

April 29, 1969

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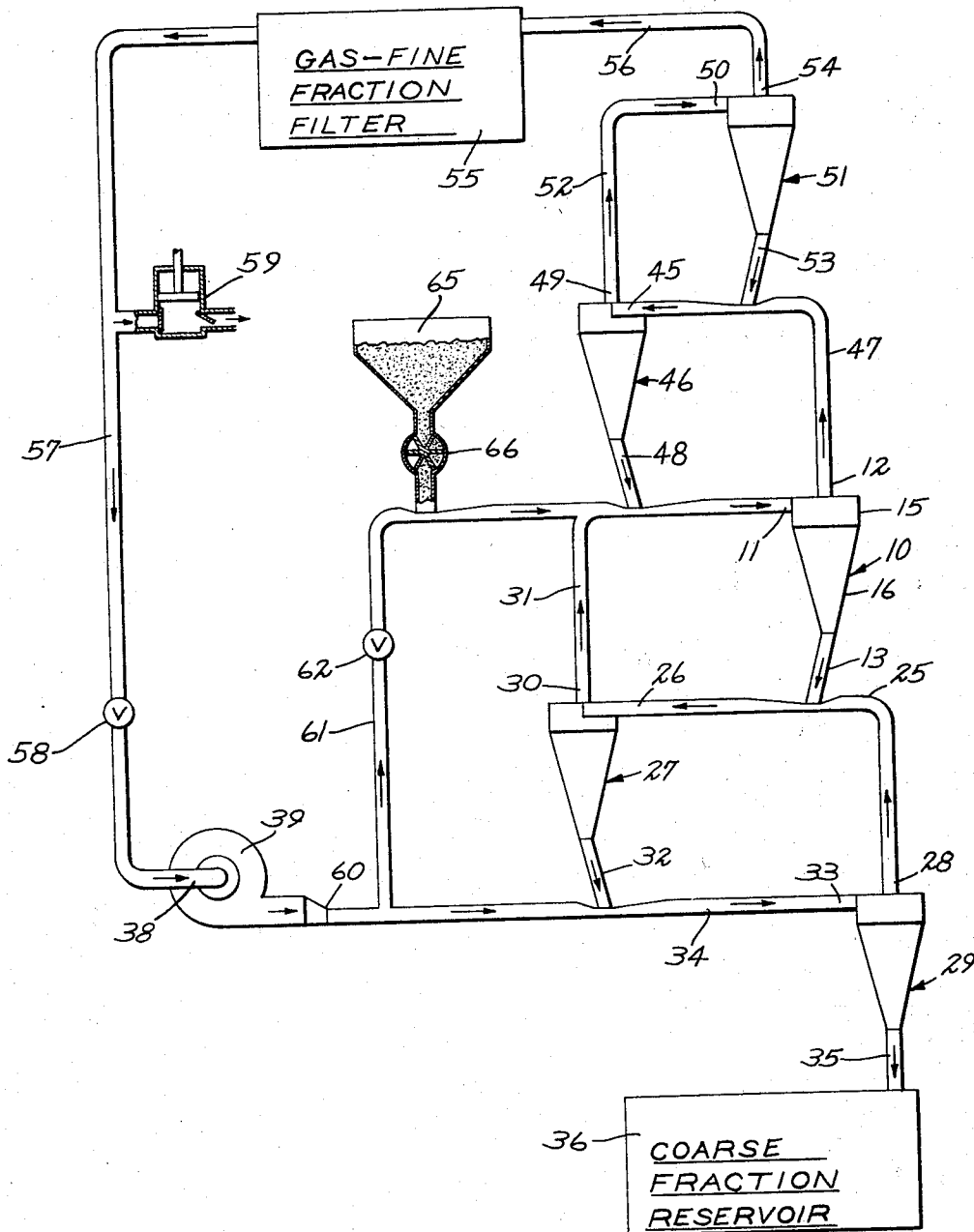
3,441,135

