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BY A. P. C.

W. DE FLIGUÉ
SEPARATOR
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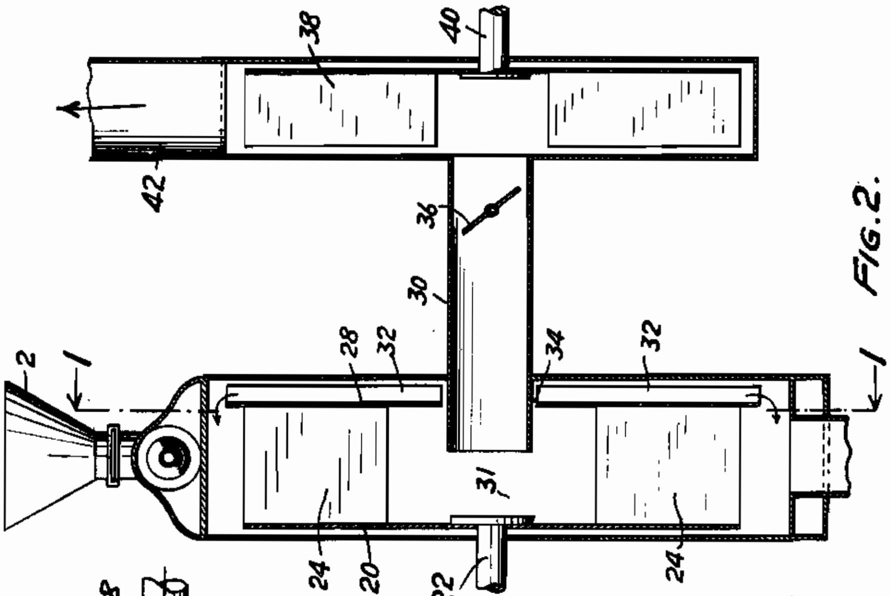

FIG. 2.

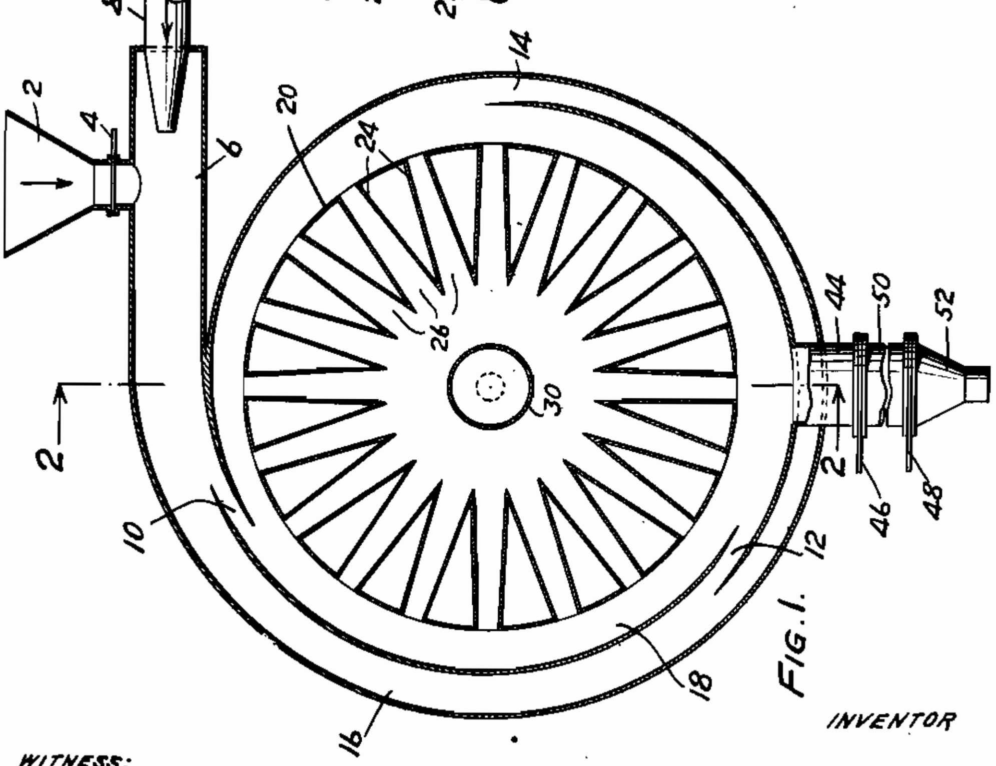

FIG. 1.

