p_b = (n-dn)KT \quad (4)$$

The total force on the particles (ndx) in the channel of length dx is then

$$p_a - p_b = dp = KTdn \quad (5)$$

The force per particle is

$$\frac{dp}{\text{number of particles}} = \frac{KTdn}{ndx} \quad (6)$$

The restraining force on movement of these particles is the frictional resistance of the gaseous carrier fluid and is equivalent to Stokes' equation for the resistance of a sphere as modified by the Cunningham correction or

$$F = \frac{6\pi r \eta}{1 + \frac{9 \times 10^{-6}}{r}} \quad (7)$$

where:

F = the restraining force

r = particle radius in cm.

η = coefficient of viscosity of the gas which for air is 170 poise at normal temperature

The velocity u of the particles under the influence of the pressure dp and as against the frictional restraint in

$$u = \frac{dp}{F} = \frac{KTdn}{nFdx} \quad (8)$$

6

or

$$nu = \frac{KT}{F} \frac{dn}{dx}$$

5 However,

$$\frac{dN}{dt} = nu \quad (9)$$

and, therefore, the rate dN/dt at which particles pass through is

$$\frac{dN}{dt} = \frac{KT}{F} \frac{dn}{dx} \quad (10)$$

or the diffusion constant

$$D = \frac{KT}{F} \quad (11)$$

The mobility M of a particle on the other hand is defined as the velocity of a particle with charge pe in a unit field, or

$$V = \frac{Epe}{F} \quad (12)$$

where:

E = field in electrostatic units

e = electronic charge 4.7×10^{-10} absolute e.s.u.

P = the number of charges per particle

F = is the restraining force as defined by Equation 7

V = velocity in cm./sec.

30 Thus when $E=1$, $V=M$ or

$$M = \frac{pe}{F} \quad (13)$$

and

$$\frac{4.7 \times 10^{-10} p}{F}$$

Under many circumstances it may be more desirable to determine the particle size r from the diffusion loss L of Equation 1 not by calculating the diffusion constant D directly, but by establishing the relationship of the diffusion constant to the mobility M . Thus the ratio M/D may be obtained from Equations 11 and 13 or

$$\frac{M}{D} = \frac{pe}{KT} = \frac{4.7 \times 10^{-10} p}{4 \times 10^{-14}} = 1.2 \times 10^4 p \quad (14)$$

Since M of Equation 13 is velocity in c.g.s. field, the value of M in practical units is $\frac{1}{300}$ of the absolute value since

$$1 \text{ statvolt} = \frac{10^9 \text{ volts}}{3.3}$$

or 1 statvolt $\cong$ 300 volts. Therefore

$$\frac{M}{D} = \frac{1.2 \times 10^4 p}{10^3} \times 3.3 \cong 4.0 p \times 10$$

55 and with $P=1$, i.e., a singly charged particle,

$$\frac{M}{D} = 40$$

Equation 1 above may then be rewritten as

$$F = \frac{S}{V} \times \sqrt{\frac{M_1 t}{40}} \quad (15)$$

where M_1 = the mobility of singly charged particles, since the diffusion constant may be defined as

$$D = \frac{M_1}{40}$$

by a well known conversion, where M_1 is defined as the velocity of cm./sec. of a singly charged particle in a field 1 volt/cm.

From Equation 15 the values of M_1 may be determined in terms of the diffusion loss as obtained from the output of the differential measuring device.

75 Having thus determined the value of M_1 for a given gaseous sample it is possible to determine the average

size of the particles since the variation of M_1 , i.e., the mobility, with particle size has been established both theoretically and experimentally. FIGURE 3, and particularly the family of curves denominated $M \times 10^2$, $M \times 10^3$, . . . $M \times 10^6$ show the values of mobility M plotted along the ordinate for various particle sizes, plotted on a logarithmic scale along the abscissa. Thus for any value of mobility M , the radius of an equivalent mono-disperse particle may be obtained from the curves of FIGURE 3. In this manner, a size determination is possible from the diffusion loss as a fraction of the original particle concentration.

In describing the operation of the instrumentality of FIGURE 1, the ultimate size information desired is obtained by means of a graphical interpretation from the curves of FIGURE 3. It will be apparent, however, that the desired size information may be obtained automatically by feeding the output of the differential measuring device to a suitable computer mechanism which performs the necessary arithmetic operations to determine the value of the mobility M and then obtaining the value of r directly by comparing this information against the stored values of M . However, for most purposes the graphic method will suffice and such elaborate mechanization will not be necessary.

