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BALLISTIC PARTICLE SIZE DISCRIMINATOR

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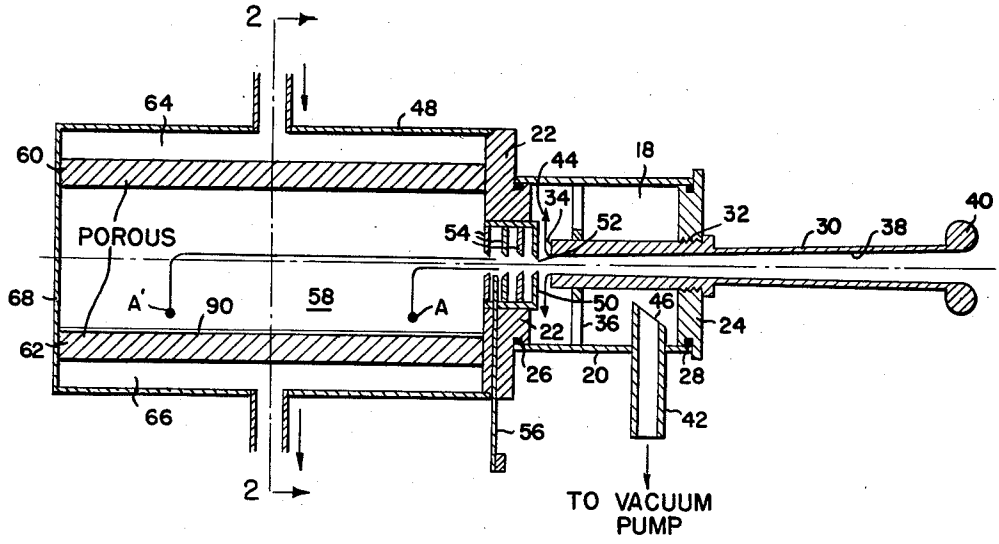


FIG. 1.

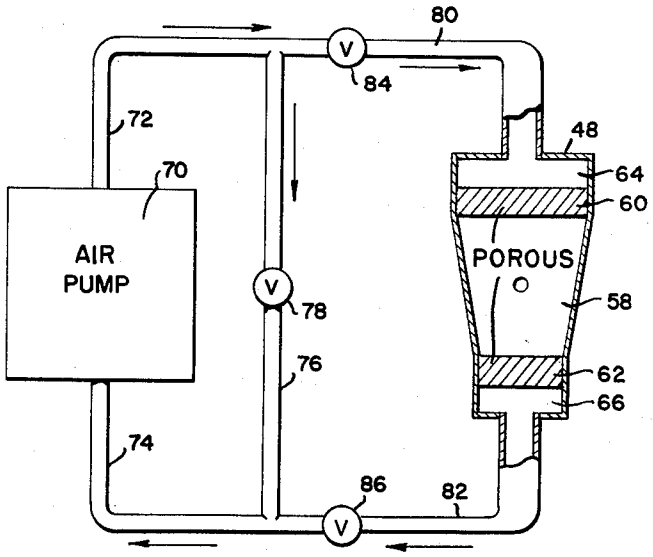


FIG. 2.

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BALLISTIC PARTICLE SIZE DISCRIMINATOR

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2 Claims. (Cl. 209—135)

This invention relates to a ballistic particle size discriminator particularly adapted for the separation, either for sampling or collection purposes of airborne particulate matter according to size.

Particulate matter, either solid or liquid, suspended in air or other gas for any substantial length of time is generally designated as an aerosol. Such aerosols have become of considerable commercial importance in their uses for the dispersion of paints, insecticides, fixatives, etc., and sampling to detect the distribution of sizes of particulate matter therein is of importance, for example, as a check on the properties of the aerosol itself and to determine the effectiveness of apparatus to produce aerosols having desired characteristics. Furthermore, aerosol formation may be a step in the production of fine particles of materials such as plastics, and in such cases not only is sampling desirable for control of production of particle size but discrimination of particles according to size may be important in the collecting operation.