WITNESS:

INVENTOR

Wladimir de Fligué

ATTORNEYS.

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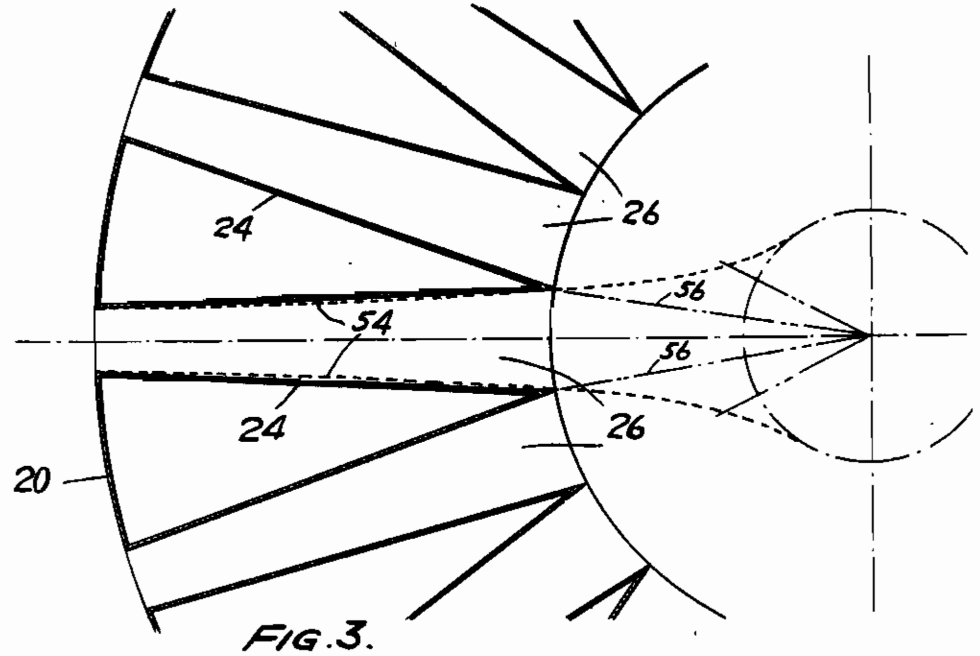

FIG. 3.

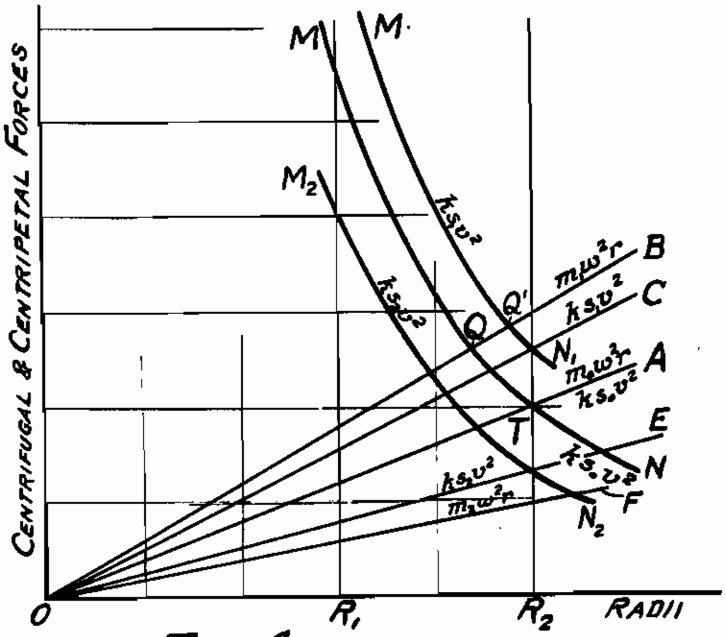

FIG. 4.