FIGURE 6 shows a diffuser construction which can be utilized as an alternative to that shown and described in FIGURE 2. Thus the diffuser of FIGURE 6 includes a plurality of tubes 60 of a predetermined diameter positioned in a cylindrical housing 61. It will be apparent, that the cylindrical tubes 60 produces essentially the same effect as the channels of FIGURE 2 in that a fraction of the particles passing therethrough will diffuse to the walls so that some fraction E of the original particle concentration appears at the output of the diffuser.

In determining the average particle size in accordance with the invention, one instrumentality has been shown and described wherein a fraction of the particle are abstracted by diffusion. However, the size may also be determined by ascertaining what fraction of the particles are in a naturally charged condition. It is a well known fact which has been established theoretically and experimentally that a mono-disperse particle concentration becomes charged under natural conditions due to the presence in the air of "small ions" which are produced by cosmic rays, natural radioactivity, etc. The birth rate of such small ions over the ocean is about two positive and two negative ions per second per cc. whereas over land the value is about 10 ion pairs per second. These small ions collide with airborne particles to produce a charged particle whenever such an ion strikes and adheres to the particle. Distribution of charges on the particles with size and the fraction of the particles which are charged has been established theoretically and experimentally by an application of Boltzmann's law which may be written as

$$\frac{N_o}{N_p} = e^{\frac{p^2 e^2}{2rKT}} \quad (16)$$

where:

p =the number of electronic charges
 e =electronic charge, 4.7×10^{-10} e.s.u. abs.
 r =the radius of the particle
 K =Boltzmann's constant, 1.37×10^{-16} erg/° K.
 T =temperature in degrees Kelvin
 N_o =the uncharged particles
 N_p =are particles having p charges

Substituting the values of the various constants into the Equation 16 above the ratio N_o/N_p takes the form

$$\frac{N_o}{N_p} = e^{\frac{2.8p^2}{10^3 r}} \quad (17)$$

for a $T=290^\circ$ K. $=17^\circ$ C. The term $p^2 e^2 / 2r$ is the en-

ergy due to p electronic charges on the sphere of radius r . The value of p assumes values of $+1, -1, +2, -2$, etc. since the particle may be singly or multiply charged both by a positive or negative charge. If Z equals the total number of particles per cubic centimeter, Z may be defined by the equation

$$Z = N_o + 2N_p \quad (18)$$

for values of $p = +1, -1, +2, -2, +3, -3, \dots +p, -p$. The $2N_p$ term is present in Equation 18 because the total number of charged particles represents the sum of those charged by positive ions and those charged by negative ions. From Equation 17 it is apparent that N_p may be defined as

$$N_p = N_o e^{\frac{-2.8p^2}{10^3 r}} \quad (19)$$

Hence, substituting the values of p , Equation 18 may be rewritten as

$$Z = N_o + 2N_o e^{\frac{-2.8}{10^3 r}} + 2N_o e^{\frac{-4 \times 2.8}{10^3 r}} + 2N_o e^{\frac{-9 \times 2.8}{10^3 r}} + 2N_o e^{\frac{-2.8p^2}{10^3 r}} \quad (20)$$

To simplify the above equation, if the particle radius r is less than 5×10^{-6} ($r < 5 \times 10^{-6}$ cm.) centimeter, the series of Equation 20 converges rapidly and the uncharged fraction of the particles

$$F_o = \frac{N_o}{Z}$$

is then defined by the equation

$$F_o = \frac{1}{1 + 2(x + x^4 + x^9 + x^{p^2})} \quad (21)$$

where:

$$x = e^{\frac{-2.8}{10^3 r}}$$

For particles larger than 5×10^{-6} ($r > 5 \times 10^{-6}$ cm.) centimeter the uncharged fraction F_o may be defined by the equation

$$F_o = \frac{1}{1.06(r \times 10^6)^{\frac{1}{2}}}$$

FIGURE 3 shows a number of curves which represent the variations of the uncharged fraction F_o with particle size, as well as the relationship of particle radius to the fraction of such particles having single, double, triple, etc. charges. Thus the curve F_o shows graphically the relationship between the uncharged fraction and the particle size and may be used to obtain the average size of an equivalent mono-disperse particle from the fraction of the uncharged particles in any particular gaseous sample.

