

Sept. 17, 1957

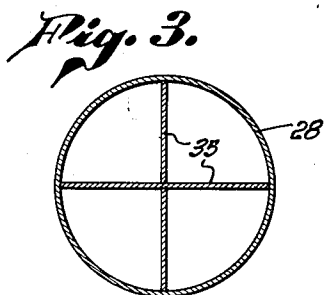
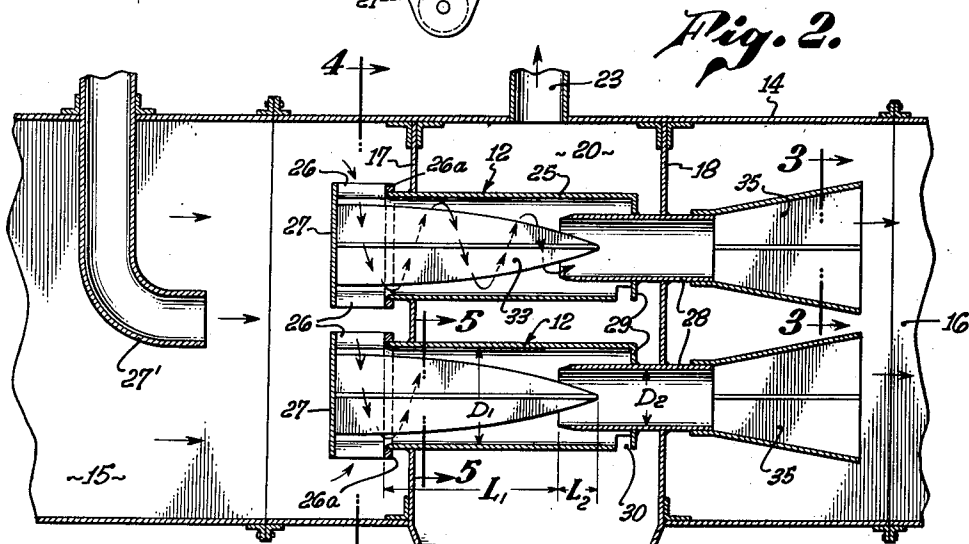
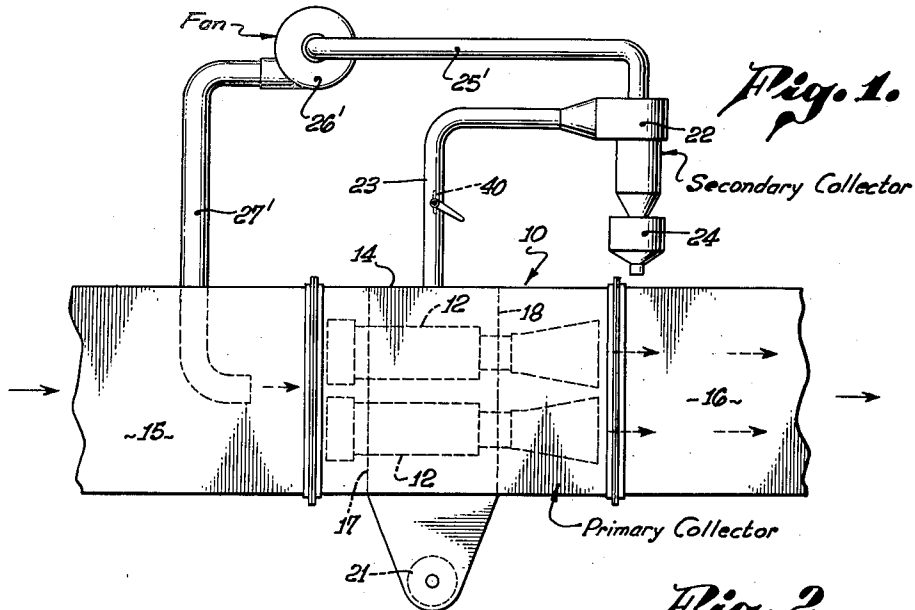
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2,806,551

