United States Patent [19]

Wilson

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[54] **VORTEX CLASSIFIER**

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[21] Appl. No.: **120,856**

[52] **U.S. Cl.** **209/144**

[51] **Int. Cl.** **B04c 1/00**

[58] **Field of Search** 209/211, 144, 145

[56] **References Cited**

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Assistant Examiner—Ralph J. Hill
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[57] **ABSTRACT**

A vortex classifier for classifying particles that differ from one another in at least one of shape, mass or density. The classifier contains a circular vortex chamber wherein a fluid is introduced at the periphery to flow in a generally tangential direction. The fluid spirals inward toward the center of the circular chamber and out. The cross dimensions of the chamber (i.e., the thickness of the chamber) varies from small to large from the periphery toward the center, respectively, the chamber volume being thereby controlled to control the radial component of the fluid velocity thereof at radially displaced regions and, in turn, to control the characteristics of particles which tend to seek and remain traveling in stable circular paths at such regions.

12 Claims, 6 Drawing Figures

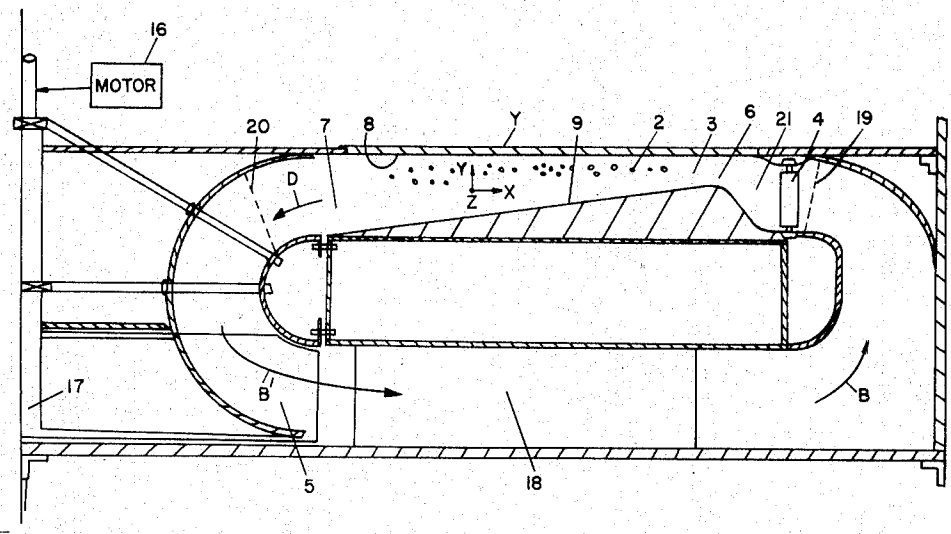
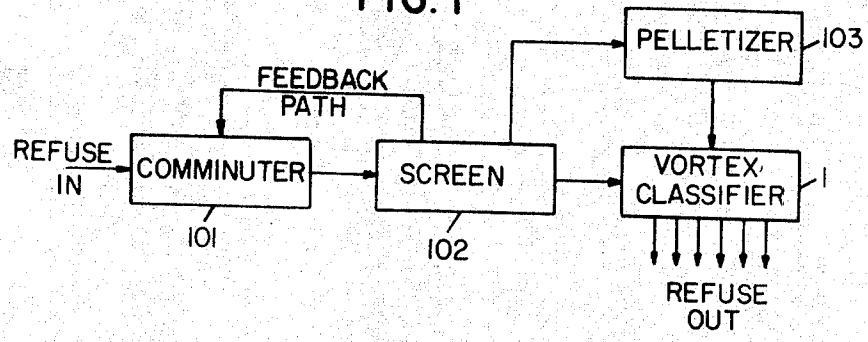