In my prior application, Serial No. 620,709, filed November 6, 1956, there is described a ballistic particle size discriminator which is particularly applicable to the grading of particulate matter in the 2 to 200 micron size range, a range within which there falls the particulate matter of most aerosols of industrial importance. In accordance with what is described in said application, particles to be separated are projected at a substantially constant velocity at a point of entry into a region of still air or other gas. The trajectory of a small particle thus projected can be divided into two distinct phases. First, there is a nearly straight segment of the trajectory over which the particle experiences a high deceleration acting over a distance approximately equal to the ballistic range and for a time which may be of the order of a few thousandths of a second. At the end of this phase of the trajectory the component of velocity of the particle in the direction of original projection is very low. In the second phase, gravitational settling of the particle upon a collecting surface or through a detecting region is dominant, the time scale of this portion of the trajectory being of the order of a second. To give an idea of the order of velocity involved under the action of gravity alone, it may be pointed out that a spherical particle five microns in diameter will require 3.3 seconds to fall a distance of only 0.10 inch. Thus, the trajectories of small particles here of interest actually have "knees" of quite small radii of curvature for small particles, the radii being greater with larger particles, so that a complete trajectory would approximate in appearance a straight line extending in the direction of projection followed by another straight line extending substantially vertically.

The ballistic discrimination process is operative only during the first phase of the trajectory during which the high rate of deceleration of a particle occurs. Gravitational settling in the second phase contributes nothing to the process of size discrimination.

When the concentration of particles per unit volume is low, discrimination in accordance with my prior application is satisfactory. However, when the particle concentration is relatively high a problem arises for the following reasons:

As a particle approaches the end of its ballistic range, that is the end of the first phase of the trajectory mentioned above, its forward velocity approaches zero and until it has fallen clear of the incident beam it presents a target to larger particles which may overtake it and collide therewith. The result of such collision is that the smaller particle, assuming the collision elastic, will gain kinetic energy and will be projected beyond its normal ballistic range limit while the larger particle will fall somewhat short of its own normal limit. The scattering effect thus produced introduces a random disorderly action which under some conditions may greatly affect the discrimination, for example, where there is a high concentration of particles and where the range of sizes is considerable. In the case of liquid droplets or in the case of semisolid materials, the colliding particles may coalesce, again defeating the discriminating action. It is, accordingly, desirable to remove each particle from the boundaries of the particle beam as soon as possible at a rate considerably in excess of the rate of removal which can be effected by gravity alone. This result may be achieved without any substantial effect on the ranges of the particles by providing a flow of air or gas in the region of the trajectory transversely thereto to produce a "settling" action. This transverse removal velocity may very considerably exceed that effected by gravity so that the apparatus may be used with its projection axis extending in any direction, the action of gravity being negligible as contrasted with the action of gravity alone in my prior apparatus which for most accurate results required the axis of projection to be substantially horizontal. To give an idea of the relative velocities involved and to explain the non-interference of the removal action with the ballistic discriminating action, it may be pointed out that a typical initial velocity at the beginning of the trajectory may be of the order of 3,000 centimeters per second, resulting in the arrival of the particle at the end of its trajectory in only a few thousandths of a second. If a transverse velocity of the air or other gas into which the particles are projected is less than one-hundredth of the initial particle velocity there is no appreciable effect on the first phase of the trajectory. Thus, consistent with the initial velocity figure just given, the transverse velocity may be anything less than 30 centimeters per second and in most practical cases a velocity of 10 centimeters per second is adequate to reduce the probability of collision to a negligible amount, being further attainable without the setting up of turbulent flow which would interfere with discrimination. Such velocity of 10 centimeters per second is, however, much greater than the settling velocity produced by gravity which, for a spherical particle 5 microns in diameter is only about 0.08 centimeter per second. The aspect of removal velocity due to gravity is thus negligible relative to the removal velocity due to transverse gas flow with the result that, as stated above, orientation of the device becomes immaterial.