WITNESS:
Robt R. Mitchell.

INVENTOR
Wladimir de Fligué

ATTORNEYS.

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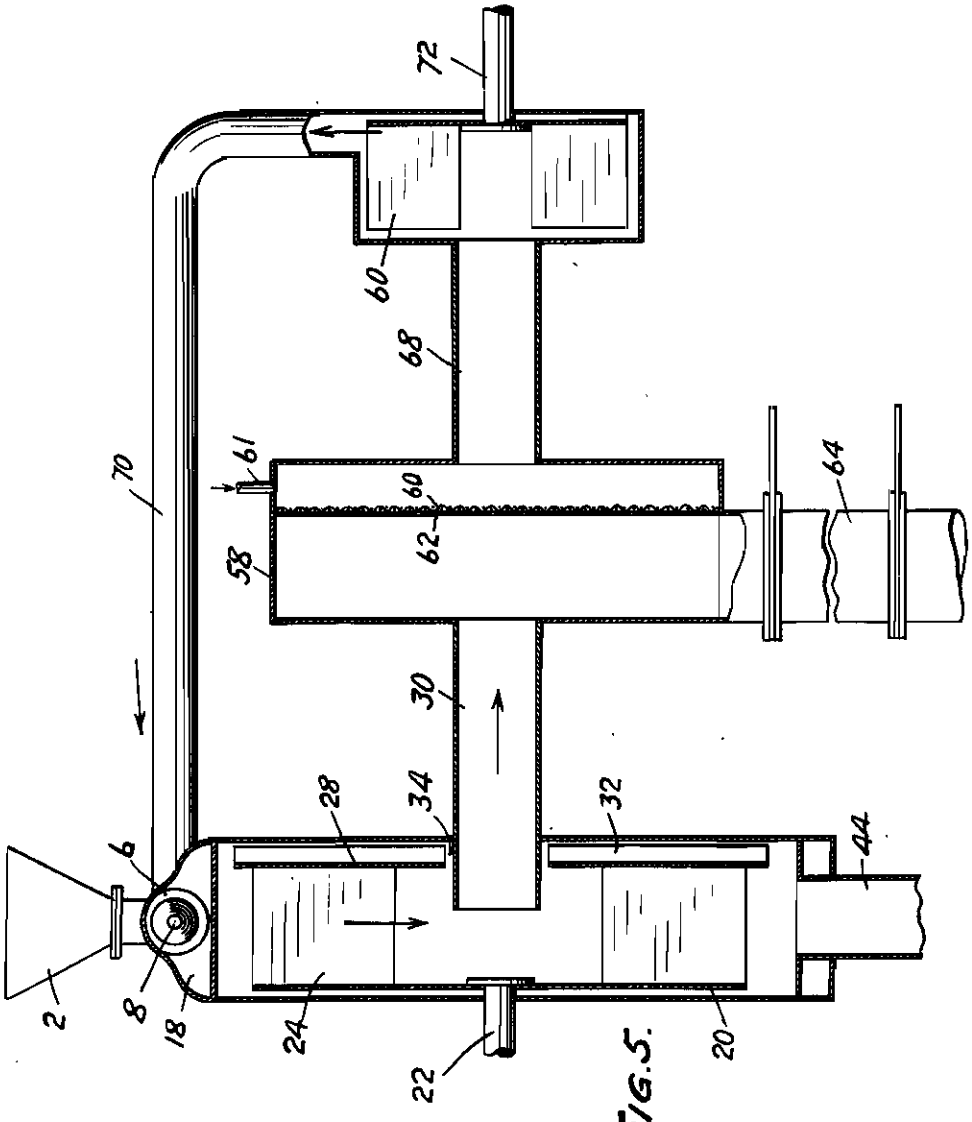

FIG. 5.

INVENTOR
Wladimir de Fligué
BY
ATTORNEYS

WITNESS:
Robt. R. Mitchel.

