United States Patent [19]
Boadway

[11] **3,862,714**
[45] **Jan. 28, 1975**

[54] **VORTEX CLARIFIER**

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[22] Filed: **Nov. 14, 1972**

[21] Appl. No.: **306,468**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 35,759, May 8, 1970, abandoned.

[52] **U.S. Cl.** **233/3**, 233/8, 233/32, 233/46

[51] **Int. Cl.** **B04b 5/04**

[58] **Field of Search** .... 233/1 R, 3, 4, 8, 27, 28, 233/32, 33, 44, 46, 17, 23 R

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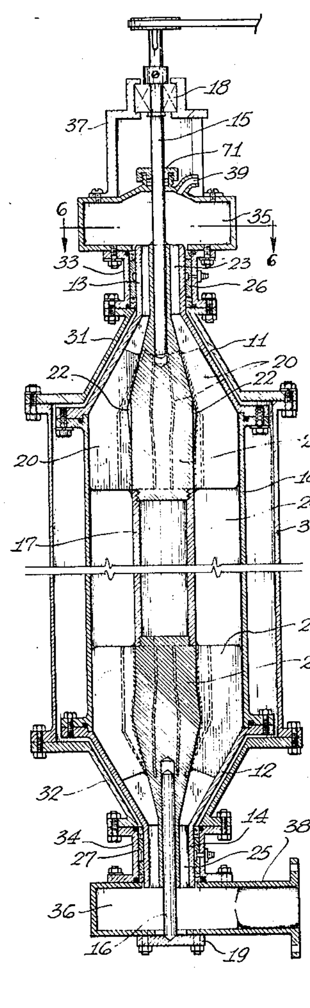
[57] **ABSTRACT**

Apparatus for the vortical separation of fluid material. An annular zone is provided between two rotating cylindrical surfaces and the fluid material introduced into this zone to form a forced vortex having also an axial component of motion of predetermined profile. The centrifugal acceleration results in a distribution of the fluid material with the more dense material located further from the axis. Various structures for separating the fractions of different density are disclosed. The apparatus is arranged so that a large portion of the energy supplied to the fluid in forming the forced vortex is recovered as the fluid leaves the device thus making it possible to treat large fluid flows at low power costs.

26 Claims, 11 Drawing Figures



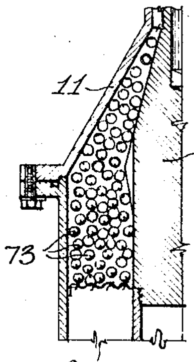


Fig. 5.

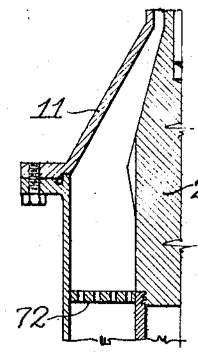
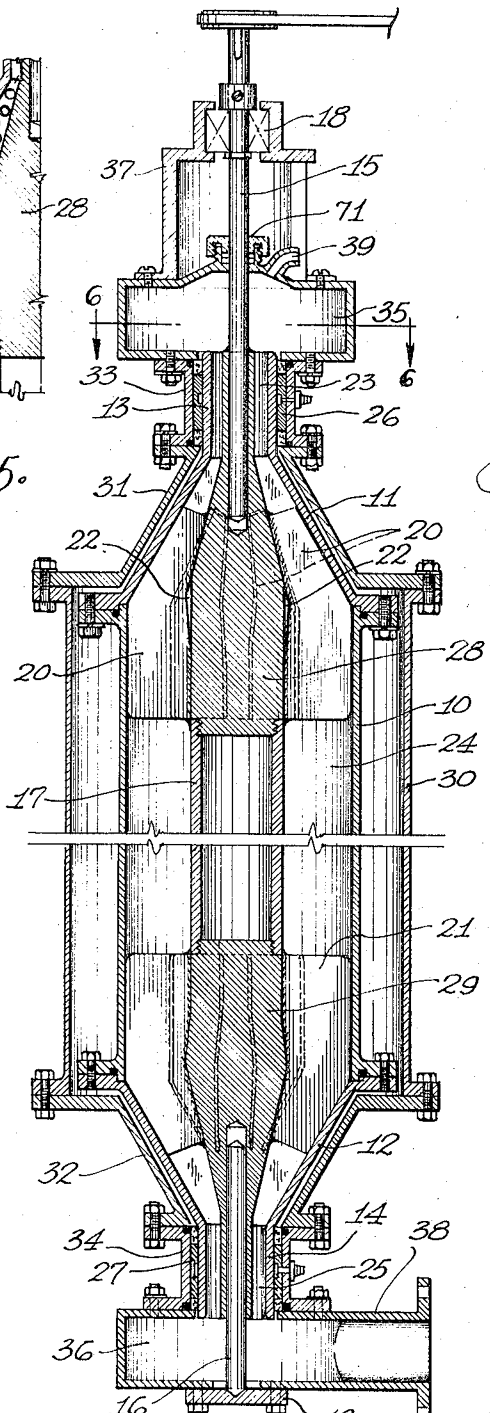