CENTRIFUGAL DUST COLLECTOR WITH LAMINAR GAS FLOW

Original Filed Oct. 16, 1951

3 Sheets-Sheet 1



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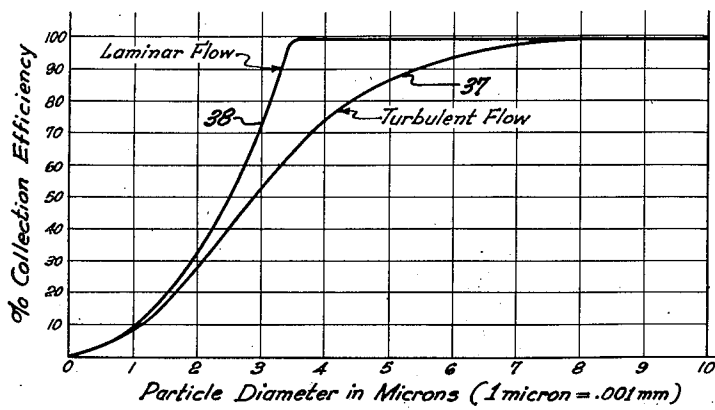
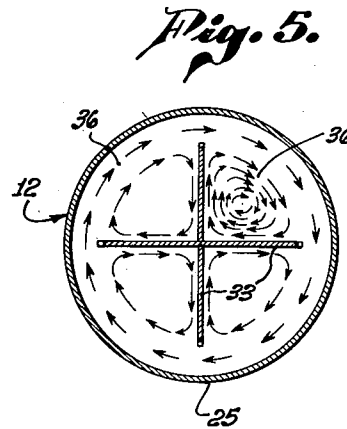
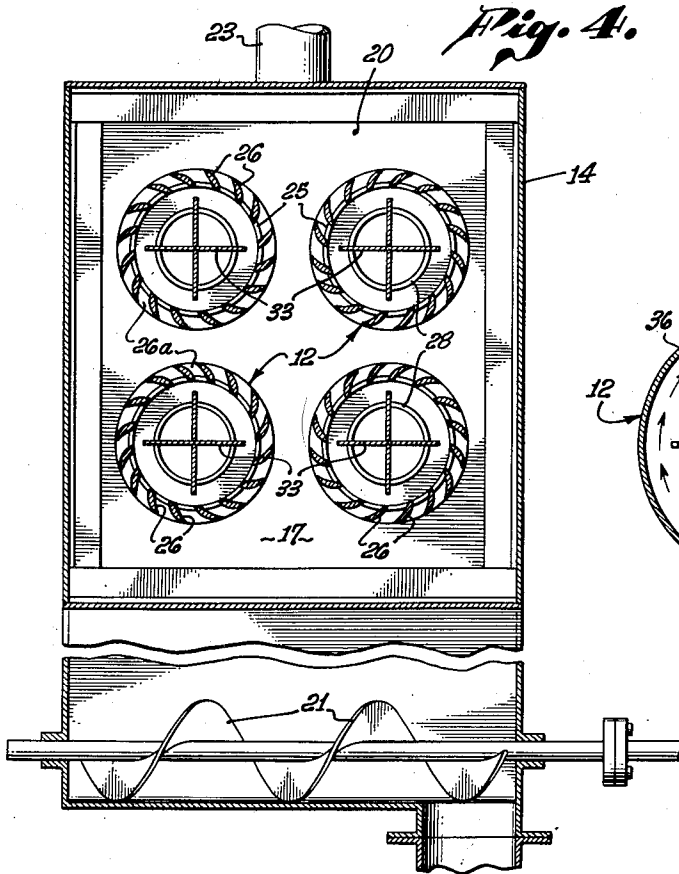
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3 Sheets-Sheet 2



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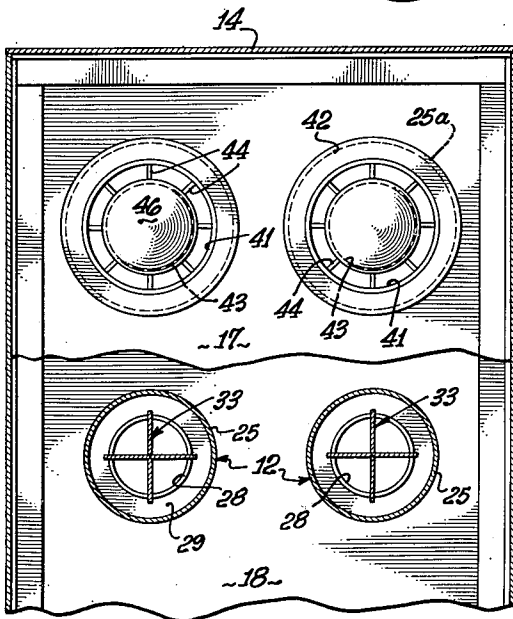
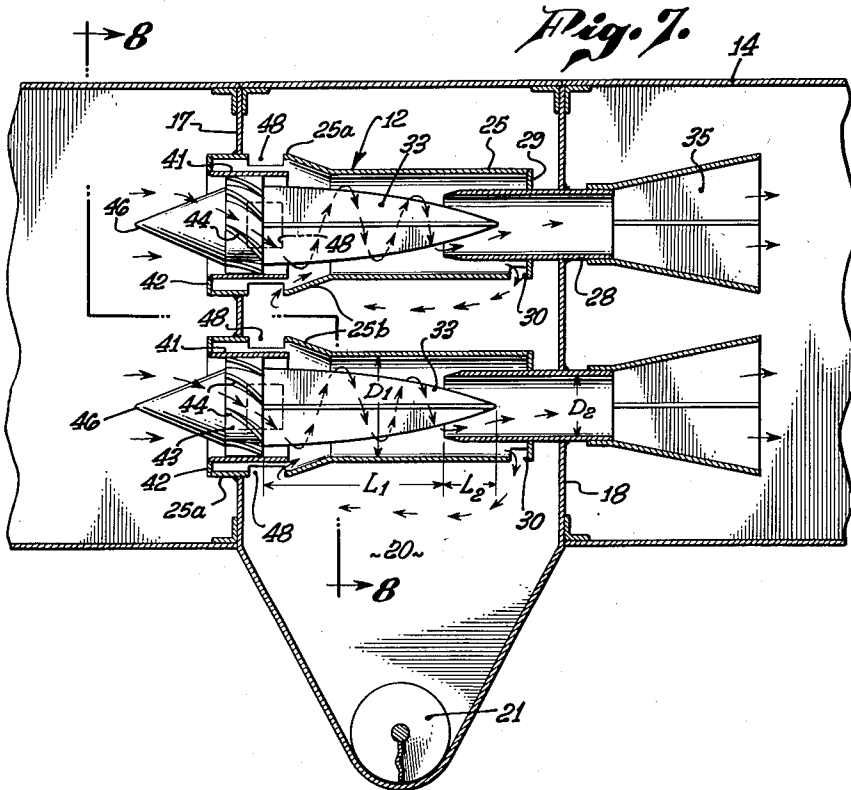
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3 Sheets-Sheet 3



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**CENTRIFUGAL DUST COLLECTOR WITH
LAMINAR GAS FLOW**

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Continuation of abandoned application Serial No. 251,503, October 16, 1951. This application October 10, 1955, Serial No. 539,385

10 Claims. (Cl. 183—80)

This application is a continuation of application Serial No. 251,503, filed October 16, 1951, and now abandoned.