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ALIEN PROPERTY CUSTODIAN

SEPARATOR

Wladimir de Fligué, Paris, France; vested in the Alien Property Custodian

Application filed June 11, 1937

This invention relates to a separator and, specifically, a separator for finely divided solid materials.

Various industries require solid materials in a finely divided state, if not in a colloidal state. Certain materialists exist naturally in this state, while others may be brought to it by grinding, condensation of vapors or the like. In all processes used to finely divide solid material, as well as in cases of natural occurrence of finely divided materials, it is necessary to separate the particles which are sufficiently fine from those which are not. Furthermore, it may be desirable to separate different substances if the original material worked in is not homogeneous. The classification in such case may be by density. One of the known processes of separation of powdered materials is based on the fact that the mass of a body is proportional to the cube of its lineal dimensions, and its cross-section is proportional to the square of such lineal dimensions.

In one process of separation of powdered materials it is sought to oppose two forces, one of which has a value dependent upon the cross-section of the body and the other dependent upon its mass. The result is that a more or less imperfect selection is effected due to the fact that the ratio of mass to section is, for a homogeneous material, dependent on the dimensions of the particles. It will be obvious, also, that particles of different densities but the same dimensions may be separated since, while the sections will be the same, the masses will be different.

Among the forces which can be thus opposed to realize selection of the above type, one may be the action of a stream of air, the other being a centrifugal force. If it is desired to select materials of successively smaller particle sizes, the mass of the particles will decrease faster than their section. The decrease in mass is proportional to the cube of the lineal dimensions and the decrease in section to the square of the same. The result is that for the minute sizes required by certain industries, the centrifugal forces in the known separator become too small and the forces due to the air flow too large to obtain an effective separation.

It is the object of the present invention to provide an apparatus for effecting separation of the above type while avoiding the difficulties inherent in the types of apparatus heretofore used. Particularly high controllable centrifugal forces may be obtained, the forces in the two cases being controllable at will and opposed in an effective fashion. Briefly stated, the apparatus comprises a rotor selector, built according to principles described below, used in conjunction with an exhauster or aspirator connected in opposition to the rotor selector and having an effect predominating over that of the rotor selector in its action as an impeller so that an air current is caused to flow radially inward through the selector.

In accordance with the invention, the selector is of an improved form to avoid the existence of critical points in the selector passages, which will determine by the position of the particle relative to them whether or not the particle will be passed or rejected by the selector. Specifically,, it is an object of the present invention to provide a selector in which throughout a substantial radial path the relation between the opposing forces acting on a particle of given size will be substantially constant. The above and other objects of the invention, relating particularly to details of construction will be apparent from the following description read in conjunction with the accompanying drawings in which:

Figure **1** is a vertical section through the improved separator taken on the plane indicated at **1—1** in Figure **2**;

Figure **2** is a vertical section taken on the plane indicated at **2—2** in Figure **1**;

Figure **3** is an enlarged sectional view illustrating the design of a separator rotor;

Figure **4** is an explanatory diagram illustrating the mode of operation of the improved selector as compared with that of the previous types; and

Figure **5** is a diagrammatic view of a modified form of separator constructed in accordance with the invention.

In the illustrated apparatus, the powdered material to be separated is fed from a supply, conventionally shown as a hopper **2**, through an adjustable valve **4** which regulates the flow into a conduit **6**, into which air is admitted through a nozzle **8**. While air may be forced through the nozzle, there may be provided only an induced flow of air by means of an impeller hereafter described. The nozzle in the latter case will be open to the atmosphere and in either case is used only to secure the necessary velocity to float the particles in an air stream.

The conduit **6** delivers the air carrying the floated particles through a series of tangentially arranged openings **10**, **12** and **14** into the housing **16** of the selector proper. The conduits are so arranged, as well as the tangential nozzles, so that the velocity of flow throughout the introductory passages is sufficiently high to prevent separation therein due to lowering of velocity.