PARTICLE CLASSIFICATION DEVICE AND METHOD

Filed Nov. 25, 1966

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FIG. 1



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FIG. 2

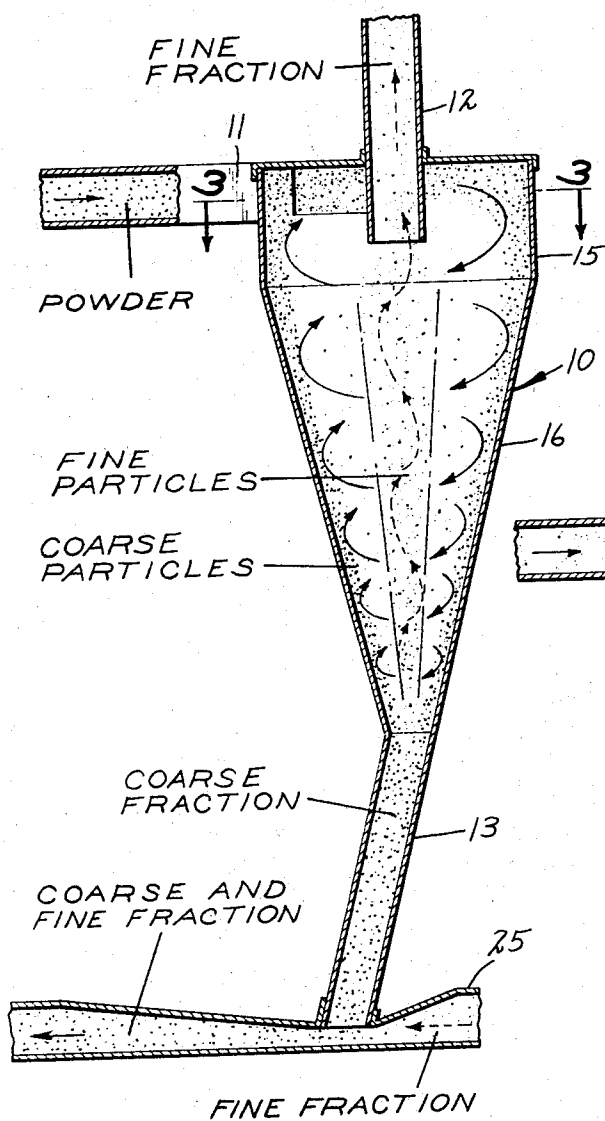


FIG. 3

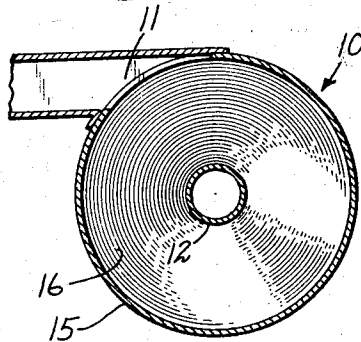
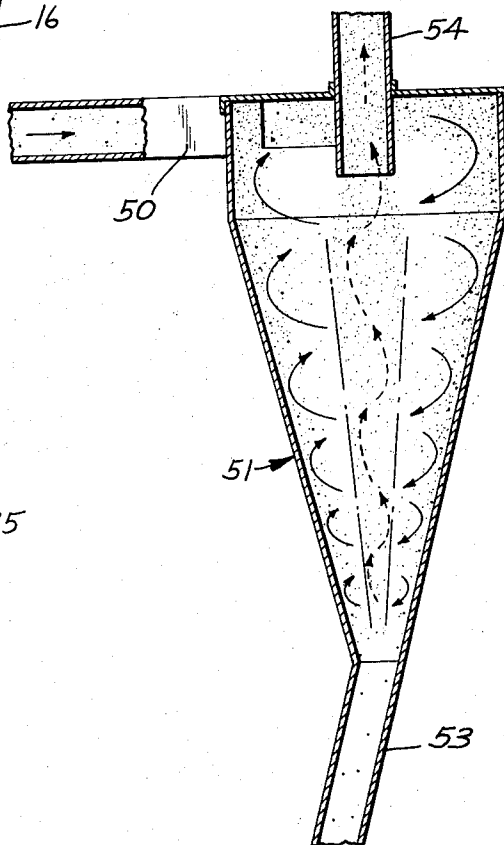


FIG. 4



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3,441,135 PARTICLE CLASSIFICATION DEVICE AND METHOD

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Filed Nov. 25, 1966, Ser. No. 597,066
Int. Cl. B04c 3/00; B07b 3/02

U.S. Cl. 209—144

6 Claims

ABSTRACT OF THE DISCLOSURE

A method and apparatus for classifying particles of a powder according to size, said apparatus having one or more separators connected to separate and reseparator the particles at a specified cut size. The separators are operated at some pressure below atmospheric pressure, determined by the specified cut size, to allow the separators to operate, practically, in the micron and sub-micron range of cut sizes.