FIG. 1



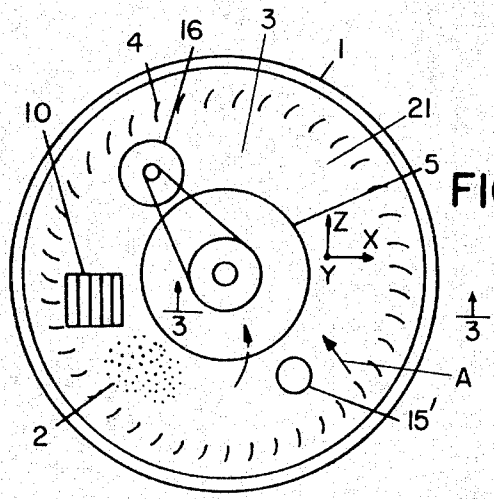


FIG. 2

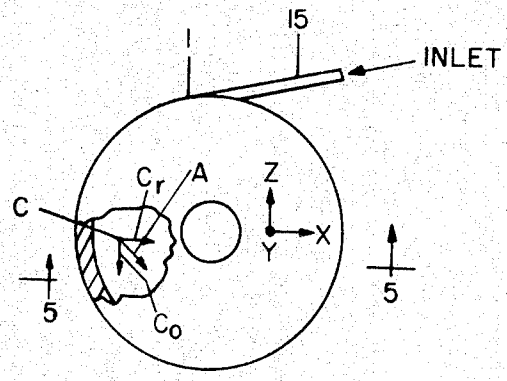


FIG. 4

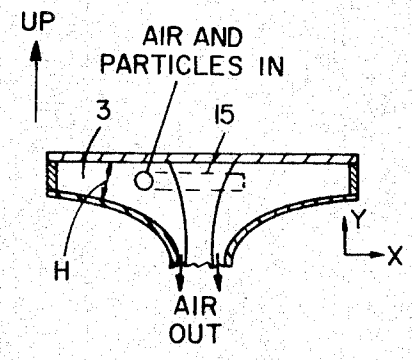


FIG. 5

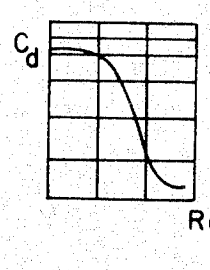


FIG. 6

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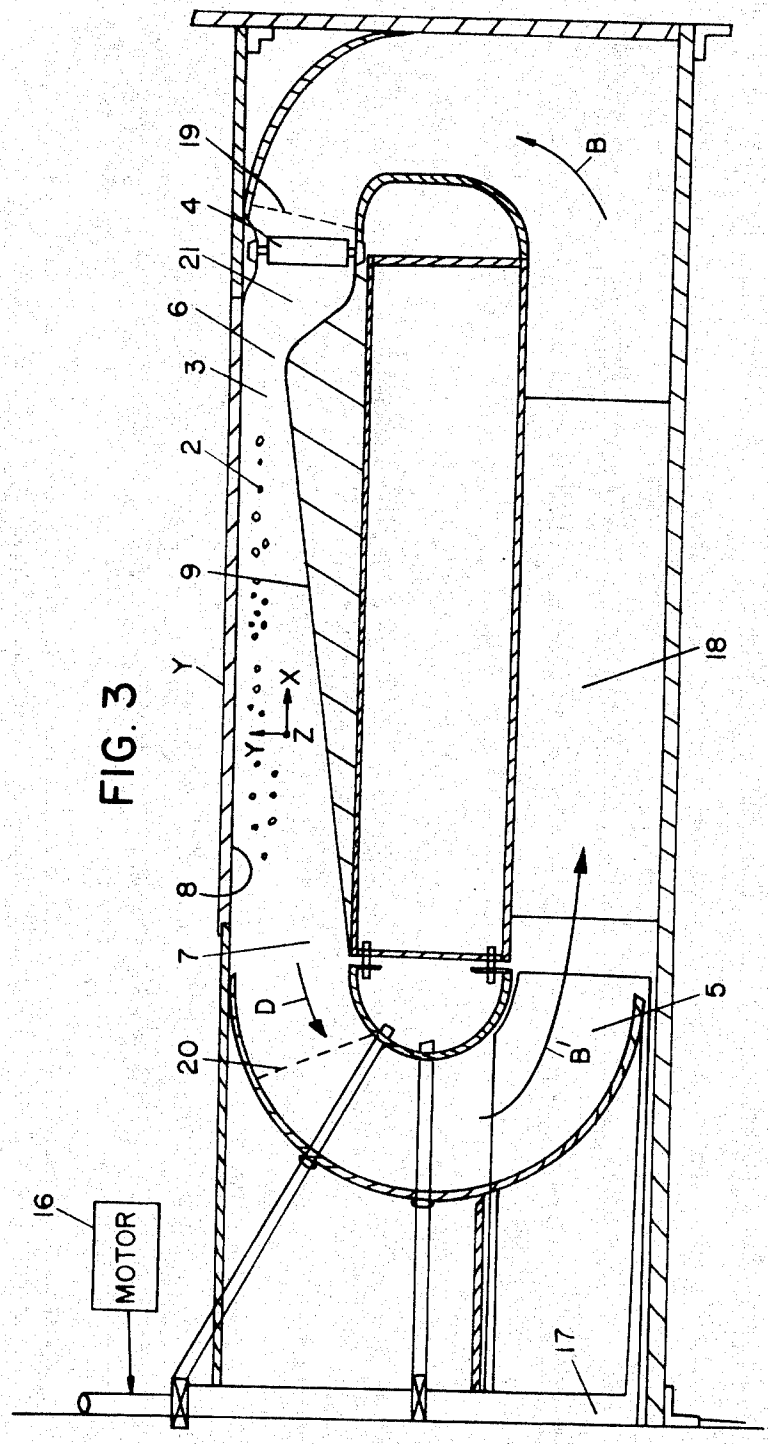