Within the housing **16** and peripherally spaced from the walls as indicated at **18** to provide an annular free space, is the selector rotor comprising a plate **20** carrying passage forming members **24** defining passages **26**, the form of which will be more fully described hereafter. A second plate **28** closes off the ends of the passages opposite the plate **20** and extends adjacent the periphery of a conduit **30** projecting approximately into the center of the opening **31** within the rotor. The plate **28** carries impeller vanes **32** having slight clearances **34** with the conduit **30** and having radial lengths substantially greater than those of the passages **26**, with the result that the impeller formed by these vanes will provide greater suction than that resulting from the passage forming elements **24**. As a consequence, there will be a slight circulation of air outwardly between the passages defined by the vanes **32**, as indicated by the arrows in Figure 2. This automatically provides a sealing effect preventing any passage of air carrying unseparated particles between the plate **28** and an adjacent wall of the housing **16**. Other sealing means such as labyrinthine packing may be used.

In order to control the flow through conduit **30**, there is provided a valve **36**. The material passing through the conduit **30** from the center of the selector rotor enters the intake of a second impeller **38** driven through a shaft **40** and discharging at **42**. The light particles which pass through the selector rotor and are discharged at **42** may be precipitated and separated in any suitable fashion, for example, by electrical precipitation, filtration or the like. The flow may be controlled also by variation of velocity of impeller **38**.

The heavier material which will not pass inwardly through the passages **26** will separate out in the annular passage **18** and may be collected in a receiver comprising an upper chamber **44**, an intermediate chamber **50** and a discharge **52**. Valves indicated at **46** and **48** may be provided so that with **48** closed the material collecting in **44** may be discharged into **50** by opening the valve **46**, and then with **46** closed **48** may be opened to provide for discharge of chamber **50** without affecting the pressure within the housing **18**, or diverting any of the air within the housing.

In the arrangement illustrated, the impeller **38** is used to produce a radially inward flow of air through the passages **26** despite the tendency of the selector rotor to act as an impeller. In other words, there are two impellers acting in opposition, and the impeller **38** prevails in its effect. The air emerging from the nozzle **8** expands just at the point where the powdered material is fed into the conduit **6** and, by reason of the expansion, aggregation of the particles after their separation and suspension by the jet is prevented. As has been pointed out above, the feeding conduit is so arranged as to maintain the air velocity sufficiently high to prevent any settling, before the air carrying the powdered material in suspension enters the rotor chamber.

In the passages **26** any particle is subjected to two forces. Since it will be taking part in a rotary motion substantially identical with that of the rotor itself, it will be subjected to a centrifugal force equal for each grain to $m\omega^2r$, in which m is the mass of the particle, ω is the angular velocity of the rotor and r is the distance of the particle from the center of rotation.

Simultaneously, each particle is subjected to centripetal force directed inwardly having a value which for practical purposes can be closely expressed as ksv^2, in which k is a constant depending on the shape of the particle, its size and the nature of its surface and which, for a material which is homogeneous, or which may be nonhomogeneous but consists of particles of more or less the same size, will be substantially the same for all the particles in the mixture being separated; and in which s is the maximum section of the particle in a plane perpendicular to the air stream in relation to the particle and v is the relative velocity of the air stream and particle. It will be noted that the average velocity of the particle in a radial direction at the entrance to one of the passages **26** will be substantially zero and, under conditions such as are here involved, the radial velocity will be quite low throughout the entire passage **26** as compared with the actual velocity of the air stream. Consequently, v may be regarded as the velocity of the air stream neglecting the radial velocity of the particle.

The opposition of the forces thus obtained permits a selection either according to the size or according to the density of the particles.

In order to secure effective separation, it is obviously desirable that the two forces should act upon any particle for a maximum length of time in such fashion as to secure the same separating effect throughout that entire time. Since, in the present apparatus, the separation takes place only in the passage **26**, the time of action of these forces is measured by the time it takes for the particle to pass (if it is to pass) through a passage **26**. Consequently, it follows that the design should be such that if a particle is to pass through a passage **26** the forces should be such at all points of that passage as to cause it to do so; and if a particle is not to pass through the passage **26** then the forces should be such as to prevent its doing so, even though it may have entered part way into the passage. It is to be understood, of course, that the separation involves statistical considerations. In other words, particles of any given size will have a range of entering velocities (due to turbulence, etc.) extending above and below some mean velocity and consequently separation effected by any such apparatus cannot be absolutely perfect. However, with attention to considerations such as those indicated above, any particle will be subjected to conditions tending to either pass it or reject it over a maximum time with consequent improved selection.