Fig. 4.



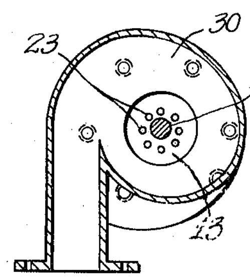


Fig. 6.

Fig. 1.

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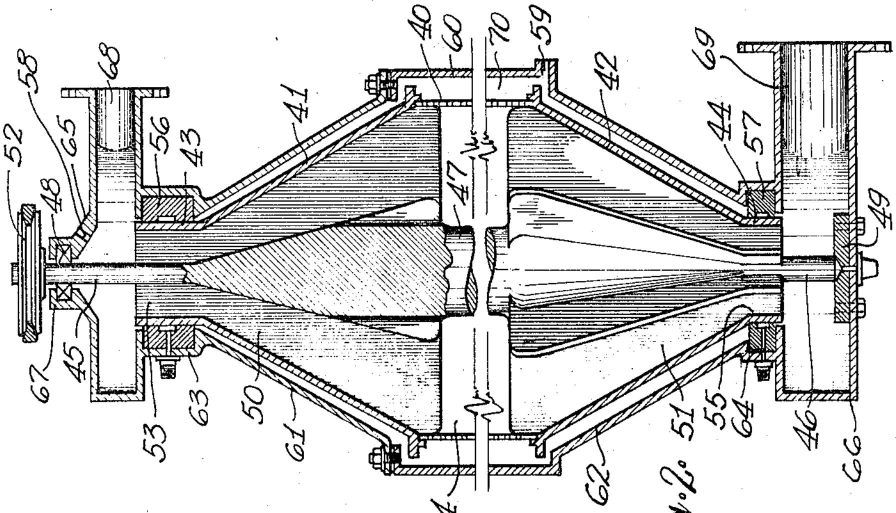

Fig. 2.