The present invention is concerned generally with centrifugal type dust collectors in which a stream of air carrying suspended particles is subjected to a whirling movement in order to separate suspended particles from the air stream by centrifugal action. More particularly, the present invention is concerned with improvements in the design of dust collectors of this type which result in increased separation efficiency, particularly in the extreme lower range of particle sizes.

In a mechanical separator of the centrifugal type, the stream of air or other gas is subjected to movement in a circular path, producing a whirling motion of the gas stream. The resultant centrifugal force imparted to the suspended particles throws the particles to the outer periphery of the stream, where they can be separated from the main gas stream. Since the force which can be applied to any particular particle is proportional to its mass, it will be appreciated that a very small force indeed can be applied to particles of extremely small mass such as those having average diameters of .010 mm. (ten microns) or less. Suspended particles of this size are extremely sensitive to local aberrations in the gas flow since the particles may be temporarily subjected to localized forces in excess of the force tending to effect separation. These factors complicate the problem of separation of extremely small particles by centrifugal processes within any practical limit since the gas stream can be subjected to a whirling motion for only a short length of time within apparatus of economic size or proportions.

The prior art reveals many efforts at improvement in collection efficiency, most of which have been directed toward better control of the particles when once separated from the stream or towards increasing the centrifugal force exerted upon the particles. Known types of mechanical separators are generally characterized by turbulent gas flow; that is, the flow of the gas stream is agitated or violent and contains many local eddy currents and whirls which in part are opposed to or detract from the main flow. It has been found that the efficiency of a given device is improved if the flow can be maintained as nearly as possible in a streamline or laminar condition.

Streamline or laminar flow may be defined as non-turbulent gas flow. This is possible only when there are no localized aberrations of the stream flow, usually referred to as eddies, which produce more or less transient changes in direction and velocity of portions of the gas stream, creating a certain amount of internal friction in the stream. Actually, perfect streamline flow cannot be achieved throughout mechanical dust collectors of commercial design but substantial improvements can be made in the design of collectors which permit a relatively close approach to laminar flow.

It thus becomes a general object of my invention to design a dust collector of the centrifugal type having a relatively high collection or separation efficiency for

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particles of extremely small size, and particularly for particles having a diameter of 10 microns or less.

It is also a primary object of my invention to devise a centrifugal type dust collector that is characterized by substantially laminar flow through the separation zone.

Another object is to provide a centrifugal type dust collector embodying the optimum proportions or relative sizes of parts to establish optimum flow conditions where-in internal and friction losses are minimized.

A further object is to utilize the relationships of certain values producing a constant known as the Reynolds number, in the design of an efficient type of centrifugal type dust collector.

Another object of the invention is to provide a centrifugal dust collector of the above type in which gas is withdrawn from the dust hopper and recirculated through the main separating tube without requiring a secondary fan or collector for the recirculated fraction of the dust stream.

These and other objects are attained in a centrifugal type dust collector having a separating tube of circular cross-section by providing a core member inside and concentric with the tube. The core member extends into the tube from the inlet end and cooperates with the tube to confine the gas stream to an annular zone between the core and tube. The relative dimensions of the core member and tube are such as to produce a Reynolds number of less than 10,000 when gas flow is at a velocity of about 1500 cm./sec. or less, in order to maintain predominantly laminar gas flow within the tube.

The core member preferably comprises a plurality of radial blades, equi-angularly spaced, and having a gently curved profile with a radial dimension decreasing away from the tube inlet. Preferably two intersecting plates are provided, forming four radial blades spaced 90° apart. The tips of the core blades extend into the outlet tube which is of smaller diameter than the separating tube.

In one form of my invention each separating tube is provided with an opening in its wall adjacent the primary gas inlet, said opening providing a secondary gas inlet that communicates with the dust hopper to admit gas from the hopper. A sleeve shields the secondary gas inlet from the main gas stream after it leaves the vanes; and the sleeve also directs gas entering through the secondary inlet to a smooth junction with the main gas stream.

How the above objects and advantages of my invention are attained will be more readily understood by reference to the following description and to the annexed drawings, in which:

Fig. 1 is a schematic layout illustrating the association with a collector of my improved design of a secondary collector and fan for recirculating a portion of the air stream;

Fig. 2 is a vertical section through a centrifugal type mechanical dust collector embodying my invention;

Fig. 3 is a transverse vertical section through the outlet tube of a single separation unit, on line 3—3 of Fig. 2;

Fig. 4 is a transverse section through a centrifugal type dust collector embodying my invention, on line 4—4 of Fig. 2;

Fig. 5 is a transverse vertical section through a single separating unit, on line 5—5 of Fig. 2;

Fig. 6 is a graph showing calculated efficiencies for two different types of flow conditions;

Fig. 7 is a longitudinal vertical section through a centrifugal type collector embodying a variational form of my invention; and

Fig. 8 is a transverse vertical section on line 8—8 of Fig. 7.