Considering a particle which is of a size such that particles of larger size should be rejected and particles of smaller sizes passed, the two opposing forces for that particular particle should be balanced throughout the radial extent of each passage **26**, or, in other words, through the passage $m\omega^2r$ should be equal to ksv^2. Since m, ω, k and s are constant, v should be proportional to $\sqrt{r}$. This means that the air velocity between the impellers of the selector should be proportional to $\sqrt{r}$; or, in other words, the decrease of the centrifugal force from the outside to the center of the selector should be balanced by an equivalent decrease in the air velocity. Since the air velocity is inversely proportional to the cross-section of the passage, the preceding condition can be realized by giving to the selector impellers such a section that the cross-section of the passage will be inversely proportional to $\sqrt{r}$.

In Figure 3 the dotted lines indicated at **54** indicate the theoretical walls for a passage **26**. In order to illustrate the nature of the curves **54**, they are produced inwardly to indicate that they are ultimately tangential to a circle which is of considerably less radius than the innermost radius of a practical passage. Between the limits of a practical passage **26**, it will be observed that the curves **54** are substantially straight lines and, as a practical matter, taking into consideration the existence of such factors as wall resistance to flow, etc., the theoretical curved surfaces may be replaced by plane surfaces of the type provided at **24**. The foregoing design, it will be noticed, assumes the axial width of each passage **26** is constant. If that is not the case, the cross-sectional design must be made to correspond so as to remain inversely proportional to $\sqrt{r}$.

The walls of the passages should be polished to prevent sticking of any of the solid material, particularly when the material has a natural tendency to stick or become aggregated. It is to be noted that with increased accuracy or sharpness of separation, the tendency of the powder to deposit on the wall would be increased, since the end to be desired is a separation such that certain particles are in equilibrium in the passages with theoretically a zero velocity. In general, of course, such zero velocity would not tend to occur unless the friction with a wall was quite high, because smooth flow would not be attained and turbulence would maintain the particles in suspension unless they were of a sticky or aggregative nature. It is further desirable to polish the surfaces because of the Coriolis acceleration which shows that a particle between two rotating impellers and moving from the outside toward the center will have a tendency to eventually hit the preceding impeller. The setting of the impellers at an angle to the radius will not avoid this because the phenomenon is dependent upon the velocity of the particle between the impellers and, therefore, is dependent upon its size. The particles composing a powdered material are, of course, different in size, so that a design avoiding the Coriolis phenomenon for one particle would not hold for another.

It will be noticed from a consideration of the radii drawn in construction lines and indicated at **58** that, if the inner radius of the selector rotor passages is made of substantial size, the centrifugal force will, to a high degree of approximation, be constant across the cross-section of any passage **26**, not differing by any more than the cosine of half the angles formed at the center by the inner ends of walls **24**.

In the above, it is also assumed that the pressure differential between the outside and center of the selector is constant throughout its rotation. For this to be true it is necessary that the pressure be the same at all points of the periphery of the selector rotor because it can be assumed that the inlet pressure at the exhaustor will not be disturbed by the existence of an unsymmetrical origin. The feeding of the air and the powdered material should theoretically be made uniform all around the rotor. This effect will be substantially achieved by having a plurality of inlets symmetrically located as at **10**, **12** and **14**, and providing a sufficient space between the selector rotor and its casing, as well as by substantially tangential feed of the air and particles in the direction of rotation of the selector. In this way, the influence of the differences of velocity between the inflowing fluid and that entrained by the selector rotor will be negligible. Complete separation of the particles is, of course, necessary, and this may be best obtained by producing expansion of air at the point of feed of the solid material, as indicated above. It is also necessary to prevent bypassing of the selector rotor by means of a labyrinth type of joint or, as in the present case, by use of an auxiliary impeller arrangement **32** to provide a slight circulation opposing any bypass.