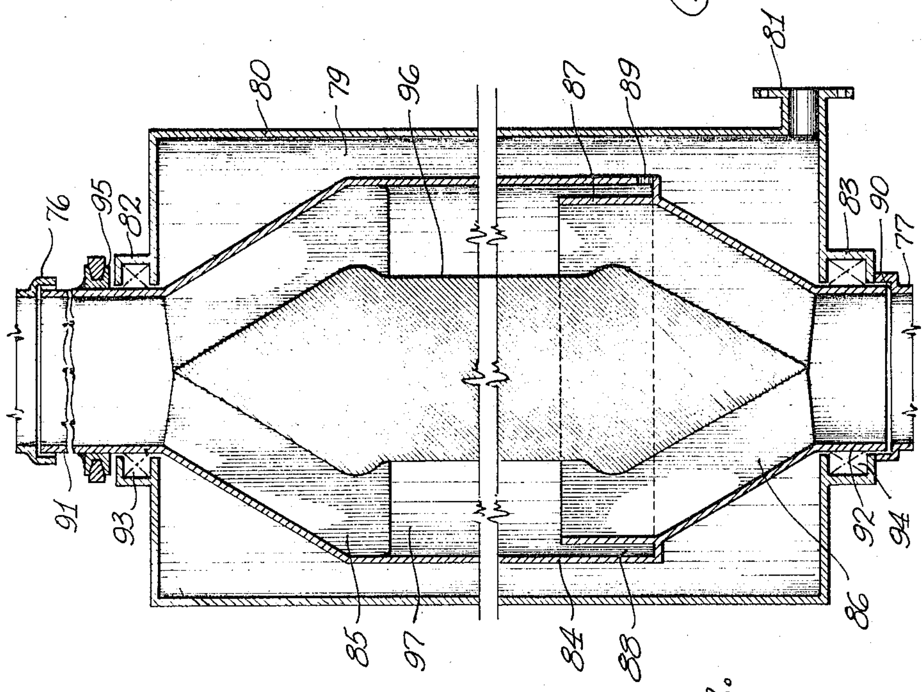

Fig. 3.

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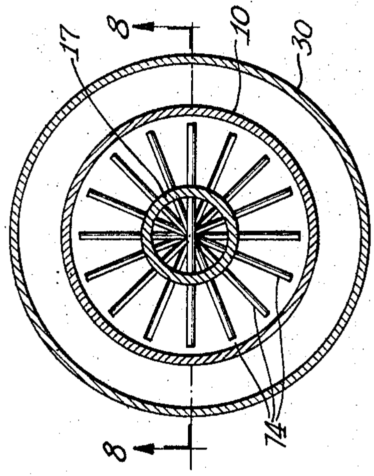

Fig. 7

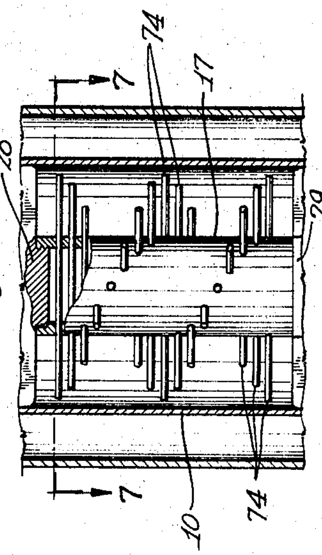

Fig. 8

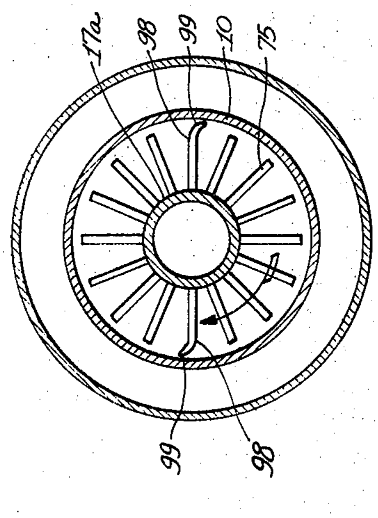

Fig. 10

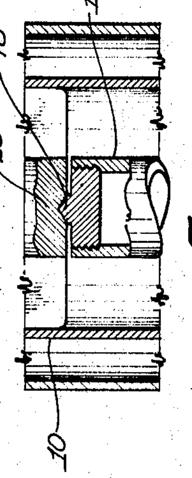

Fig. 11

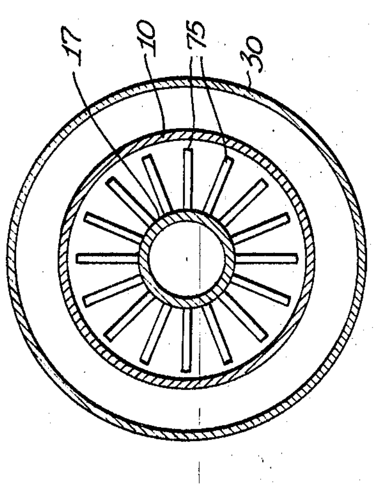

Fig. 9

VORTEX CLARIFIER

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of application Ser. No. 35,759 filed May 8, 1970, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to a method and mechanical devices for the vortical separation of fractions of fluid mixtures.

It is known that vortical separation of fluid material can be performed by supplying angular momentum to the fluid so that the resulting centrifugal acceleration causes a density related distribution of material. In such known methods the flow of the fluid can be either a free vortex, having shear between adjacent layers and a constant energy content at all radii, or a forced vortex as in a centrifuge, where there is no shear between adjacent layers, or a situation intermediate between these two cases. More specifically in a forced vortex the velocity of any small volume of the fluid may be expressed as:

$$V = k\ r$$

whereas in a free vortex the corresponding expression is:

$$V = k/r$$

The intermediate situation can be described by the relationship:

$$V = K\ r^n \qquad -1 < n < 1$$

a vortex with n outside the range set out would not be stable.