Fig. 1 is a diagrammatic illustration of a primary collector operating in conjunction with a secondary col-

lector and a fan to circulate through the secondary collector a portion of the load. The primary collector, indicated generally at 10, is constructed in accord with my invention and includes a plurality of individual separating units, each indicated generally at 12 in Fig. 2. Collector 10 is here shown as including four separating units 12 arranged in parallel but it will be realized that any desired number of units may be employed according to the total gas volume that it is desired to pass through the collector.

Collector 10 includes an outer shell or housing 14 which is designed to conform in cross-sectional shape to the main gas duct, here shown as being rectangular, but other types of shells may be used since the invention is not limited to any particular design or shape of the shell. At the inlet end, shell 14 is connected to section 15 of the gas duct which delivers the dust laden gas stream to the primary collector. At the outlet side, shell 14 is connected to the exhaust section 16 of the gas duct through which the cleaned gas is conducted to any desired place.

Extending transversely across shell 14 are two spaced parallel header plates 17 and 18 which seal off respectively the inlet and outlet sides of the gas duct. Between plates 17 and 18 but outside separating units 12 is a space which constitutes a dust fall chamber 20 within which dust separated from the gas stream by units 12 is collected. This separated dust falls to the bottom of chamber 20; and the bottom of the chamber is preferably a hopper formed with inclined side walls that direct the dust within reach of screw conveyor 21 by which the dust may be removed. Other suitable and known means, such as tipping valves or the like, may be used instead of a screw conveyor to effect removal of the dust from the collecting hopper.

Secondary collector 22 is connected by duct 23 to the top of dust fall chamber 20, as may be seen in Fig. 2. Duct 23 leads to the inlet of the secondary collector 22 which may be of any suitable type; and it is here shown as being a mechanical collector of the centrifugal type. A bag filter may be used as the secondary collector. Dust separated out in the secondary collector accumulates in hopper 24 from which it may be removed by gravity in any suitable manner, either periodically or continuously as may be desired. The cleaned air from the secondary collector passes through duct 25' to the inlet of fan 26'; and after passing through the fan flows through duct 27' which is connected to inlet duct section 15 to introduce the air into the main duct ahead of the primary collector.

Separating units 12 are of the through type in which the gas enters at one end of the unit and leaves at the other end. Each unit consists of a cylindrical separating tube 25 within which is a separating chamber. Each separating tube 25 extends through header 17 and is supported thereby near the inlet end. At the inlet end each tube 25 is provided individually with suitable means for imparting a whirling motion to the gas stream as it enters the separating tube, such as an assembly of vanes 26 shown particularly in Fig. 4. The vanes 26 for each tube may be secured to a ring 26a which slips over the inlet end of a tube 25 and is then fastened to the tube in any suitable way. The inlet end of tube 25 and the side of vanes 26 is covered by plate 27 so that the entering gas strikes the curved surfaces of the vanes and enters in a generally tangential direction. The result is a circular movement given to the incoming gas stream which follows a spiral path as it moves axially of tube 25.

At the opposite or outlet end of tube 25 is located concentric outlet tube 28 which is of smaller diameter than separating tube 25 and is likewise preferably cylindrical. The outlet tube is preferably of uniform diameter until the tube passes through header plate 18 which engages and supports the outlet tube. Separating tube 25 has an annular end wall 29 which engages outlet tube 28 to hold the two tubes concentric and support the inner end of the separating tube. Beyond the header plate, outlet

tube 28 retains its circular cross-section but flares outwardly, its diameter increasing in the direction of gas flow, as may be seen particularly in Fig. 2.

Outlet tube 28 extends through end wall 29 into the separating tube for a short distance forming at the end of the separating tube an annular space. Through this annular space a small portion of the gas stream moves and carries dust separated by centrifugal action to dust outlet 30 located in the side wall of tube 25 at a low point, and preferably at the end of the tube.

Supported by end plate 27 within each separating tube 25 is core member 33. The core member is located concentrically of tube 25 and is designed to confine the gas stream within the tube to an annular zone between the inner cylindrical surface of tube 25 and the extremities of the elements of the core member. Core 33, as shown particularly in Fig. 5, is composed of two intersecting plates at right angles to each other, thus providing four radially extending blades which are equi-angularly spaced around and extend outwardly from the longitudinal axis of tube 25. It is preferred that there be four such blades, although a larger or smaller number may be used if desired. If a smaller number is used, the effect of the core in guiding the gas stream or confining it to the annular zone desired is reduced and there is a corresponding reduction in the improvement obtained in the collection efficiency. On the other hand, a larger number of blades than four increases the guiding effect but also greatly increases the friction between the gas stream and the core member with the result that a greater amount of energy is required to move the gas stream through the separating unit at a given velocity. Core members with continuous surfaces which are surfaces of revolution can be found in known devices; but it is preferred to avoid such designs with continuous surfaces because of the comparatively high friction loss resulting from the great surface in contact with the whirling gas.

The radial dimension of each of the blades of core 33 decreases gradually from the inlet end of the tube to the tip of the core, producing a gently curved profile of each blade when seen in side elevation as in Fig. 2. All four blades are the same shape. The curved profile is preferred to a straight line since the maximum radial dimension of the core member is maintained for as long a time as possible and then is gradually reduced toward the tip to permit the inner end of the core to be inserted in outlet tube 28. Clearance between the tip of the core and the walls of outlet tube 28 must be somewhat greater than the minimum clearance between the core and the wall of tube 25 in order to provide sufficient net area for the gas stream.