The general objects of the invention are concerned with the attainment of the desirable ends just described and will become more apparent from the following description, read in conjunction with the accompanying drawing, in which:

Figure 1 is an axial section of a preferred form of apparatus provided in accordance with the invention; and

Figure 2 is a section taken on the plane indicated at 2—2 in Figure 1 and also showing diagrammatically an air flow controlling means for producing removal of particles from the beam thereof.

Throughout the following to avoid complexity of description it will be understood that where particles are referred to not only solid particles but liquid droplets are included. Furthermore, while reference will be made particularly to air as a suspending gas of an aerosol it will be understood that other gases or vapors are also included.

Reference may now be made to the figures which illustrate a device for sampling aerosols which has a high degree of discriminating action and which effectively achieves the theoretical conditions which are required for optimum operation.

A chamber **18** is provided by a cylinder **20** and end plates **22** and **24** which are sealed to the cylinder **20** through the use of O-rings **26** and **28**, the assembly being desirably maintained by a series of spring clips (not shown) which may be readily released to permit disassembly for cleaning and subsequent reassembly. A nozzle tube **30** is threaded through the plate **24** at **32** and terminates in an orifice at **34** beyond the point where it extends through a central opening in a supporting spider **36** secured in the tube **20**. This support is provided to insure accurate axial alignment of the parts which is necessary for the attainment of uniform results. The bore **38** of the nozzle tube **30** may be cylindrical but desirably converges in the direction of flow therethrough, this convergence serving to reduce turbulence in the flow and to focus the particles to enhance the collimation of the particles which pass through an aperture hereafter described. The entrance end of the tube **30** is desirably rounded as indicated at **40** to minimize any disturbing effect the instrument may have on the aerosol, this being a requirement for unbiased sampling. Extending through the wall of the cylinder **20** is a tube **42** arranged for connection to a constant speed vacuum pump for the maintenance of a jet of the aerosol through the tube **30**. This tube **42** desirably enters the chamber **18** at a location substantially removed from the exit end **34** of tube **30** so that the air flow indicated by the arrows **44** is uniform in all radial directions about the axis of the tube. This uniformity of flow is further improved by having the end of tube **42** which enters the chamber **18** bevelled as indicated at **46** to afford an entrance directed away from the end **34** of tube **30**. For uniformity of sampling the vacuum pump should operate at constant displacement and the pressure of the aerosol at the entrance to tube **30** should be constant.

An enclosure **48** is secured to the plate **22**. Secured within the plate **22** is an assembly comprising a disc **50** having a surface perpendicular to the axis of the nozzle **30** which is also the axis of the cylinder **20**. For proper results, axial symmetry must be precisely maintained. The disc **50** is provided with an aperture **52** also centered on the axis. This aperture should have a very sharp edge provided by bevelling on the side away from the impinging jet. If the edge is not sharply bevelled there is scattering and consequent loss of discrimination. For best results, the sharpness of the edge should be such that its radius of curvature is less than the radius of curvature of the smallest particles involved which are to be discriminated. The angle of the bevel should be such that its surface inside the aperture **52** will not be engaged by a particle suffering maximum deviation from axial motion.

Assuming, initially, that the aperture **52** and the bore of the nozzle tube **30** are both circular in cross-section, satisfactory results require that the diameter of the aperture should be no more than one-third the diameter of the discharge end of the bore of the nozzle tube **30**. There are several reasons for this:

There will necessarily be a variation in velocity across the diameter of the nozzle tube **30**, and to secure uniformity of velocity of particles entering the aperture **52**, the aperture must receive only particles which are moving within a limited radius from the axis. At a distance

from the axis equal to one-third the radius of the discharge end of the bore of tube **30** the velocity may be about 10% less than at the axis and the figure given above would be to insure that there was no more than a 10% spread in velocity of the particles entering the aperture **52**.

Secondly, since the aperture at **52** effectively represents a stagnation point for flow from the nozzle tube **30**, the chamber at **48** being closed as pointed out more fully hereafter so far as entry of air or gas from the nozzle tube is concerned, the flow lines necessarily diverge radially across the face of the plate **50**. Particles off the axis are deflected with the gas flow, and to have the particles pass through the aperture **52** before they are deflected to an unsatisfactory extent the boundary of the aperture **52** must be close to the axis.