The present invention provides a forced vortex which has an axial velocity. In the past it has proven difficult to obtain this condition, due to the formation of instabilities in the vortex, except with highly viscous slurries in which the viscosity damps out unwanted relative movement in the fluid. Such instabilities arise because it is difficult to obtain axial movement without some radial movement and fluid moving radially maintains its hydraulic energy and thus changes the tangential velocity. The present invention provides novel apparatus for sustaining fluid flow in a configuration very close to that of a theoretically ideal forced vortex even in low density fluids and as used hereinafter the term "forced vortex" means a vortex which substantially approaches the theoretical forced vortex. A forced vortex is advantageous in obtaining separation due to the lack of shear between adjacent layers. Fluid shear acting on particles with a high surface to mass ratio retards their separation.

The term "fluid" as used in this specification is intended to include particulate solids, liquids and gases and mixtures thereof which exhibit the properties of a fluid.

SUMMARY OF THE INVENTION

One aspect of the present invention is the use of a forced vortex formed in a separation annulus between two synchronously rotating cylindrical surfaces for the separation of heavy and light fractions from fluids.

A further aspect of the present invention is concerned with the method and apparatus required to establish the forced vortex in the fluid. The kinetic energy is supplied gradually to the inflowing liquid which is subdivided into separate streams arranged so that all portions arrive at the separation annulus with the appropriate kinetic energy. Preferably, this is achieved by causing the fluid to flow between coaxial conical surfaces subdivided into pockets by vanes.

Yet another aspect of the present invention is concerned with recovering the kinetic energy supplied to the fluid after it has passed through the separation annulus. This has particular advantages in the separation of fine material which requires a high rate of rotation. If the energy supplied to the material cannot be recovered it may not be economically feasible to perform this separation.

The separating apparatus of the present invention consists of a stationary outer casing in which is mounted a rotatable assembly. The rotatable assembly includes an annular separation zone. A first set of impeller blades is provided to increase the angular momentum of the fluid to be separated so that it forms a forced vortex in the annular separation zone causing the more dense material to be displaced outwardly. The fluid also has an axial component of velocity which need not be constant throughout the separation zone. That is the axial velocity may have a radial distribution. A second set of impeller blades is driven by the fluid leaving the separating zone and recovers energy from the fluid. The first and second sets of impeller blades are mounted on a common shaft so that only enough power to compensate for various frictional losses need be supplied. The separated material can be removed by permitting it to accumulate in the separation zone and interrupting operation periodically, i.e., batch operation. Alternatively, collection orifices can be formed on the exterior of the annular separation zone for removal of the more dense material.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side view, in section, of one embodiment of a separator suitable for batch operation,

FIG. **2** is a side view, in section, of a second embodiment of a separator suitable for continuous operation,

FIG. **3** is a side view, in section, of a third embodiment of a separator suitable for the separation of gases,

FIGS. **4** and **5** are fragmentary views, in section, of variations in the distributor structure shown in FIG. **1**,

FIG. **6** is a cross-section taken along the line **6—6** in FIG. **1**,

FIGS. **7** and **8** are fragmentary views showing a modification of FIG. **1** using rods in the separating zone,

FIG. **9** is cross-section view showing a further modification of FIG. **1** using vanes in the separating zone, and

FIGS. **10** and **11** are fragmentary views showing a further modification of FIG. **1** having scraper blades in the separating zone.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring first to FIG. **1**, there is shown in cross-section apparatus for separating material using the forced vortex principle. The apparatus consists of a stationary outer casing formed from a tubular cylinder **30** securely attached to upper and lower truncated conical sections **31** and **32** which, in turn, are attached to bearing sections **33** and **34**. Inlet and outlet vortex chambers **35** and **36** are positioned communicating with the top and bottom of this casing, respectively, a venting tube **39** being provided in the top wall of vortex chamber 35. A further bearing section 37 is positioned above vortex chamber 35. Suitable supports, not shown in FIG. 1, are provided for this stationary assembly.