Reference to Figure 4 will illustrate some of the characteristics of operation of the improved device as compared with an arrangement having radially extending vanes so that the passages increase in size radially outwards. A comparison will now be made showing the characteristics of the improved separator as compared with the characteristics of this other type, which comparison will serve to illustrate the characteristics of the improved separator as compared with various other types not in accordance with the invention.

In Figure 4, the centrifugal and centripetal forces are plotted against the radial position of a particle. The values R_1 and R_2 of the radius are assumed to be the radial limits of a passage such as **26**.

For a given angular velocity of the separator rotor and a given air flow condition representing, for example, some definite velocity of flow at the radius R_2, let it be assumed that the mass and cross-sectional area of a particle in equilibrium are m_0 and s_0 respectively. According to the design principles indicated above, it follows that the straight line OA will represent the variations of both $m_0\omega^2r$ and ks_0v^2 with the radius. Of course, these are opposite in sign so that the particle is in equilibrium throughout this entire straight line, and, a fortiori, between the radius limits R_1 and R_2.

Now, consider a particle having a mass m_1 greater than the mass m_0, but having the same cross-section s_0, i. e., particles of the same size but higher density. The curve representing the values of $m_1\omega^2r$ will be a straight line OB. This throughout its entire extent, will lie above the curve OA, which will still represent the value ks_0v^2. Consequently, the forces will be such as to reject this new particle throughout the entire passage **26**. Attention must again be called to the fact that the distribution will be of a statistical nature, so that a particle such as the one last mentioned might well enter part way into the passage **26**. However, since it will be subjected to an expelling force through the entire radial extent of the passage **26**, it is extremely likely that, despite its entrance into the passage, its direction of movement will be reversed and it will be ultimately rejected. The rejection is the more certain, of course, as the mass m_1 differs from the equilibrium mass m_0.

Again let us consider a particle having the same section S_0, as the equilibrium particle, but having a smaller mass m_2 i. e., a lower density. The curve OF will represent the centrifugal force acting on this particle, while OA will still represent the force due to air flow. The curve OF lies wholly below the curve OA and accordingly, throughout the extent of the passage **26**, there will be a tendency toward passage of the particle inwardly beyond the radius R_1.

Let us now consider a particle of the same density as the particle m_0, s_0 but of larger size, i. e., of both larger mass and larger section. Remembering that the mass is proportional to the cube of the lineal dimensions and the section to the square of the same, we can write, if c is the linear dimension:

$$\frac{m_0}{m_1}=\left(\frac{C_0}{C_1}\right)^3;\ \frac{C_0}{C_1}=\sqrt[3]{\frac{m_0}{m_1}}$$

$$\frac{S_0}{S_1}=\left(\frac{C_0}{C_1}\right)^2;\ \frac{C_0}{C_1}=\sqrt[2]{\frac{S_0}{S_1}}$$

$$\sqrt[2]{\frac{S_0}{S_1}}=\sqrt[3]{\frac{m_0}{m_1}};\ \frac{S_0}{S_1}=\left(\frac{m_0}{m_1}\right)^{\frac{2}{3}}$$

If the function $m_1\omega^2r$ is represented by the line OB, the function ks_1v^2 will be represented by a line OC, which, according to the above, will lie between OA and OB. Accordingly, a particle m_1, s_1 of the same density but of larger size introduced between the impellers will be subjected throughout the entire length of the passage to an ejecting force.

Similar reasoning will show that a particle of mass m_2 and section s_2 of the same density as the particle m_0, s_0 but of smaller size, will be represented by the curves OE and OF, respectively, so that a particle of such type will be carried inwards by the prevailing centripetal force throughout the radial extent of the impellers.

Summarizing, the various curves in Figure 4 represent the following in comparison with the particle m_0, s_0, which is in equilibrium and represented by the curve OA:

OA and OB—A particle of the same size and higher density.
OA and OF—A particle of the same size but lower density.
OA and OC—A particle of the same mass and lower density.
OA and OE—A particle of the same mass and higher density.
OB and OC—A particle of the same density but larger size.
OE and OF—A particle of the same density but smaller size.