This invention pertains to an improved particle classification device and more specifically to a classification device in which the classification occurs under a pressure less than atmospheric pressure.

Powders of various materials are utilized to an ever increasing extent in present day technology. In many of the various industries that use powder, such as powdered metallurgy, magnetic tape, etc., certain characteristics must be rigidly controlled. In such cases particle size is one of the most important properties of powders and governs such phenomena as flowability, packing density, and physical reactivity. For this reason, powders are ordinarily prepared to a given size specification by a process which is termed classification. Classification in general is the separation of a powder into a coarse fraction containing coarse particles, having a size somewhat larger than a cut size, and a fine fraction containing fine particles having a size equal to or less than the cut size. The cut size is equivalent to the separation point or the particular size of particles about which the powder is separated. Although there should be at least some particles having a size larger or coarser than cut size and at least some particles having a size smaller or finer than cut size, it is not necessary to actually have any particles with a size equal to the cut size in the powder. Particle size is usually expressed in terms of particle diameter. If particles are not spherical, an equivalent or apparent diameter may be used. One common method is to express size in terms of an equivalent spherical particle having the same settling velocity as the particle in question.

In the prior art the best known type of classifying device is the screen or sieve which simply allows the fine particles to pass therethrough and maintains the coarse particles thereabove. However, the usefulness of the screen or sieve is generally restricted to classifying particles coarser in size than 100 microns. Air classifying devices are usually used for obtaining size classification in the range below 100 microns. In general there are two types of air classifying devices: gravitational air classifying devices and centrifugal air classifying devices. Gravitational air classifying devices are limited primarily to particle classification above 50 microns because of the low separation velocities that are involved with finer sizes.

Centrifugal air separators, which have much higher separation velocities, are used for most dry classification applications. Centrifugal air separators are generally grouped into two categories: one, the equipment is stationary and the air rotates therein, for example the cyclone separator; two, the equipment rotates and the air

passes therethrough, for example, the centrifuge. Although centrifugal air separators are capable of separating fine powders into fine and coarse fractions, the sharpness of separation is usually not good. That is, the dividing line between the fine and the coarse fractions is not well defined and both groups will have some particles of the same size therein. This lack of sharpness of the separation in the centrifugal air separators becomes more pronounced as finer powders are processed. To provide sharpness of separation in the prior art the powders must be reprocessed many times. Also, in order to achieve a very small cut size at reasonable gas flow rates, very high separating forces must be exerted on the particles. Such high forces are usually obtained in gas classifiers by causing the gas to whirl at high velocities in stationary-type classifiers or by high speeds of impeller rotation in rotary classifiers. Because of practical limitations of either equipment construction or power consumption, conventional gas separators are limited as to the smallest cut size that can be achieved with reasonable gas handling capacities. Conventional separators are not capable of achieving separations at cut sizes smaller than one micron particle diameter and usually cannot give sharp separations at cut sizes below 10 microns.

It is an object of the present invention to provide a new and improved particle classifying device.

It is a further object of the present invention to provide a new and improved method of classifying particles.

It is a further object of the present invention to provide a particle classifying device which is capable of separating particles in the micron and submicron range.

It is a further object of the present invention to provide a particle classifying device and method which can achieve sharp separations in the micron and submicron range without requiring excessively high rotor speeds or gas velocities.

These and other objects of this invention will become apparent to those skilled in the art upon consideration of the accompanying specification, claims, and drawings.

Referring to the drawings, wherein like characters indicate like parts throughout the figures:

FIGURE 1 is a diagrammatic view of an embodiment of the classifying device;

FIGURE 2 is an enlarged axial sectional view of a single cyclone separator depicting the powder passing through a first stage of separation;

FIGURE 3 is a sectional view as seen from the line 3—3 in FIGURE 2; and

FIGURE 4 is a view similar to FIGURE 2 depicting the powder passing through the last fine stage of separation.