A rotatable assembly is mounted within the outer casing, closely spaced from the inner walls thereof. This assembly consists of a tubular cylinder 10 integrally connected at each end to vaned hollow conical portions 11 and 12. The conical portions 11 and 12 terminate in cylindrical members 13 and 14 having a plurality of holes 23 and 25 extending therethrough. Typically there are six holes symmetrically arranged in each of the pair of cylindrical members 13 and 14. A tubular support member 17 is positioned along the common axis of cylinder 10 and conical portions 11 and 12 so that member 17 and cylinder 10 form an inner and an outer cylinder rotating in synchronism and defining a separating annulus therebetween. Member 17 is connected to solid central hubs 28 and 29 of the vaned conical portions 11 and 12. These hubs taper at their ends as conical portions coaxial with conical portions 11 and 12 to leave an annular passageway from top to bottom of the rotatable assembly. Thus, hub 28 and conical portion 11 cooperate to form two coaxially positioned cones as do hub 29 and conical portion 12. The six holes in each of member 13 and member 14 communicate between the respective vortex chambers and this annular passageway. Connected between the solid central cores and inner surfaces of conical sections 11 and 12 are sets of impeller blades 20 and 21, respectively. A preferred arrangement has 12 impeller blades, six blades substantially coextensive with the corresponding conical section defining vane pockets in registration with the six holes in the cylindrical members 13 and 14 alternating with six shorter blades further sub-dividing the vane pockets to give twelve passageways.

The assembly is supported axially for rotation about an axis coincident with the axis of the casing on two spindles 15 and 16 attached to the tapered ends of central hubs 28 and 29, by welding or other suitable method. Spindle 15 is supported in upper bearing 18 and spindle 16 is supported on a lower bearing plate 19. Bearing 18 functions as both a rotational and thrust bearing supplying radial support to spindle 15 so that it may be connected to a drive pulley. While bearing 19 is capable of supporting some radial and axial thrust its major purpose is to support the end of spindle 16 in a stable manner. Spindle 16 performs an essential function in occupying the central axis of chamber 36 to prevent the formation of any cavity or gas core with resulting instability. Preferably bearing 18 is a roller bearing and bearing 14 a water lubricated Teflon sleeve. A seal 71 is provided where spindle 15 passes through the top wall of vortex chamber 35. Large diameter bearings are provided by the outer surfaces of cylindrical sections 13 and 14 which contact corresponding bearing surfaces 26 and 27 formed by plastic sleeves press-fitted into the housings formed by bearing sections 33 and 34 respectively. These sleeve bearings are provided with passages for water injection and abut against small packing seals which retard sediment from entering and wearing the bearing but are loose enough to permit the water used for lubrication to pass through. Bearing surfaces 26 and 27 thus provide radial support to the rotating assembly.

In operation of the device of FIG. 1, spindle 15 is driven by a suitable power source, such as an electric motor (not shown). Liquid containing particulate material to be separated, such as fine sediment, is supplied to vortex chamber 35. Any gases released from the liquid escape through venting tube 39. The liquid, having acquired a rotational flow pattern with angular momentum and a consequent drop in pressure, exits downwardly through the holes 23 in cylindrical section or member 13 in the rotatable assembly. Thus a flow path is provided for the fluid subdivided into separate streams. Additional angular momentum is supplied to the liquid by impeller blades 20 so that the liquid rotates at the same angular velocity as the inner and outer walls of the annular chamber 24, and thus forms a forced vortex between two synchronously rotating cylindrical surfaces. It is, of course, an essential feature of the forced vortex that there should be practically no relative motion between the different portions of the fluid and the structure of the impeller section is arranged so that kinetic energy is gradually supplied to the inflowing material so that each portion arrives at the separation annulus 24 with the kinetic energy appropriate to its radius. After leaving the vortex chamber 35, the fluid path is directed outwardly between the inner surface of conical portion 11 and the outer surface of the conical portion of hub 28. This path is initially divided into six zones by the longer vanes or blades 20 and subsequently divided into twelve zones by the further six shorter vanes, thus confining the fluid in an array of vane pockets. It is a feature of the present invention that the forced vortex is combined with an axial velocity and as the liquid moves downwards into separating chamber 24, the heavier material migrates to the outer wall and is retained there while the lighter material is removed through passage 25 and outlet vortex chamber 36. Continued downward movement of the liquid leads it to exit through the holes 25 in cylindrical section 14 into vortex chamber 36. The acquired angular momentum of the liquid is given up to impeller blades 21 and further diminished in vortex chamber 36 to appear as pressure in the liquid exiting by pipe 38. Because impeller blades 21 extract energy from the liquid the power required to be supplied to shaft 15 represents only the losses occurring in the apparatus.