The family of curves N_1, N_2, N_3 , etc., on the other hand, show the relative percentage of particles having single, double, triple, etc. charges as a function of particle size. Thus it may be seen from the curve N_1 that the percentage of singly charged particles varies with particle size and has a maximum at a radius of approximately 5×10^{-6} cm. The remaining curves which represent multiple charged particles, i.e., two, three, four or more charges per particle, are similar to curve N_1 except that they are displaced towards the right, i.e., towards the larger sizes, since the larger the particle the more likely it is to intercept and hold one or more of the "small ions" produced by cosmic rays or natural radiation.

The curve F_o representing the uncharged fraction for various particle sizes is related to the family of curves N_1, N_2 , etc. in that the value of F_o for a given radius is equal to the total number of particles (100%) minus the sum of the charged particles (percent N_1 , percent N_2 ,

etc.) shown by the curves N_1 , N_2 , etc. Thus, for example, at a size $r=1 \times 10^{-5}$ cm. approximately 46 percent of the particles have a single charge as shown by the intercept "a" on the curve N_1 . Furthermore, 19 percent of the particles have two charges, as shown by the intercept b on the curve N_2 , 5 percent have three charges, as shown by the intercept c , and approximately 1 percent have four charges, as shown by the intercept d . Thus adding all of these values together it can be seen that 71 percent of the particles of that size have one or more charges and that the value of the uncharged fraction F_0 , at $r=1 \times 10^{-5}$ cm. should be approximately 29 percent, which is borne out by the intercept e on the curve F_0 . Thus it can be seen that the various values along the curve F_0 may be checked by adding the ordinate values of the respective curves N_1 , N_2 , N_3 , etc. at various radii and subtracting from 100 percent.

Referring now to FIGURE 7, there is shown a fragmentary schematic diagram of an apparatus for determining the average size by measuring the uncharged fraction from which the average size may be determined. Hence, a pair of sampling probes 71 and 72 positioned in a smoke stack 73 or any other similar area which is being monitored for particle size. Probe 72 is coupled by means of a conduit 74 to a dilution chamber 75 identical in construction to that shown in FIGURE 1 wherein the sample is diluted and then applied to a measuring apparatus to determine the concentration of the particle bearing gaseous sample.

The sampling probe 71 on the other hand is connected to a chamber 76 which contains a pair of electrodes 77 which are energized to establish an electric field through which the gaseous sample passes. The naturally charged particles entrained in the gaseous sample are drawn to the electrodes 77 and removed from the gas, so that the particle concentration is reduced by removing the fraction thereof which is charged. Because of this characteristic action such a device is referred to as a "denuder" in that it strips or denudes the sample of the charged particles.

The gaseous sample exiting from the chamber 76 contains only uncharged particles and is coupled into a dilution chamber 78 and from there to a measuring device wherein the treated and untreated samples are measured simultaneously to provide an indication of the original particle concentration Z as well as the number of uncharged particles N_0 . From these the magnitude of the uncharged fraction F_0 is obtained by applying these output signals to a ratio measuring device to produce electrical signal proportional to N_0/Z and hence the value of F_0 . The "average" particle size may then be obtained from the curve F_0 of FIGURE 8 for an equivalent monodisperse particle concentration having the same value of F_0 .

Referring now to FIGURES 8 and 8a there is shown a denuder construction which may be utilized in the system of FIGURE 7. The denuder shown generally at 79 includes two concentric cylindrical electrodes 80 and 81 which define an annular space 82 through which the particle bearing gaseous medium passes. A pair of insulating sleeves 83 and 84 separate the electrodes and the whole assembly is sealed against leakage by the O-ring seals 85. A radial electric field is established across annular space 82 by applying energizing voltages $+V$ and $-V$ to the respective electrodes and the charged particles are drawn to the electrodes and removed.

The central electrode 81 is supported in a fashion which may be seen clearly in FIGURE 8a which shows an exploded view of the electrode support assembly. Thus the electrode 81 is supported in cone-shaped receptacles 86 in end plugs 87 and 88 and is supported therein by means of cross-shaped support members 89 and 90 which fit into retaining slots 91 in the electrode 81 and corresponding slots 91 in the end plugs. In this manner a simple and effective apparatus for removing the charged

particles from the gaseous medium is provided although it will be apparent that other denuder configurations may obviously be used in carrying out the instant invention.