A somewhat similar blade assembly 35 is provided in the flared portion of outlet tube 28 where a plurality of radially extending blades are arranged as shown in Fig. 3. Two intersecting plates are used to provide four blades equally spaced at 90° intervals about the axis of the outlet tube and extending entirely across the tube from wall to wall thereof. The purpose of these blades is to arrest the whirling motion of the gas flow and cause it to move primarily in a straight forward direction out of the outlet tube and along gas duct 16.

Having described the construction of a preferred form of my invention, the theory of its design and operation will now be discussed. Laboratory tests on a number of dust collectors of known designs indicate that gas flow through them is essentially turbulent in character and it is believed that predominantly turbulent gas flow characterized all known designs. By mathematical analysis it can be shown that the theoretical collection efficiency of a cyclone or centrifugal type dust collector with turbulent flow follows an exponential law, the collection efficiency being that fraction of the entering dust which is separated from the dust stream and retained within the collector. This exponential law may be expressed generally by the statement that in the centrifugal

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type collector under given uniform conditions of gas flow each unit area of collecting surface in succession from the gas inlet toward the gas outlet collects the same percentage of suspended particles of any given size in the gas stream flowing over this unit surface. This law of collection holds true only if the centrifugal force acting on the dust particles is always of the same magnitude throughout the length of the collector; and therefore this condition is assumed to exist in order to give a common basis for analysis of various collectors although minor variations in the centrifugal separating force may occur in actual practice. Expressed mathematically, the collection efficiency of a turbulent flow centrifugal type dust collector is as follows:

$$(1) \quad E = \left(1 - \frac{1}{e^{wF}}\right) \cdot 100\%$$

when

E = collection efficiency in percent

e = 2.718 (base of Napierian logarithms)

w = the radial migration velocity of the particles within the collector measured in a direction perpendicular to the collecting surface, expressed in m./sec.

F = the specific collecting area expressed in square meters per cubic meter of gas per second ($\text{m}^2/\text{m}^3/\text{sec.}$)

According to the above expression, collection efficiency can be calculated strictly speaking, only for particles of any one size; but for practical purposes a given calculation may be assumed to apply to particles within a narrow size range. The collection efficiency for each one of a plurality of such ranges of particle sizes can be calculated separately and then the several efficiencies averaged in order to obtain the overall efficiency when the stream carries dust particles over a wide range of sizes. For example, to determine the overall collection efficiency for particles ranging in size from 0 to 10 microns, the efficiency for each of ten equal fractions of one micron size range can be calculated individually and then averaged.

For particles 10 microns and less in diameter, the collection efficiency for particles of given sizes, as determined by the above formula, when plotted appears as curve 37 in Fig. 6 where the collecting chamber is assumed to have a diameter of 12.5 cm. and a specific collecting area F of 1.41 $\text{m}^2/\text{m}^3/\text{sec.}$ The specific gravity of the particular dust in this case is 2.6 g./cm.³.

It can be demonstrated mathematically that the collection efficiency E of a similar centrifugal type collecting unit in which the gas flow is laminar follows the law

$$(2) \quad E = (wF) \cdot 100\%$$

where w and F have the same meanings as before. Assuming a collecting unit of the same physical characteristics as before, the calculated collection efficiency for particles of given sizes in a centrifugal type dust collector in which the flow is laminar is plotted as curve 38 in Fig. 6.

It will be noted that at the upper range of particle sizes the maximum theoretical collection efficiencies both converge toward 100%; whereas the theoretical possible collection efficiency under laminar flow conditions is substantially greater for particle sizes in the range of 2 to 7 microns with a maximum difference at about 3.5 microns. For example, for a particle size of .004 mm. or 4 microns the collection unit with turbulent flow collects only about 73% whereas with laminar flow the same unit collects approximately 99% of the particles. It will be understood that these calculated efficiencies are of course ideal and can never be reached in actual practice but nevertheless they can be approached and substantial improvements made in collection efficiencies by properly controlling the character of the gas stream flow.

The character of fluid flow can be predicted or determined in a satisfactory manner from the Reynolds number, which is widely used for this purpose. The Reynolds number is a dimensionless constant and is a function of

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the dimensions of the fluid duct (or of a body around which the fluid is flowing), and the velocity, density, and viscosity of the fluid, as expressed in the following formula:

$$(3) \quad R = \frac{vd\rho}{\mu} = \frac{vd}{K}$$

In the present case the fluid is a gas and the symbols have the following meanings:

v = the gas velocity between the guiding surfaces in cm./sec.

d = the distance between the guiding surfaces measured in cm.

ρ = the density of the gas in grams/cubic cm.

μ = absolute viscosity of the gas in poises.

K = kinematic viscosity of the gas = $\frac{\mu}{\rho}$.

It has been determined by laboratory experiment that gas flow between two spaced surfaces or through a circular pipe is laminar when the Reynolds number does not exceed 2000. When the Reynolds numbers fall in the range of 2000 to 10,000, and occasionally to still higher values, the flow is passing through a transition zone in which flow may be either laminar or turbulent and under some conditions may change from time to time if conditions are unstable. Above 10,000 for the Reynolds number the flow is usually turbulent, although some authorities consider completely turbulent flow does not occur until the Reynolds number exceeds 30,000; but the critical values of the Reynolds numbers depend on the circumstances of each case.