In the figures the numeral 10 designates a first separator stage having an inlet 11, a fine fraction outlet 12, and a coarse fraction outlet 13. The separator 10 may be any of the well known types including gravitational or centrifugal air separators, however, because the operation of the centrifugal air separators is far superior to that of the gravitational air separators, the use of centrifugal air separators in this device is preferred. Also, in the present embodiment, the cyclone type centrifugal air separators are utilized for purposes of simplicity. It should be understood, however, that the use of cyclone separators in the disclosed embodiment should not in any way limit the scope of this invention. Detailed views of a single cyclone separator are illustrated in FIGS. 2, 3, and 4.

FIGURES 2 and 3 illustrate the internal construction and operation of a typical cyclone separator wherein it is operating as the first separator stage 10 of the system in FIGURE 1. The various portions of the cyclone separator in FIGURES 2 and 3 have been designated with

the same numbers as those which were utilized in conjunction with the first stage 10 in the system illustrated in FIGURE 1 to indicate the manner in which the cyclone separator illustrated in FIGURES 2 and 3 will be connected into the system of FIGURE 1. The main body of the separator 10 has a cylindrical portion 15 and a frusto-conical portion 16 attached thereto. The cylindrical portion 15 and the frusto-conical portion 16 are integrally attached and form a continuous cavity therein. The inlet 11 is tangential to and in communication with the cylindrical portion 15 while the fine fraction outlet 12 is coaxial with and positioned in the upper surface of the cylindrical portion 15. The coarse fraction outlet 13 is positioned at the extreme tip of the conical portion 16. The particles entering the input 11 are conveyed by a gas, such as air or the like, and enter the cylindrical portion 15 of the body with a predetermined velocity. Because of this velocity and because the inlet 11 is tangential to the cylindrical portion 15, the gas and the mixture of coarse and fine particles travel in a downwardly spiraling path, indicated by the solid arrows, to form a vortex adjacent the inner surfaces of the cylindrical portion 15 and conical portion 16. Because the lower end of the body is restricted, the downwardly spiraling gas and particles gradually change direction axially, and spiral upwardly in the center of the vortex indicated by the dotted arrows. This upwardly spiraling gas and particle mixture, indicated by the dotted arrows, forms a smaller vortex within the outer vortex formed by the downwardly spiraling gas. The axial change of direction of the downwardly spiraling gas, or the mass transfer of gas from the outer vortex to the inner vortex, takes place gradually over the entire tapered length of the conical portion 16. As the vortices spiral within the body of the separator 10, the heavy or coarse particles are forced outwardly in the vortices and eventually travel downwardly into the coarse fraction outlet 13. Simultaneously the fine particles remain in the gas and eventually spiral upwardly into the fine fraction outlet 12.

The cyclone separator 10, as well as the gas classifiers function by virtue of a greater gas drag per unit mass experienced by the smaller particles. The greater gas drag can be seen by noting that the drag of a particle is proportional to the diameter of the particle while the mass of the particle is proportional to the diameter cubed and, therefore, the drag per unit mass of the particle is inversely proportional to the diameter squared. The separator 10 causes a centrifugal force to be exerted on the particles in a direction to counteract the gas drag force. Those particles for which the centrifugal force is greater than the force due to the gas drag will be separated from the gas and forced toward the walls of the separator 10 where they will pass out through the outlet 13 as the coarse fraction. Those particles for which the centrifugal force is less than the force due to the gas drag will be carried with the gas and pass out of the separator 10 through the outlet 12 as the fine fraction. The size or the diameter of the particles at which this separation occurs is known in the art as the cut size.

The inner and outer vortices of the separator 10 may continue past the lower end of the frusto-conical portion 16 into the outlet 13 where reentrainment of the coarse particles in the gas can occur. In the present embodiment, a conduit 25 is in communication with the coarse fraction outlet 13 and carries a small portion of the gas and the coarse particles entrained therein to a destination which will be described presently. The diameter of the conduit 25 is reduced somewhat at the junction of the coarse fraction outlet 13 to produce a slight aspirating effect which aids in drawing the coarse fraction from the outlet 13. In addition, the coarse particles entering the conduit 25 from the outlet 13 are thoroughly mixed with the gas flowing in the conduit 25 and conveyed thereby.