The solid material remains positioned against the inner surface of wall 10 while the equipment is operating. It is restrained from downward sliding movement by friction caused by the relatively high reaction force of the wall against the material. When the rotation of the equipment stops, the solids slide downwardly and are removed through the outlet chamber. Thus, the equipment functions in a batch mode of operation. This is particularly suitable for the clarification of fluids with a small solids content since large amounts of fluid flow can be handled between dump periods with relatively low power consumption.

The preferred configuration of hubs or conical sections 28 and 29 has a bulge or protuberance to force the liquid flow further away from the central axis at one section of its downward path. The particular shape of the protuberance controls the radial distribution of fluid axial velocity. Increasing the protuberance reduces the axial velocity at smaller radii adjacent support member 17 and increases the axial velocity towards the outside. In order that any gases released from the liquid should not be trapped under the bulge, passageways 22 are formed in hub 28. Preferably, passageways 22 are formed by a pair of slots symmetrically positioned on opposite sides of the protuberance. It is a significant feature of the structure of this invention that the inlet and outlet distributors, formed by conical portions 11 and 12 and their associated impellers, provide identical profiles of fluid axial velocity in order to avoid relative inward and outward movement of the fluid.

An unequal radial distribution of axial velocity has been found to be particularly useful in separating a light liquid, such as oil, from water. The configuration of protuberances 28 and 29 is enlarged to provide a lower axial velocity adjacent support member 17 thus providing a zone for concentration of the oil. The oil collects along support member 17 and slides upwardly through passageways 22, which are also enlarged in this embodiment, and exits through venting tube 39. The enlarged bulge of protuberance 29 serves an additional function by preventing the oil collected along support member 17 from flowing downardly out of the separating zone. While these changes improve the separator performance for oil removal it will be understood that the increased velocity adjacent cylinder 10 makes the separator less efficient for heavy materials.

The action of the distributors in imparting additional angular momentum to the fluid results in a radial distribution of velocity occurring which takes the form of fluid circulation in the vane pockets. Depending on the viscosity of the fluid supplied to the apparatus, the turbulent circulating motion of the fluid set up in each vane pocket may not be totally attenuated before the fluid moves to the separating zone 24. This unwanted fluid motion may be overcome by providing an increased number of blades 20, resulting in smaller vane pockets and, hence, smaller eddies which decay more rapidly. Alternatively, a perforated plate 72 can be fitted at the outlet of the distributor to the separating zone as shown in FIG. 4. An alternative arrangement, shown in FIG. 5, is to provide the vane pockets with a filling of friction packing 73, held in place by suitable means such as a screen, to force the fluid motion to follow the rotation of the walls. The structures shown in FIGS. 4 and 5 have the possible disadvantage that should the fluid contain large particles, a separate device to remove these particles would be required before the fluid is supplied to the separator.

FIG. 2 illustrates an alternative embodiment of the invention designed for continuous removal of separated sediments. A stationary outer casing is formed by a tubular cylinder 60 integrally attached to conical sections 61 and 62. Upper and lower bearing sections 63 and 64 are formed in the extremities of the conical sections. An inlet vortex chamber 65 having an entry pipe 68 and a venting aperture 58 is attached above bearing section 63 and an exit vortex chamber 66 having an exit pipe 69 is attached below bearing section 64. Suitable supports, not shown, are provided for the outer casing. Cylinder 60 is provided with an outlet orifice 59.