There are several factors in centrifugal type separating units that tend to stabilize flow conditions, keeping them laminar rather than turbulent, as long as the Reynolds number is 10,000 or less. The whirling gas stream tends to move in a spiral path without being diverted into local eddies. The comparatively high centrifugal acceleration acting on the stream probably is the reason for this behavior. Also the dust suspended in the stream increases its actual viscosity by an indefinite amount so that flow is more nearly laminar than for the same gas without any suspended particles, other conditions remaining the same. Friction and roughness at the bounding surfaces increase turbulence. Hence, by reducing friction and keeping all surfaces smooth and streamlined, normal tendencies toward turbulence are reduced and flow is stabilized as laminar at a higher Reynolds number than otherwise possible. By taking full advantage of these minor factors flow can be kept predominantly laminar in a centrifugal separating unit of the present type at values of about 10,000 or less for the Reynolds number produced by my improved design.

Assume a typical conventional centrifugal separating unit of circular cross section and a radius of 6.25 cm., through which a stream of air is moving under a head within the normal range of 1.5 to 4.0 inches of water pressure drop across the separating unit. Assume that the moving stream of air has a linear velocity of 1500 cm./sec. and a temperature of 200° C. The density ρ is .000742 g./cc. and the absolute viscosity μ is .00026 poise, giving a kinematic viscosity of .350. Substituting these values in the formula for the Reynolds number

$$R = \frac{vd}{K} = \frac{1500 \times 6.25}{.350} = 27,000 \text{ approximately}$$

Gas flow in a dust collector having these characteristics is always turbulent.

By comparison consider the flow conditions in a separating unit designed according to this invention and as shown in Fig. 2. Here core member 33 occupies a position at the center of cylindrical tube 25, confining free gas flow to an annular zone bounded on the outside by the internal surface of tube 25 and having its inner boundary determined by the outer edges of radial vanes 33. Assume that the minimum distance between the wall of

tube 25 and the outer edges of core member 33, which occurs at the point of maximum diameter of core member 33, is 1.25 cm. or $\frac{1}{40}$ the diameter of the separating tube which has been assumed in the previous example to have an internal diameter of 12.5 cm. If the gas stream has the same velocity (1500 cm./sec.) as it moves through a separating unit 12 as illustrated in Fig. 2 at a temperature of 200° C., then the Reynolds number may be calculated as follows:

$$R = \frac{v \cdot d}{K} = \frac{1500 \times 1.25}{.350} = 5400 \text{ approximately}$$

Under these conditions the gas flow may be assumed to be stabilized in a laminar condition or at least a predominantly laminar condition since laminar flow exists for most of the distance between the core and tube.

Laboratory test with a collecting unit of this type demonstrate that with a given pressure drop across the collecting unit, for example 3 inches of water, the gas volume that can be passed through a centrifugal collecting unit embodying the present invention and having laminar flow, is about 25% to 30% higher than the gas volume that can be passed through a unit with the same size collecting tube 25 but having turbulent flow. Apparently this condition results from the fact that the gas stream under turbulent conditions uses up a substantial amount of energy in useless work. This energy goes to maintain the many internal eddies or local agitations in the main stream and does not help to maintain the main gas stream. When laminar gas flow without local agitations can be established, the energy required to maintain gas flow at a given rate through the separating unit is substantially decreased; and conversely, for a given pressure drop across the tube a greater volume of gas can be passed through the collection unit per unit time.

A particular advantage of the form of core 33 illustrated herein is believed to be that it establishes a desirable degree of laminar flow with a minimum frictional resistance to flow. Apparently in each of the four quadrants of the cross-shaped core gas swirls (as at 36 in Fig. 5) are set up by the frictional drag of the main stream rotating in the annular zone around the core. The swirl in each quadrant rotates at its outer surface in the same direction as the main stream so that there is little if any frictional drag between the main stream and the localized swirl in each quadrant. The effect is to cause the main gas stream to roll around and on the swirls as if rolling on roller bearings. The result is stability of the main gas flow with a minimum of friction or energy loss by virtue of contact with core 33.

The gas swirls in the quadrants of the core have little if any movement in the direction of the axis of the separating tube. This fact lends stability to the main gas flow and helps maintain its laminar character. Any dust that enters these swirls is thrown out in a short time because the centrifugal force applied to it while in the swirl is relatively high.

In a centrifugal dust collector of the type shown herein, a small fraction of the total gas stream travels along the wall of each separating tube 25 to the end of the tube where it leaves the tube through dust outlet 30. This part of the gas assists in discharging separated dust from the collecting tube and carrying it into the dust fall chamber 20. This type of circulation is maintained by fan 26 withdrawing gas from chamber 20 through duct 23. Since the dust content in this gas is relatively high, it is customary and preferable to pass the air through some type of secondary collector, as indicated at 22 in Fig. 1. The fraction of air so withdrawn customarily is in the neighborhood of perhaps 10% to 15% of the main gas stream, the quantity of air withdrawn being regulated by any suitable means, such for example as damper 40 in duct 23. The fraction of air so withdrawn from chamber 20 may be discharged to the atmosphere or it may be reintroduced into the gas stream by duct 27 which

discharges it to the main inlet duct 15 upstream from separators 12. As a result, this fraction of the total gas stream is continually recirculated.