Referring to FIGURE 1, one end of the conduit 25 is connected to the input 26 of a second coarse stage 27,

which is in all respects similar to the first stage 10. The other end of the conduit 25 is connected to a fine fraction outlet 28 of a third coarse stage, 29, which is also similar to the first stage 10. A fine fraction output 30 of the second coarse stage 27 is in communication with the input 11 of the first stage 10 through a conduit 31. A coarse fraction output 32 of the second coarse stage 27 is in communication with an input 33 of the third coarse stage 29 through a conduit 34. A coarse fraction output 35 of the third coarse stage 29 is connected to a coarse fraction reservoir 36, which accumulates the coarse fraction. Thus, as the coarse particles leave the first stage 10 through the coarse fraction outlet 13, they enter the input 26 of the second coarse stage 27 where they are again separated into coarse and fine fractions. In the second coarse stage 27 the fine fraction is conducted back to the input 11 of the first stage 10 through the conduit 31 and is recirculated through the first stage 10. Also, the coarse fraction leaving the second coarse stage 27 through the coarse fraction outlet 32 is conveyed to the input 33 of the third coarse stage 29 through the conduit 34, where it is again separated, with the fine fraction leaving the fine fraction outlet 28 and being conveyed to the input 26 of the second coarse stage 27 through the conduit 25.

It should be noted that each time a powder is classified or separated in one of the stages, such as stage 10, most of the coarse particles leave the stage through the coarse fraction outlet and most of the fine particles leave the stage through the fine fraction outlet. However, there is some overlapping and a few of the fine particles will leave through the coarse fraction outlet while a few of the coarse particles will leave through the fine fraction outlet. This overlapping of the particles is referred to as the sharpness of separation, with a decrease in overlapping being referred to as a sharper separation. Since each of the various stages 10, 27, and 29, separate additional percentages of the coarse particles from the fine particles, each of the additional stages 27 and 29 will increase the sharpness of separation. For example, assuming that the first stage 10 separates the powder entering input 11 so that 95 percent of the fraction leaving the outlet 13 is coarse particles, the second coarse stage 27 will separate an additional percentage of the fine particles from the recirculated coarse particles, and the third coarse stage 29 will separate a further percentage of the remaining fine particles from the coarse particles. Thus, the outlet 35 of the third coarse stage 29 has substantially pure coarse particles passing therethrough, however, to obtain absolutely pure coarse particles it would require, theoretically, an infinite number of stages.

The fine fraction outlet 12 of stage 10 is connected to an input 45 of a second fine stage 46 through a conduit 47. A coarse fraction outlet 48 of the second fine stage 46 is connected to the input 11 of the first stage 10 through the conduit 31. A fine fraction outlet 49 of the second fine stage 46 is connected to an input 50 of a third fine stage 51 through a conduit 52. A coarse fraction outlet 53 of the third fine stage 51 is in communication with the conduit 47, and thus the input 45 of the second fine stage 46. A fine fraction outlet 54 of the third fine stage 51 is in communication with a fine fraction filtering device 55 through a conduit 56.

An axial sectional view of the third fine stage 51 is illustrated in FIGURE 4. In this view it can be seen that the construction and operation are substantially similar to the construction and operation previously described in conjunction with the first separator stage 10 illustrated in FIGURE 2. The solid arrows portray the outer vortex spiralling downwardly and the dotted arrows portray the inner vortex spiralling upwardly within the separator. It should be noted that the majority of particles in the fine stage 51 are fine particles, which leave the outlet 54 as the fine fraction, and that there are only a few coarse particles, which leave the outlet 53 and return to the input 45 of the second fine stage 46.

The filtering device 55 is designed to separate fine particles from the gas conveying them. The gas separated from the fine fraction in the filtering device 55 is conducted to an input 38 of a pressure means 39 through a conduit 57. In this embodiment the pressure means 39 is illustrated diagrammatically as a fan and may be any device capable of impelling gas molecules through the system. The conduit 57 has a valve means 58 therein to regulate the flow of gas through the conduit 57. Thus, the fine fraction leaving the first stage 10 through the fine fraction outlet 12 is conveyed through stages 46 and 51 to increase the sharpness of separation, as described in conjunction with the coarse fraction.