While a number of particular embodiments of this invention have been shown it will, of course, be understood that it is not limited thereto since many other modifications both in the circuit arrangement and in the instrumentalities employed may be made. It is contemplated by the appended claims to cover any such modifications as fall within the true spirit and scope of this invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a device for measuring the average size of airborne particulates, the combination comprising means adapted to receive gaseous samples containing particles to be measured, means to treat one of said samples to remove a fraction of said particles in accordance with the size of said particles, and means to determine the average size of said particles from the reduction in particle concentration, said last mentioned means including particle measuring means for simultaneously comparing said treated and untreated gaseous samples and deriving an output signal representative of the difference in particle concentration.

2. In a device for obtaining the average size of airborne particles from the mobility characteristics of the particles, the combination comprising means adapted to receive two particle bearing gaseous samples and to reduce the particle concentration in one of the gaseous samples in proportion to the particle size including means for treating said one gaseous sample by establishing an electric field to remove all particles in said sample having mobility in said field, the fraction of the particles thus removed being a function of the particle size, and means to determine the average size of said particles from the reduction in particle concentration, said last mentioned means including particle measuring means for simultaneously comparing said treated and untreated gaseous samples and deriving an output signal representative of the difference in particle concentration.

3. In a device for obtaining the average size of airborne particles from their mobility characteristics, the combination comprising particle mobility sensitive means for obtaining samples, one of said samples being treated to reduce the particle concentration as a function of the average particle size, and means including an expansion chamber to produce droplet clouds from said particles of said samples to measure the reduced concentration as an index of the average size of said particles.

4. In a device for obtaining the average size of gas entrained particles from their mobility characteristics, the combination comprising means to treat a portion of a particle bearing gaseous sample to reduce the particle concentration as a function of the average particle size including means to intercept all particles in said portion having charge mobility, and means for simultaneously measuring the particle concentration in the treated and untreated portions of said gaseous sample to determine the change in concentration as an index of the average particle size, said last named means including means to subject said treated and untreated portions to an adiabatic expansion to form droplet clouds about said particles.

5. In a device for obtaining average particle size from the charge mobility characteristics of the particles in a pair of gaseous samples, the combination comprising means to remove from one of the samples all particles having charge mobility to reduce the particle concentration as a function of average particle size, and means to measure the change in particle concentration as an index of the average particle size, said last mentioned means including particle measuring means for simultaneously comparing said gaseous samples and deriving an output signal representative of the difference in particle concentration.

6. In a system for monitoring an area to determine the average size of the particle population in said area

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by means of the charge mobility characteristics of the particles, the combination comprising means to sample the gaseous atmosphere in said area under controlled conditions including means to dilute the particle bearing gaseous sample with a particle free, constant temperature gas stream to reduce the particle concentration and particle coagulation, means to remove from a portion of said sample prior to dilution all particles having charge mobility to reduce the particle concentration as a function of average particle size, and means to measure the change in particle concentration of said portion as an index of the average particle size, said last mentioned means including particle measuring means for simultaneously comparing the sample prior to removal of the particles having charge mobility and said portion and deriving an output signal representative of the difference in particle concentration.

7. In a device for obtaining average particle size from their diffusion characteristics, the combination comprising a diffusion member adapted to receive a particle bearing gaseous sample and to intercept a fraction of the particles by diffusion to the surfaces thereof to reduce the particle concentration as a function of size, and means to measure the change in particle concentration as an index of the average particle size, said last mentioned means including particle measuring means for simultaneously comparing said gaseous sample and a second separate sample of the gaseous medium which has not been treated in said diffusion member, and deriving an output signal representative of the difference in concentration of the particles.

8. In a device for obtaining the average size of gas

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entrained particles from their diffusion characteristics the combination comprising means to treat a portion of a particle bearing sample to reduce the particle concentration as a function of the average particle size including means to intercept a portion of said particles by the effect of thermal diffusion and means for simultaneously measuring the particle concentration in the treated and untreated portions of said gaseous sample to determine the change in concentration as an index of the average particle size, said last named means including means to subject such treated and untreated portions to an adiabatic expansion to form droplet clouds about said particles the density of which is a measure of the particle concentration.

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