In the present instance, the recirculation of a portion of the gas stream is utilized to assist in controlling and determining the Reynolds number of the collection units. It will be noted from Formula 3 above that the Reynolds number of a particular construction decreases with an increase in the gas viscosity; and the viscosity of the gas stream can be increased by increasing the concentration of dust particles suspended in it. Hence by recirculating through the cyclone a portion of the gas and with it some of the dust previously extracted from the hopper, the dust content of the stream delivered to the inlets of the several separators 12 can be increased over the concentration of dust otherwise appearing in the gas stream.

In order to establish laminar flow in the centrifugal separating units, it has been determined experimentally that certain relationships or proportions of the several parts are preferable. These include the internal diameter D_1 of each separating tube 25, the diameter D_2 of each outlet tube 28, the distance from the inlet end of tube 25 to the inner end of outlet tube 28 as indicated by L_1 which also equals the exposed length of the core piece 33 in the separating chamber, and the distance which the core piece projects into outlet tube 28, as designated at L_2 . It is preferred that L_1 should be between 1.3 and 1.8 times D_1 and L_2 should be about .5 to 1.0 times D_2 . The minimum diameter of the outlet tube, or the diameter D_2 of the portion of uniform diameter should be between .5 and .7 times the diameter D_1 of the separating chamber. Each of the four blades of core 33 extends radially outward from the tube axis a distance equal to .4 D_1 , making the minimum thickness of the annular zone around the core member equal to .1 D_1 . The physical thickness of the zone increases toward the outlet end of tube 25; but in fact the active zone does not increase in thickness at the same rate since the bulk of the whirling gas tends to move inwardly away from the wall of tube 25 to reach outlet tube 28.

There is shown in Figs. 7 and 8 a modified form of my invention which differs from the form first described chiefly in the arrangement for recirculating through the separating unit a portion of the gas stream and separated dust. In the separator of Fig. 2, the power for recirculation purposes is supplied by fan 26; but in the form of Figs. 7 and 8 no external source of power is used, energy for this purpose being obtained from the main flow of gas. For this purpose, each separating unit 12 has been modified by changing somewhat the design of separating tube 12. At the inlet end, each tube 25 is provided with a section 25a of enlarged diameter joined to the main section of normal diameter by a frusto-conical transition section 25b. Within and annularly spaced from the walls of tube section 25a is a short sleeve 41 of circular cross-section. Sleeve 41 is here shown as cylindrical and having an internal diameter substantially equal to the diameter of the main portion of separating tube 25. Sleeve 41 is supported at the open end of the separating unit forming the primary gas inlet by an annular end wall 42 which closes the space between sleeve 41 and enlarged section 25a to the incoming gas stream. Thus the inner surface of sleeve 41 defines the outer boundary of the whirling gas stream in the initial portion of the separating unit, in the same manner as the wall of tube 25 does in the form previously described.

Ring 43 carries around its outside surface a plurality of integrally formed vanes 44. The diameter of the tips of vanes 44 equals the internal diameter of the sleeve 41 so that the vane assembly is supported in the sleeve by engagement with it. Conical baffle 46 having a base diameter equal to the external diameter of ring 43 is mounted on the upstream side of the ring and shapes the incoming gas stream into an annular body which enters

vanes 44 while moving axially of the separating unit. The vanes impart a whirling motion to the gas stream as it enters the separating tube and the annular zone between the inside surface of sleeve 41 and core member 33. Core member 33 is constructed as previously described and is mounted on the downstream side of base ring 43.

A construction using a vane assembly as shown in Fig. 7 is illustrated for the purpose of showing means for imparting whirling motion to the gas stream when entry to the separating unit is in an axial direction. Vanes of this type may be used in the separating unit of Fig. 2; and likewise vanes of the type first described may be used in the construction of Fig. 7, with suitable modifications of the supporting structure, to permit tangential entry of the gas stream from the side of the tube.

It will be understood that various changes may be made in the shapes of sleeve 41 and section 25a within the scope of my invention. For example, sleeve may taper for part or all of its length with the smaller end inside the separating tube. This is advantageous when the tube axis is vertical as the spin-producing vanes 44 can then wedge inside the sleeve to support the vanes in place. If sufficient taper is provided on sleeve 41, the increase in diameter at section 25a can be reduced or eliminated, which lessens the cost of manufacture of the separating tube.

Cleaned gas is discharged from the separating units through outlet tube 28 into which core member 33 projects. The flared end of outlet tube 28 is provided with straightening vanes 35, all as previously described.

Separated particles, along with a small fraction of the total gas stream, leave each separating unit 12 through outlet 30 at the end of the tube adjacent end wall 29. This portion of the gas stream carries the separated materials into dust fall chamber or hopper 20 where the particles can fall into the bottom of the chamber for removal by screw conveyor 21.

It will be noted that the enlarged section 25a of each separating tube has one or more secondary gas inlet openings 48. As the whirling gas stream, which is moving at a comparatively high velocity, moves past the gap between the inner end of sleeve 41 and the wall of tube 25, it creates at the gap a zone of relatively low pressure. Although the pressure need not be lowered by any great amount, it is sufficiently below the pressure existing in chamber 20 to draw into the tube through inlet 48 a portion of the gas in chamber 20. Sleeve 41 shields the secondary gas inlet against the main gas stream, which would otherwise strike directly against the outlet and interfere with entry of gas through opening 48. Sleeve 41 also directs gas entering through opening 48 along the axis of the separating tube to a smooth junction with the main gas stream. There is also drawn in a certain proportion of suspended dust particles which acts to increase the viscosity of the gas stream. The presence of this additional suspended material is utilized to maintain or increase the viscosity of the whirling gas stream in order to decrease the Reynolds number when calculated as explained above. The magnitude of the fraction of the total gas recirculated in this manner between ports 30 and 48 can be controlled by proper design of the tube and is normally in the neighborhood of 10% to 15% of the throughput. It will be noted that in this case recirculation is obtained without any external source of power, as in Fig. 1.