As contrasted with the results obtained by the use of the improved separator described above, consideration may be given to the action of the type having ordinary radially extending vanes and, consequently, outwardly diverging passages. Consider the same equilibrium particle m_0, s_0 referred to above.

In this case, assuming radial vanes, the cross-section of the passage is proportional to the radius and the velocity is inversely proportional to the radius, so that a curve ks_0v^2 is a second degree curve such as indicated at MN. It will now be necessary to specify where the particle is at equilibrium, and let it be assumed that the equilibrium occurs at the radius R_2, namely, at the entrance end of a passage. The curve OA will still represent the value of $m_0\omega^2r$, but if equilibrium is to occur at radius R_2, the curve MN will now represent the value of ks_0v^2, as indicated above, and will intersect the line OA at T at the abscissa R_2. Between the limits R_1 and R_2 the curve MN will lie above the curve OA, which means that the centripetal force will exceed the centrifugal force. In other words, if the particle under consideration once enters within the radius R_2, it will be pulled by a continuous increasing force within the separator.

Now consider a particle having the same cross-section s_0 but a larger mass m_1, so that as before $m_1\omega^2r$ will be represented by the line OB. OB intersects MN at Q at a radial distance within the limits of the passage. Outwardly of Q the centrifugal force exceeds the centripetal force on such a particle, while inwardly of Q the reverse is true. In other words, if the initial entering velocity of this type of particle will not carry it inwardly of the point Q, it will be rejected. On the other hand, if it passes the point Q, it will be very strongly urged inwardly and will pass the separator rotor. So far as rejection of this particle is concerned, therefore, the separator passage has an effective length only that represented by the difference of the radii of the points Q and R_2. Not only is the radial distance between R_1 and Q ineffective to reject the particle, but rather it is very effective to pass the particle.

If we consider a particle of section s_0 and mass m_2, i. e., material of the same size as m_0, s_0 but of lower density, the curve MN will still represent the force ks_0v^2. Line OF will represent the centrifugal force $m_2\omega^2r$, and it can be seen that such a particle will be passed through the selector.

A particle of the same density as m_0, s_0 but of larger size, for example, m_1, s_1, will have the curves OB and M_1, N_1 as its characteristic curves. These curves intersect at a point Q', and it can be seen that between Q' and R_2 the particle will be expelled, while between R' and Q' it will be forced inwardly. Therefore, only the part of the passage between Q' and R_2 will be effective for the removal of undesired particles.

A particle of the same density but of smaller dimensions will be subject to forces represented by the curves OF and M_2, N_2, with the result that the centrifugal force is always smaller than the centripetal force, so that such a particle will be passed throughout the passage.

It is obvious from the above demonstration that the improved selector is far more efficient in rejecting undesirable material of either large size or high density than a selector in which the impellers have a constant thickness, with the result that the separation is much more sharply defined. In the improved selector the nature of the predominating force acting on a particle will be constant independently of the radius. In the radial vane selector, on the other hand, the selection is only effective at or near the inlet of the passages limited by the vanes.

The conditions of separation may be varied in different ways, for example, by changing the velocities of the selector and impeller rotors, by throttling flow through conduit **30** or **42**, by controlling or introducing air through nozzle **8**, etc.

In Figure 5 there is indicated another embodiment of the invention involving the provision of a substantially closed system which is capable of somewhat more effective control of the flow and consequently of the separation. In this figure, the separator proper is the same as that heretofore described. The conduit **30**, however, provides flow into a filter chamber, indicated at **58**, provided with a support **60** for filter material **62**. The particles which pass the selector separate in the chamber **58** and may be removed through the valved exit **64**. An admission port for air is provided at **61** and serves to permit the replacement of any air lost with the powdered material. A conduit **68** connects the filter chamber with a compressor **66** driven through a shaft **72**, which compressor delivers air through conduit **70** from the jet **8**, which serves for the entrainment of the powdered material. Regulation in this case may be effected by control of either the shaft **22** or **72**. During normal operation there will be little flow of air through the passage **61**.

WLADIMIR DE FLIGUÉ.