The pressure means 39 has an outlet 60 which is connected to the input 11 of the first stage 10 through a conduit 61. The conduit 61 has a valve 62 therein to regulate the amount of flow entering the input 11. The powder which is to be separated is introduced into the conduit 61 by means of a mixing device 65. In FIGURE 1 the mixing device 65 is diagrammatically illustrated as a simple hopper in communication with the conduit 61 at a position where the diameter is reduced slightly to create an aspirating effect which aids in drawing the particles from the mixing device 65. It should be understood that the mixing device 65 could be placed in communication with the conduit 31 adjacent the input 11 of the separator 10 and the entire conduit 61 could then be eliminated. However, the device 65 has been illustrated in the position illustrated for ease of explanation. Also, the reduced diameter in the conduit 61 at the junction of the mixing device 65 is not essential but it enhances the operation thereof. It should be further understood that a much more sophisticated device might be utilized which could form a portion of the pressure means 39 but since it does not constitute a portion of this invention, it will not be elaborated upon further.

A valve means 66 is placed in the outlet of the mixing device 65 to regulate the flow of particles therethrough. Thus, as the pressure means 39 forces the conveying gas through the conduit 61 to the input 11 of the first stage 10, the powder will be drawn from the mixing device 65 and conducted with the gas. The powder will be classified by the stages 10, 27, 29, 46, and 51, after which the fine fraction will be removed from the gas by the filtering device and the coarse fraction will accumulate in the reservoir 36. In each of the coarse outlets 13, 32, 48 and 53 of the stages 10, 27, 46 and 51, respectively, as well as the outlet of the mixing device 65, the conduit connected therewith is reduced slightly in diameter to produce an aspirating effect in the outlet. The conduit with a reduced diameter is illustrated to simplify the disclosure but it should be understood that other devices, for example the rotary valve means 66, might be utilized at the junctions specified and the particle classifying device would operate all such embodiments or alterations which come within the scope of this invention and are deemed to be obvious from this disclosure.

The drag previously described, experienced when a particle moves relative to a gas, is due to the impact of the gas molecules on the surface of the particle. When the mean free path of the gas molecules approaches or exceeds the size of the particles, the gas molecules do not transmit as much of their momentum to the particles and are said to "slip" past the particles. This "slip-flow" results in a reduced drag on the particles. Since the molecular mean free path increases as gas pressure is reduced, the gas drag on particles diminishes as the pressure is reduced below the point at which the molecular mean free path approximately equals the magnitude of the particle diameter under consideration. Thus, by reducing gas pressure in the separator 1 particle gas drag is reduced and very fine cut sizes are achieved without resorting to excessively high rotational gas or rotor speeds. FIGURE 1 shows a diagrammatical illustration of a pump 59 having the inlet thereof interposed in the conduit 57 and

the outlet thereof vented to atmosphere. It will be understood that any pump capable of reducing the pressure within the system to the required amount may be utilized and that shown is for illustrative purposes only.

The entire system illustrated in FIGURE 1 is closed or isolated from the atmosphere and the pressure therein is reduced somewhat below atmospheric pressure by the pump 59. The amount that the internal pressure by the reduced below atmospheric pressure to provide the desired cut size depends upon a variety of factors including the size of particles, which it is desired to classify, the type and size of classifier or separator utilized and the velocity of the gas at the outlet 60 of the pressure means 39.

For example, if a four-inch diameter cyclone is operated as a classifier at an absolute pressure of $\frac{1}{30}$ atmosphere with an inlet gas velocity of 50 feet per second, a cut size of 0.5 micron may be realized with a particle having a specific gravity of 2.70. If the same cyclone is operated as a classifier at atmospheric pressure with an inlet gas velocity of 50 feet per second a cut size of only 1.7 microns may be realized with similar particles. To realize a cut size of 0.5 micron at atmospheric pressure would require an inlet gas velocity of 500 feet per second. An inlet gas velocity of such a magnitude would require an exorbitant power to attain. A cut size of less than 0.3 microns can be achieved by a further reduction in pressure. However, such smaller cut sizes cannot be obtained by an increase in velocity since it would require that the inlet gas velocity exceed the velocity of sound.

As another example, a twelve-inch diameter rotary classifier operating with a rotor speed of 3600 r.p.m., and an air rate of 40 cubic feet per minute, which would give a cut size of 0.3 micron at $\frac{1}{30}$ atmospheric pressure, would only give a cut size of 2 microns at atmospheric pressure with all other variables equal. To achieve the comparable cut size at atmospheric pressure would require a rotor speed of 20,000 r.p.m., at which the rotor tip speed is approximately sonic. Although lower cut sizes would theoretically be achieved by increasing rotor speed, lower cut sizes are precluded by structural limitations, except at radically reduced capacity. These limitations do not apply when reduced cut sizes are achieved by reducing gas pressure in the classifier.