Having disclosed certain forms of my invention it will be evident that various other embodiments may occur to persons skilled in the art without departing from the spirit and scope of my invention. Consequently, it is to be understood that the foregoing is considered to be illustrative of, rather than limitative upon, the invention as defined in the appended claims.

I claim:

1. In apparatus for separating suspended particles from a gas stream by centrifugal action, the combination com-

prising: a separating tube of uniform circular cross section having at one end an inlet and at the other end separate outlets for the cleaned gas and for the separated particles, the outlet for cleaned gas being formed by an outlet tube concentric with and smaller in diameter than said separating tube and extending inwardly of the separating tube from said other end past the outlet for the separated particles; a gas guiding core member inside and concentric with the separating tube and cooperating with the separating tube to confine the gas within the tube to an annular zone between the tube and core member, said core member extending inwardly from the inlet end of the separating tube to a point inside the outlet tube and having a diameter at the inlet end of the separating tube greater than the diameter of said outlet tube and decreasing in radial dimension toward the outlet end of the separating tube; and means at the inlet end of the separating tube for imparting a whirling motion to the gas stream as it enters the annular zone.

2. Apparatus as in claim 1 in which the length of the core member within the outlet tube is between about .5 and 1.0 times the diameter of the outlet tube.

3. Apparatus as in claim 1 in which the distance between the inlet end of the separator tube and the inlet end of the outlet tube is between about 1.3 and 1.8 times the internal diameter of the separating tube and the diameter of the outlet tube is between about 0.5 and 0.7 times the internal diameter of the separating tube.

4. Apparatus as in claim 1 in which the radial thickness of the annular zone at the inlet end of the separating tube is about $\frac{1}{10}$ the internal diameter of the separating tube at the inlet end.

5. In apparatus for separating suspended particles from a gas stream by centrifugal action, the combination comprising: a separating tube of circular cross section having an inlet at one end and at the other end a first outlet for cleaned gas and a second outlet for separated particles, said tube having a main separating section of normal diameter and a section of enlarged diameter at the inlet end provided with a gas inlet opening; a sleeve of the same diameter as said main separating section located concentrically within the enlarged section of the separating tube but spaced therefrom and extending past said inlet opening in the enlarged section; a gas guiding core member inside and concentric with the sleeve and extending inwardly from the inlet end of the tube, said core member cooperating with the sleeve and tube to confine the gas stream within the tube to an annular zone around the core member, the core member comprising a plurality of radially extending blades substantially equiangularly spaced around the axis of the separating tube; and means at the inlet end of the tube for imparting a whirling motion to the gas stream as it enters the annular zone; and a particle receiving housing enclosing the separating tube and communicating with the interior thereof through the opening in the enlarged section and the second outlet whereby gas discharged from the tube through said second outlet may be drawn into the tube through the opening in the enlarged section.

6. In apparatus for separating suspended particles from a gas stream by centrifugal action, the combination comprising: a separating tube of uniform circular cross section having at one end an inlet and at the other end separate outlets for the cleaned gas and for the separated particles, the outlet for cleaned gas being formed by an outlet tube concentric with and smaller in diameter than said separating tube; a gas guiding core member inside and concentric with the separating tube and cooperating with the separating tube to confine the gas within the tube to an annular zone between the tube and core member, said core member extending inwardly from the inlet end of the separating tube to a point inside the outlet tube and having a diameter at the inlet end of the separating tube greater than the diameter of said outlet tube and decreasing in radial dimension toward the outlet end of the sepa-

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rating tube; and means at the inlet end of the separating tube for imparting a whirling motion to the gas stream as it enters the annular zone.

7. In apparatus for separating suspended particles from a gas stream by centrifugal action, the combination comprising: a separating tube open at one end to provide a primary gas inlet and having adjacent the other end means providing a first outlet for cleaned gas and means providing a second outlet for separated particles, said tube also having an opening in its wall adjacent the primary gas inlet forming a secondary gas inlet; means at the primary inlet end of the tube for imparting a whirling motion to the gas stream as it enters the tube; a gas guiding core member inside and concentric with the tube and extending inwardly from said whirling motion imparting means, said core member cooperating with the tube to confine the gas stream within the tube to an annular zone around the core member; a particle receiving housing surrounding the separating tube and communicating with the interior thereof through the secondary inlet and the second outlet whereby gas discharged from the tube through the second outlet can re-enter the tube through the secondary inlet; and a sleeve carried by the separating tube at its open end

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and extending thereinto past the secondary gas inlet and spaced from the tube wall at the secondary inlet to shield the secondary inlet from the main gas stream in said annular zone and to direct gas entering the tube through the secondary inlet axially of the tube to a junction with the main gas stream at the inner end of the sleeve.

8. Apparatus as claimed in claim 7, wherein the sleeve carried by the separating tube provides a support for the whirling motion imparting means.

9. Apparatus is in claim 7 wherein the gas guiding core member comprises a plurality of radially extending blades substantially equi-angularly spaced around the axis of the separating tube.

10. Apparatus as claimed in claim 7, wherein the gas guiding core member projects into and axially of the means providing said first outlet.

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