A further reason for using a quite small opening at **52** is that aerodynamic disturbances to the left of that aperture occur to a material extent roughly through an axial region of a length about equal to the radius of the aperture. If the aperture is small this disturbing region is correspondingly small and the particles will be subjected to a minimum of disturbance.

In general, it may be said that the aperture **52** should be small in comparison with the discharge opening of the tube **30**. The considerations just given will, of course, apply whether the aperture and tube opening are or are not circular.

Beyond the aperture **52** in the direction of motion of the particles are a series of baffles **54** each of which is provided with an aperture slightly larger than the aperture **52** and similarly provided with sharp edges by bevelling as shown. The purpose of these apertures is to damp out turbulence produced at the aperture **52** so that toward the left of the arrangement of baffles the air within the chamber **48** is quiescent to correspond to the theoretically desired conditions for deceleration of the particles. A shutter **56** is guided in the member **22** to be moved across the apertures in the baffles **54**, this shutter being moved outwardly to start a sampling period and inwardly to end it. This shutter is desirable since if the sampling were started and stopped by starting and stopping flow of air through tube **42** transient conditions would occur giving rise to serious errors in results.

What has been so far described is shown in my prior application. In that application a chamber corresponding to **48** was completely enclosed to provide a dead body of air or gas into which the particles were projected and within which they ultimately fell by the action of gravity.

In accordance with the present improvement the chamber **48** has a special construction and provides for a transverse flow of air or gas as will now be described.

As shown particularly in Figure 2, the chamber **48** has a transverse section providing in its central portion a tapered region **58** through which air or gas flow takes place in a downward direction as viewed in Figure 2. Above and below the region **58** are walls **60** and **62** provided by a relatively thick porous material such as fritted glass, sintered metal, porous porcelain, or the like. Above and below these walls are respective chambers **64** and **66** providing headers for the inflow and outflow of air or gas. The ends of the several chambers and of the walls are closed by an impermeable wall **68** to segregate the chambers.

An air pump **70** has its discharge passage **72** and its suction passage **74** connected by a by-pass **76** provided with a flow controlling valve **78**. The upper end of this by-pass is connected at **80** to the header **64** while the lower end of the by-pass is connected at **82** to the header **66**. Valves **84** and **86** are provided to control flow through these connections. The by-pass valve **78** is open to such extent as to provide stable operation of the pump **70** and in connection with the additional valves **84** and **86** serves to produce the desired rate of flow of air or

gas through the chamber 48. The porous walls 60 and 62 insure an even and uniform distribution of the air flow across the region 58, the tapered arrangement of which serves to minimize any turbulence. The major pressure drops through the system between the connections 80 and 82 occur within the porous walls 60 and 62, there being only a slight pressure drop across the region 58 which assumes an average pressure corresponding to the stagnation pressure resulting from flow through the nozzle tube 30. As already indicated, the linear velocity of flow through the region 58 may be of an order less than 30 centimeters per second and may satisfactorily, consistent with other conditions which have been given, be in the neighborhood of 10 centimeters per second.

The various parts in proximity to the suspended particles are desirably metallic to avoid the existence of electrostatic fields which might affect the trajectories of the particles. Thermal insulation, not shown, may surround the chamber 48 to minimize convection currents in the air due to temperature gradients.

The particles may be collected upon a filter paper or other porous material 90 located above the porous wall 62.

Operation of the apparatus is as follows:

With the right-hand end of tube 30 positioned to receive the aerosol to be sampled, removal of air or gas from tube 42 produces a jet impinging on the plate 50 and, in effect, on the body of air or gas existing at the opening 52 as a result of the effective closure to any exterior flow of the chamber 48. Particles traveling sufficiently close to the axis are thus projected through the aperture 52 and through the aligned apertures in the baffles 54 so as to attain characteristic trajectories within the region 58. All of the particles thus entering through the aperture 52 have approximately the same initial linear velocity and directions having only slight deviations at most from the axis of the apparatus. As described above, the first phase of the trajectory of each particle occupies only a few thousandths of a second at most with the result that the cross flow of air or gas in the region 58, which flow has no component of motion in the direction of the axis, has no appreciable action on this first phase of the trajectory, there being applied to the particles in that phase of the trajectory only a negligible deviation from their original paths. From the standpoint of axial component of motion, the particles then essentially come to rest, but are then picked up by the transverse flow and carried quickly out of the limits of the beam of particles defined by the first phases of their trajectory. This matter of carrying them out of the beam involves velocities much greater than those which would exist by reason of gravity alone, and consequently collisions between particles of different sizes are minimized. The particles are carried by the transverse flow to the collecting surface defined by the filter paper or the like indicated at 90. As pointed out in the introductory portion of this specification, the transverse flow velocities which would ordinarily be used are much greater than those which would be produced by gravity, and therefore the effect of gravity is essentially negligible and the apparatus may be used in any position, not necessarily with its axis horizontal.

Instead of collecting the particles on a surface such as 90 they may, of course, be counted by photoelectric means, there being provided in such case transparent regions in the walls of the chamber 48 through which light may be introduced to be dispersed by the particles and through which they may be viewed and counted by a photoelectric counting system. Suitable light collimating

means may be, of course, provided to define a plane, with additional means to define portions thereof to limit the region or regions in which particles are counted.

While the apparatus may involve a considerable range of dimensional aspects, it will be informative to cite as follows typical usable dimensions for the discrimination of particles in a range of 2 to 200 microns size, this size being the diameter of equivalent spheres.

The sampling tube 30 may have a length of 10 inches, and the chamber 48 may have a similar length, the only relationship, however, which is desirable in the case of these lengths being that the tube 30 should be at least as long as the collecting region so that all particles which enter the tube 30 may be fully accelerated to substantially the velocity of flow therethrough. Assuming an exit diameter of tube 30 of 0.16 inch, its inlet diameter may be about 0.42 inch. The spacing between the outlet 34 and plate 50 may be about 0.080 inch. The diameter of aperture 52 may be about 0.030 inch. In such case, the diameter of each opening in the baffles 54 may be about 0.046 inch with spacings between the baffles of 0.062 inch, this same spacing existing between the plate 50 and the baffle adjacent thereto. The tube 20 may have a length of 3.5 inches and a diameter of 1.75 inches. Typical operating conditions may involve a pumping rate through the tube 42 of 1.12 liters per second, a gauge pressure in the tube 20 of −2.2 centimeters of mercury, and a gauge pressure in the region 58, corresponding to the stagnation pressure of the jet, of −0.02 centimeters of mercury. With such dimensions and conditions particles ranging in size from 5 microns to 65 microns may be well discriminated.

As will be evident from the foregoing, various changes may be made in details of embodiment of the invention without departing from the scope thereof as defined in the following claims.

What is claimed is:

1. Apparatus for the discrimination of particles in gaseous suspension comprising a chamber having a restricted aperture in a wall thereof, means including a nozzle in alignment with the aperture for directing a stream of gas containing particles in suspension towards said aperture to project particles through the aperture into gas within said chamber, said aperture having an opening area substantially smaller than the internal cross-section of the discharge end of said nozzle so that all particles of the same size entering said aperture do so at substantially the same velocity, said chamber providing an extended free space in the direction of projection of particles through said aperture so that particles to be discriminated are slowed down to substantially zero velocity in the direction of said projection by gas friction alone, means providing a flow of gas within said chamber in a direction transverse to the direction of said projection, and means defining a surface within said chamber to be traversed by the trajectories of the particles entering the chamber.

2. Apparatus according to claim 1 in which said means providing a flow of gas within the chamber includes extended porous walls bounding said chamber on opposite sides of the axis of the aperture and through which said flow of gas enters and leaves said chamber.

References Cited in the file of this patent

UNITED STATES PATENTS

2,255,206	Duncan	Sept. 9, 1941
2,702,471	Vonnegut	Feb. 22, 1955
2,815,858	Rich	Dec. 10, 1957