FIG. 3

INVENTOR.

BY

VORTEX CLASSIFIER

This invention was made in the course of work performed under a contract with the Department of Health, Education and Welfare.

The present invention relates to vortex classifiers wherein particulate carried in an inwardly spiralling fluid stream spreads and becomes radially positioned in a stable orbit and is removed from the stream at the particular orbit.

Work done with the apparatus of the present invention has been in connection with the sorting of refuse. The problems generally encountered in refuse sorting are discussed in an application for Letters Patent entitled "Impact Sensor and Coder Apparatus," Ser. No. 120,857 filed Mar. 4, 1972 by the present inventor and another. A discussion of problems involved in refuse sorting and background information are also included in the thesis referred to in said application. The vortex classifier discussed here is intended as being complementary to the apparatus discussed in the application and thesis.

Accordingly, an object of the present invention is to provide a method of an apparatus for segregating particulate in a refuse-sorting system.

A further object is to provide vortex classifier apparatus to perform such segregation.

A still further object is to provide vortex classifier apparatus in which particulate is segregated at radially spaced regions therein on the basis of at least one of shape, mass and density.

Another object is to provide vortex classifier apparatus and method of more general use as well.

These and other objects are disclosed in more detail hereinafter and are particularly pointed out in the appended claims.

By way of summary, the objects of the invention are attained by a method of classifying particles that differ from one another in at least one of shape, mass and density that include the steps of introducing the particles to a fluid stream having a tangential component of velocity and an inwarldy directed radial component, controlling the relationship between magnitude of the tangential component of velocity and the radial component thereof to provide a stable radial position for each of the various particles in the inwardly spiralling fluid stream, and removing the particles from the fluid stream at radially spaced position in the stream.

The invention is hereinafter discussed upon reference to the accompanying drawings, in which:

FIG. 1 is a system, in block-diagram form, employing a vortex classifier of the present invention;

FIG. 2 is a plan view of one such vortex classifier;

FIG. 3 is a section view, on an enlarged scale, taken upon the line 3—3 in FIG. 2, looking in the direction of the arrows;

FIG. 4 is a version of the classifier in FIG. 1 in simplified form;

FIG. 5 is a partial section side view taken upon the line 5—5 in FIG. 4 looking in the direction of arrows and, again, is a simplified version of apparatus employing the present inventive concept to allow easier explanation of the underlying principles; and

FIG. 6 is a curve with logarithmic coordinates to show the relationship between the drag coefficient on a sphere and Reynolds number in a turbulent air flow.