A rotatable assembly is formed by a tubular perforate cylinder 40 integrally connected to vaned conical portions 41 and 42. A tubular support member 47 is connected to the hubs of vaned portions 41 and 42 which terminate in spindles 45 and 46. Sets of impeller blades 50 and 51 are carried between the hubs and outer portions 41 and 42, respectively. Spindle 45 is supported in a bearing 48 carried by a bearing section 67 and terminates in a pulley 52 for connection to a suitable source of driving power. Spindle 46 is supported on a bearing plate 49 having provision for water injection. Additional bearings are formed by the cylindrical ends 43 and 44 of conical portions 41 and 42 which engage water lubricated bearing surfaces 56 and 57 carried in outer casing sections 63 and 64, respectively.

The operation of the apparatus of FIG. 2 is similar to the operation of the apparatus of FIG. 1. That is, liquid containing solids to be separated is supplied through entry pipe 68 to inlet vortex chamber 65. The liquid acquires angular momentum and exits downwardly through annular passage 53. The liquid then acquires additional angular momentum from impeller blades 50 and moves smoothly into the annular chamber formed between perforated cylinder 40 and support member 47. The heavier material moves outwardly through the perforations in cylinder 40 into a further annular chamber 70 formed between the rotating assembly and the stationary casing from where it can be removed via orifice 59. The lighter material proceeds downwardly past the impeller blades through passage 55 into outlet vortex chamber 66 from which it exits via pipe 69. In passing impeller blades 51, energy is absorbed from the fluid, thus reducing the power required at pulley 52. Venting aperture 58 formed in the upper casing of vortex chamber 65 permits any gas entrained with the liquid to escape. As described in connection with FIG. 1, passageways may be formed in the hub of conical section 41 to permit any gas trapped under the bulge to escape.

Chamber 70 is operated under pressure, the flow of sediment being controlled by throttling the exit flow through aperture 59. There is an increased frictional loss with this embodiment since there is a shear zone between rotating cylinder 40 and the almost stationary sediment in chamber 70. The spacing between the conical portions of the rotating and stationary assemblies is kept as small as possible to prevent the sediment flowing towards the bearings.

FIG. 3 shows an embodiment of the present invention particularly adapted for the separation of gases of differing densities. Outer casing 80 is of cylindrical configuration and positioned on suitable supports, not shown. A gas exit pipe 81 is provided in the lower part of casing 80 and bearing sections 82 and 83 are formed in the upper and lower parts of the casing. A rotatable hollow structure is formed by shell 84 carrying inwardly directed sets of vanes 85 and 86 terminating on a closed inner surface 96. Shell 84 is supported for rotation about its axis by thrust bearing surface 90 formed in a lower extension of casing 80. Shell 84 is formed with upper and lower tubular cylindrical sections 91 and 92 which cooperate with bearings 93 and 94 held in bearing sections 82 and 83, respectively. A driving pulley is attached to shell 84 around cylindrical section 91. Shell 84 is formed with a re-entrant section 87 defining an annular collection chamber 88 with an exit orifice 89. The structure provides a stationary collector chamber 79 between outer casing 80 and rotatable shell 84.

In operation, gas enters downwardly from a fixed pipe 76 into cylindrical section 91, diverges outwardly from the axis on meeting surface 96 and acquires angular velocity close to that of rotating shell 84 from blades 85. As the gas passes into the separating zone, the heavier gas migrates to the outer wall and enters re-entrant section 88 whence it exits through orifice 89. Lighter gas remains closer to the axis of the separator and exits through cylindrical section 92. Orifice 89 is much smaller than orifice 81. This maintains a relatively low pressure in stationary collector chamber **79** and avoids problems at bearings **93** and **94.**

It has been found that some turbulence can be caused in the separating annulus **24** by the transfer of material from one radius to another during the separating operation and also by machine vibrations and motor speed oscillations. FIGS. **7** and **8** show a modification of the apparatus of FIG. **1** designed to reduce this turbulence by providing additional friction surface in the separating annulus. Specifically, support member **17** is provided with a plurality of rods **74** extending outwardly towards the inner wall of cylinder **10** but, preferably, stopping about one-half inch short thereof. Preferably, the rods extend completely through the hub and are brazed thereto. Since support member **17** is keyed or otherwise rigidly fixed to hubs **28, 29** the rods rotate synchronously with the fluid and cylinders. This provides a friction surface to suppress turbulence in the separating zone but permits sediment collected against the inner wall to be dislodged for removal in the surge of fluid occurring when the equipment stops. An alternative structure, shown in FIG. **9**, uses longitudinally extending vanes **75** attached to member **17** to inhibit angular fluid movement relative to the steady rotation established in the separating annulus. Preferably the vanes **75** are attached by welding, brazing or soldering.