It should be noted that the single stage 10 could be operated at a reduced pressure and would separate sub-micron particles. However, passing the separated particles through additional stages and recirculating them in a fashion similar to that described in conjunction with the system illustrated in FIGURE 1 greatly improves the sharpness of separation.

Thus, the present invention provides means for classifying submicron particles without requiring excessively high rotor speed or gas inlet velocities. In addition, the present invention greatly improves the sharpness of classification, or separation at a predetermined particle size.

While I have shown and described a specific embodiment of this invention, further modifications and improvements will occur to those skilled in the art. I desire it to be understood, therefore, that this invention is not limited to the particular form shown, and I intend in the appended claims to cover all modifications which do not depart from the spirit and scope of this invention.

I claim:

1. An improved particle classification system comprising:

(a) separating means in said system having at least a classifying chamber with a powder inlet and fine and coarse fraction outlets for separating powders into fine and coarse fractions, said system being substantially sealed for precluding communication with the atmosphere;

(b) input means operatively attached to said powder

- inlet of said separating means for introducing powder therein;
- (c) accumulating means attached to said fine fraction outlet for accumulating the fine fraction;
- (d) accumulating means attached to said coarse fraction outlet for accumulating the coarse fraction;
- (e) means for producing a differential pressure in said separating means between the inlet and the outlets to provide a flow of gas and powder therethrough; and
- (f) pressure reduction means operatively connected to said system for reducing the pressure of the gas therein below atmospheric pressure an amount dependent upon the cut size about which the coarse and fine fractions are separated to reduce the density of the gas and the drag on individual powder particles.
2. An improved particle classification system as set forth in claim 1 wherein the separating means includes a centrifugal gas separator.
3. An improved particle classification system as set forth in claim 1 wherein the means for separating the fractions includes a plurality of separators connected by their respective inlets and outlets and making up a plurality of stages so the fractions leaving the fine and coarse outlets of the first stage pass through second stages which in turn separate the fractions again and recirculate some through said first stage.
4. An improved particle classification system as set forth in claim 1 wherein the pressure reduction means is further characterized by lowering the absolute pressure within the system to within a range of approximately 0.1 to 0.001 atmosphere for separating the fine and coarse fractions at a cut size below approximately ten microns.
5. An improved particle classification device comprising:
- (a) first, second and third separating stages each having a powder inlet and fine and coarse fraction outlets for separating powders into fine and coarse fractions;
- (b) input means operatively attached to said powder inlet of said first separating stage for introducing powder therein;
- (c) accumulating means operatively attached to said fine fraction outlet of said second separating stage for accumulating the fine fraction;
- (d) accumulating means operatively attached to said coarse fraction outlet of said third separating stage for accumulating the coarse fraction;
- (e) means operatively connecting said fine fraction

- outlet of said first separating stage with said powder inlet of said second separating stage, said coarse fraction outlet of said first separating stage with said powder inlet of said third separating stage, and said coarse fraction outlet of said second separating stage and said fine fraction outlet of said third separating stage with said powder inlet of said first separating stage; and
- (f) pressure means operatively connected to said first, second, and third separating stages for reducing the pressure therein sufficiently below atmospheric pressure to separate the fine and coarse fractions at a cut size below approximately ten microns.
6. An improved method of particle classification including the steps of:
- (a) providing a powder having a fine and a coarse fraction;
- (b) reducing the air pressure below atmospheric pressure in a particle classification system, being substantially sealed for precluding communication with the atmosphere, an amount dependent upon the cut size about which the coarse and fine fractions are separated to reduce drag in the system;
- (c) introducing said powder into separating means in said system having fine and coarse fraction outlets;
- (d) causing said separating means to separate said powder into a fine and a coarse fraction by moving said powder through said means at a desired rate by creating a differential air pressure thereacross; and
- (e) collecting said fine fractions and collecting said coarse fractions.

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TIM R. MILES, *Primary Examiner*.

U.S. Cl. X.R.

209—154