Before describing a preferred embodiment of the invention with reference, primarily, to FIGS. 2 and 3,

there follows in the next few paragraphs an overall discussion of the principles involved with reference to FIGS. 4 – 6. For present purposes, it is assumed that air and particles to-be-separated are introduced to flow in a generally tangential direction through an inlet 15 to the circular vortex classifier designated 1. The air travels in a spiral path within the stationary vortex chamber 3 thereof, from the periphery toward the center and out, as indicated the chamber 3 being an open, unencumbered structure which permits free vortex flow of the air. In the discussion to follow it is assumed that all particles are of the same shape, (e.g., spherical) and size and that distribution along the radial direction is therefore made on the basis of mass or density.

Referring now to FIG. 4, the particle designated C is assumed to have a density ρ_p and to be traveling in a stable orbit of radius r_o; that is, the particle C is traveling in a circular path about the center of the vortex chamber under the influence of the various forces now to be discussed. The air (or other fluid, as the case may be) at r_o has a tangential component of velocity C_o, a radial component of velocity C_r, and a density ρ_f. The particle C, in the present discussion, is assumed to have an equivalent spherical radius r_p. In this circumstance the particle C will travel at the tangential velocity C_o of the air in the vortex chamber and will experience only the drag force due to the relative inward velocity C_r. The inward drag force must be that necessary to give the particle C the required acceleration ($a = C_o^2/r_o$) toward the center of the chamber if a stable circular orbit of r_o is to be maintained. In this circumstance, the force P on particle C is given by the following expression:

$$P = C_d \pi r_P^2 . (\rho_f C_r^2)/(2g_c) \tag{1}$$

where C_d is the drag coefficient, r_P is the equivalent spherical radius of the particle, and g_c is a constant dependent only on the dimensional system used to define force and mass. The expression (1) assumes that the only relevant force on the particle C at rotational equilibrium is drag of the air flow. So long as the vortex chamber is horizontal as shown (i.e., the axis of the circular vortex chamber 3 is oriented in the vertical direction) the effect of gravity can be ignored for particles of the small size (i.e., the order of 0.5 inches maximum linear dimensions and 1 ounce in weight) that would be separated in such a system and just so long as the particles do not touch the upper or lower walls of the chamber.

$$m_P = \rho_P (4/3) \pi r_P^3 . \tag{2}$$

According to Newton's Law, the force P in equation (1) can also be given in the form

$$P = ma/g_c . \tag{3}$$

Combining equations (1) and (2) and substituting C_o^2/r_o for a therein provides the following expression for spherical particles:

$$C_d \pi r_P^2 \rho_f C_r^2 / 2g_c = \rho_P (4/3) \pi r_P^3 \, C_o^2/(r_o g_c) \tag{4}$$

and

$$r_o = (1/C_d)\ (8/3)\ (C_o/C_r)^2\ (\rho_P/\rho_f)\ r_P. \tag{5}$$

It can be seen from expression (5) that the absolute velocity does not affect the equilibrium radius r_o since the latter is a function of the ratio C_o/C_r, or the flow angle $\tan^{-1}(C_o/C_r)$. However, the drag coefficient C_d is somewhat dependent on the Reynolds number, Re_P, which involves C_r and is defined by the expression

$$Re_P = (C_r \cdot 2r_P)/\mu_f\ \rho_f, \tag{6}$$

where μ_f is the fluid viscosity. A curve of C_d as a function of Re_P is shown in FIG. 6 for a sphere in turbulent flow. Typically, the Reynolds-number range of interest for an air system is in the low, constant-drag-coefficient part of the curve. For example, for typical values r_P=0.01 feet; C_r=50 feet per second; $\mu_f = 1.2 \times 10^{-5}$ pound mass per second-feet; ρ_f= 0.075 pound mass per cubic foot; the value of Re_P is 0.0625×10^5. In this circumstance, the drag coefficient C_d can be taken as constant at 0.43. It is of interest to note, however, that though the main gas flow will be turbulent in a classifier of the type herein disclosed, nevertheless flow relative to a spherical particle may be sub-critical (i.e., laminar separation will occur) for which a high, but still appreciably constant, drag coefficient C_d is more appropriate. Furthermore, because the tangential component of air flow C_o in the vortex chamber **3** is unconstrained, the flow behaves as a "free vortex," that is, the tangential component C_o varies inversely with the radius to maintain constant angular momentum.

From the foregoing explanation, it can be seen that the stable radius r_o at which any particular particle will be found is determined by the ratio C_o/C_r; and that ratio at any radial position in the vortex chamber is determined by the height designated h in FIG. **5** of the chamber **3** at any position r_o. Furthermore, if the fluid flow is assumed to be one-dimensional as an approximation (that is, constant fluid velocity across the height of the flow channel) and to be incompressible and the volume of the particles to be negligible compared with the volume of the classifier section, then the choice of a channel height h at any one radius r_o is open and all other channel heights at other radii may be determined from it.

Turning now to FIGS. **2** and **3**, a vortex classifier is shown generally at **1** for the comminuted materials shown at **2** introduced through particle inlet **15'**. The classifier **1**, as shown in FIGS. **2** and **3**, includes the circular vortex chamber **3** to receive a fluid stream—in the illustrative embodiment, air. The air stream, as discussed, is introduced at the periphery, shown generally at **6**, of the vortex chamber **3** passing vanes **4** oriented to direct the air in a direction to provide a tangential velocity vector to the fluid. Thus, the air at the periphery flows in the direction indicated by the arrow designated A which shows a tangential vector and a radial vector of air flow, the air passing spirally as a free vortex flow through the chamber **3** toward the outlet-end thereof, shown generally at **7**, and out the direction of an arrow D under the impetus of a fan **5**. As shown in FIG. **3**, the vortex chamber has cross dimensions which are, relatively, small at the inlet end **6** and increase toward the outlet end **7** (in the predetermined fashion later discussed), the stable radial position of a specific particle **2** being determined by the mass, the density and the shape of that particle and the ratio of the components of the velocity of the fluid, i.e., C_o/C_r. The ratio C_o/C_r of the air velocity components at any specific radial position, as discussed elsewhere herein in greater detail, is controlled by properly shaping the walls of the vortex chamber. Thus, as shown in FIG. **3**, the upper wall labeled **8** of the chamber **3** is horizontal and the lower wall labeled **9** is inclined. The chamber heights are chosen to provide a vortex chamber that has greater circumferential area at the periphery and lesser circumferential area at the center region the imbalance between the inward fluid drag on a particle displaced outward from its equilibrium radius and the force necessary to provide the centripetal acceleration at that radius will increase with radial displacement.

A plurality of scoops **10** serves to remove particles from said chamber. In operable apparatus, the particles **2** can be introduced near the top of the chamber, as shown, to be propelled around the chamber, but remaining near the upper surface for a number of revolutions while seeking the stable radial position before mentioned. Gradually, however, the particles will sink toward the lower surface **9** under the influence of gravity to be withdrawn from the vortex chamber as classified material. The scoops **10** may be stationary or they may be solenoid or otherwise activated to pop into and out of the chamber **3** in some predetermined time sequence. The manner of using scoops or whatever other removing means may be used will depend upon other characteristics of the particular classifier.

With the foregoing in mind, a typical small-sized air separator is specified below to segregate spruce, polystyrene, vinyl and hard rubber which have densities respectively of 29, 66, 84 and 100 lbm per cubic foot. The stable classification radius for spruce is chosen at 2.5 feet and for rubber at 5 feet. The classification radius for the other two materials or any other intermediate materials can be chosen and the height of the vortex chamber contoured accordingly, or the smooth cross-sectional slope shown in the figures can be chosen and r_o for each will be somewhere between 2.5 and 5.0 feet. For r_o = 5 feet for hard rubber

$$(C_o/C_r)^2 = C_d \cdot \tfrac{3}{8}\ (\rho_f/\rho_P) \cdot r_o/r_P = \tfrac{3}{8} \cdot 0.43 \cdot 0.075/100 \cdot 5.0/0.01 \tag{7}$$

and

$$C_o/C_r = 0.246 \tag{8}$$

The flow angle is $\tan^{-1}(C_o/C_r) = \tan^{-1} 0.246$ and is 13.03° in the example for hard rubber. For spruce to achieve a stable orbit at r_o = 2.5 feet, using the same mathematics as above, C_o/C_r = 0.323 and the flow angle is 17.93°. If the fluid friction at the walls is neglected, which is a resonable assumption for large classifiers, the angular momentum of the flow will be constant in the vortex chamber **3** (as occurs in a free-vortex flow) and the velocity C_o at 2.5 feet will be twice the value of C_o at the 5.0 foot radius, and

$$C_{r(at\ 2.5')} = 2 \cdot (0.246/0.323)\, C_{r(at\ 5')}. \tag{9}$$

If the fluid is assumed to be incompressible and the particles make up a small portion only thereof, as before discussed, then the fluid volume V passing through the chamber is a constant and in the example

$$V = 2\pi r_0 h C_{r(at\ 2.5')} = 2\pi r_0 h C_{r(at\ 5.0')} \quad (10)$$

$$\text{and } \frac{h_{2.5'}}{h_{5.0'}} = \frac{5.0}{2.5}\frac{C_{r(@5.0')}}{C_{r(@2.5')}} = \frac{2 \cdot 0.323}{2 \cdot 0.246} = 1.313. \quad (11)$$

Similar type calculations can be used to provide other heights for the vortex chamber **3**.

The above simplified analysis may be considerably refined, with small improvements in the predictions by: (1) Compressible-flow analysis: When the fluid is a gas (such as air) at, say, velocities of over 100 ft. per second, compressibility (density changes) would lead to either different equilibrium radii for given hardware (channel shape) or the specification of a different channel shape for given equilibrium radii. (2) Two-dimensional flow: The flow field can be calculated allowing for pressure and velocity gradients due to streamline curvature. Such changes would have most effect at the inner radius where the flow must turn to an axial direction to leave. If one surface of the channel is chosen to be a shape other than planar, streamline-curvature analysis will give closer predictions. (3) Boundary-layer considerations: The boundary layers on the channel walls will be three-dimensional, because the stream-flow direction is non-radial while the pressure gradient must be radial. Accordingly, the ratio C_o/C_r will change markedly through the boundary layer. For the boundary layers not to affect the classification radius adversely, one of two conditions should apply: (a) the particle size should be large relative to the boundary-layer thickness, and (b) the particle should develop a lift force as it sinks into the boundary layer, keeping it in the main stream. (4) Non-spherical particles: While it will be possible to limit the particle sizes in the feed to a narrow range (by sieving, for instance) the particles will be of a variety of shapes. If the size is small, the drag coefficient (for low-Reynolds-number relative flow) will depend on both density and shape. Material of one density will then achieve a range of equilibrium radii. Classification will be successful if this range, depending on range of shape, of radii does not overlap that of another material. If classification of mixed materials of similar densities is required, it may be economically worthwhile to pelletize the feed so that particle shape can be approximately standardized.

The explanation herein has used air as the carrier fluid, but liquids such as water, for example, can be employed. Also, the system shown in FIG. **1** contains a comminuter **101** to reduce the size of refuse to particles, a screen **102** to standardize the size and to feedback oversize particles, and a pelletizer **103** to render the particles uniform, should that be necessary. The apparatus in FIGS. **2** and **3** models a device actually devised to perform the classifying function herein disclosed and the values given previously are typical of this particular device. The overall radius of the actual classifier partially shown in FIG. **3** is five feet and the other dimensions are scaled accordingly in that figure.

The air for classifying is provided by a fan **5** driven by an electric motor **16** through a shaft **17**. A vane guide and support **18** serves along with other structural elements (not all shown) to support the wax bottom **9** of the vortex chamber. The air passes through a channel in the direction of the arrow B, through a screen **19** and the vanes **4** to an annular chamber **21** (which can be seen in FIG. **2** and **3** through a transparent top) and thence, into the vortex chamber **3**, passing eventually through a further screen **20** and back to the fan **5** (see the arrow labeled D').

Modifications of the invention herein disclosed will occur to persons skilled in the art, and all such modifications are considered to be within the spirit and scope of the invention.

What is claimed is:

1. A vortex classifier for comminuted materials and the like that comprises, a stationary substantially circular vortex chamber to receive a fluid stream and sufficiently unobstructed to allow formation of a free vortex, means for introducing to the vortex chamber particles to be classified, means for introducing the fluid near the periphery of the vortex chamber in a direction to provide a free vortex having a tangential velocity vector and an inwardly directed radial velocity vector, an outlet for the fluid near the center of the chamber, means for controlling the tangential velocity and the radial velocity of the fluid flow at radially spaced regions within the chamber, the distribution of said particles in stable radial orbits being determined by the shape, size and density of the particles and the velocity of the fluid at various radial positions of the vortex chamber, and means for selectively removing the particles at spaced radial regions of the vortex chamber.

2. A vortex classifier as claimed in claim **1**, in which the walls of the chamber are contoured to determine the radial velocity vector of the fluid at said radially spaced regions.

3. A vortex classifier as claimed in claim **1**, in which the axis of the circular vortex chamber is oriented vertically to provide a vortex chamber that is oriented substantially horizontally, the fluid passing from the inlet to the chamber to the outlet therefrom, along an inwardly spiraling, generally horizontal path.

4. A vortex classifier as claimed in claim **3** in which the height or vertical dimension of the vortex chamber is smaller at the periphery that at the center region thereof.

5. A vortex classifier as claimed in claim **4** in which the means for selectively removing the particles after they have attained an equilibrium radius of rotation comprises scoops adapted to pop into and out of the chamber at said radially spaced regions.

6. A vortex classifier as claimed in claim **5** in which the means for removing the particles comprises a plurality of scoops disposed in the vortex chamber.

7. Apparatus as claimed in claim **1** that includes means for comminuting the material prior to introduction thereof to the vortex chamber.

8. Apparatus as claimed in claim **7** that includes means for providing uniformity of the comminuted materials that are introduced to the vortex chamber.

9. Apparatus for classifying particles that comprises, in combination: a stationary, substantially circular vortex chamber to receive a fluid and sufficiently unobstructed to allow the fluid to flow in a free vortex flow within the chamber from the periphery to the center

thereof; means for introducing the fluid at the periphery of the vortex chamber as a fluid stream forming a free vortex having a tangential component of velocity C_o and an inwardly directed radial component C_r thereof, said vortex chamber having a height dimension h between the walls of the chamber that varies from small to large from the periphery toward the center thereof, respectively, the magnitudes of the velocities C_o and C_r at any radial position r_o within the vortex chamber being a function of the velocities C_o and C_r of the fluid upon introduction to the chamber and the magnitudes of h at the radial position r_o; means for introducing the particles to the vortex chamber, the particles being propelled by the fluid stream in an orbital path within the vortex chamber; and means for selectively removing the particles at radially spaced regions in the vortex chamber once the particles have achieved rotational equilibrium.

10. Apparatus as claimed in claim **9** in which the vortex chamber is horizontal, the dimension h being the distance betweeen the upper and lower walls of the chamber.

11. Apparatus as claimed in claim **10** which includes vanes located outward from said periphery and oriented to direct the fluid into the vortex chamber in the direction which provides said free vortex.

12. A method of classifying each particle of a group of particles that differ from one another in at least one of shape, mass and density, that comprises introducing the group of particles to a fluid stream having a tangential component of velocity C_o varying as in a free vortex flow and an inwardly directed radial component C_r, controlling the relationship between magnitude of the tangential component of the velocity C_o and the magnitude of radial component C_r to establish the stable radial position within the free vortex flow for each particle of the group of particles in the inwardly spiraling fluid stream, and removing each of the particles from the fluid stream at said stable radial position in the stream.

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