An additional problem occurs when separating heavy solids such as are found in metallurgical sludges. The sediment obtained in such separating operations packs in a dense bed against the inner wall of cylinder **10** and is not dislodged by the surge of fluid when the equipment stops. The structure shown in FIGS. **10** and **11** overcomes this problem. Support member **17***a* is supported by pins **78** received in corresponding recesses in top and bottom hubs **28** and **29** so that it is free to rotate relative to cylinder **10.** As in the embodiment of FIG. **9**, longitudinally extending vanes **75** are attached to member **17***a*.

In operation, the vaned assembly **17**a will lag behind the rotation of cylinder **10** during start-up but will be brought to synchronous speed by the action of the rotating fluid. When the equipment is stopped, the inertia both of the rotating fluid and the assembly itself results in continued rotation of the vanes and a consequential fluid agitation to disperse the sludge.

Two of the vanes, identified as **98** in FIG. **10,** may be extended to within one-sixteenth inch of the inner surface of cylinder **10** and have attached to their tips a sharp blade **99** having a forward curvature in the direction of rotation. Blades **99** are preferably formed of metal but may also be formed from plastic or rubber. The additional scraping action provided by blades **99** aids in dislodging sludge, however it will be noted that the arrangement in which the vanes are not provided with blades **99** but the assembly is arranged for free rotation is also effective for this purpose.

I claim:

1. A method for producing a forced vortex in a fluid contained in a separating annulus defined by two synchronously rotating cylindrical surfaces comprising the steps of:

establishing a rotational flow pattern in said fluid,

providing a flow path for said fluid maintaining said rotational flow pattern and subdivided into a plurality of separate streams corresponding portions of each having substantially equal axial velocity,

providing flow path segments of radial extend increasing up to the dimension of said annulus to impart additional rotational kinetic energy to the fluid while maintaining corresponding portions of each stream at substantially equal axial velocity, and

recombining the streams at least adjacent the periphery of said separating annulus while maintaining the angular and axial velocities of adjacent portions of the fluid in the annulus substantially equal thereby forming a forced vortex.

2. A method as set out in claim **1** wherein the step of providing flow path segments of increasing radial extent is the step of directing fluid flow between coaxial cones.

3. A method as set out in claim **2** wherein the step of providing a subdivided flow path is the step of providing vanes extending between said coaxial cones, the assembly rotating synchronously with said cylindrical surfaces.

4. A method as set out in claim **3** further including the step of providing friction packing in the subdivided flow path.

5. A method as set out in claim **3** further including the step of passing each subdivided stream through a perforated plate rotating with said cones immediately prior to entering said separa annulus.

6. Apparatus for producing a forced vortex in a fluid contained in a separating annulus defined by two synchronously rotating cylindrical surfaces comprising:

first means for establishing a rotational flow pattern in said fluid,

second means defining a flow path for said fluid maintaining said rotational flow pattern and subdivided into a plurality of separate streams corresponding portions of each having substantially equal axial velocity,

third means including flow path segments of radial extent increasing up to the dimension of said annulus imparting rotational kinetic energy to each of said separate streams while maintaining corresponding portions of each stream at substantially equal axial velocity, and

means recombining said separate streams at least adjacent the periphery of said separating annulus while maintaining adjacent portions of the fluid in the annulus with substantially equal angular and axial velocities thereby forming a forced vortex.

7. Apparatus as set out in claim **6** wherein the radial boundaries of said flow path segments in said third means are defined by two coaxially positioned cones.

8. Apparatus as set out in claim **7** wherein said third means includes a plurality of vanes extending between said cones, said vanes and cones rotating synchronously with said cylindrical surfaces.

9. Apparatus as set out in claim **8,** wherein said first means is a vortex chamber and said second means is a cylindrical member with axially extending circumferentially positioned holes communicating the outlet of said vortex chamber with passages between said vanes and rotating synchronously with said cylindrical surfaces.

10. Apparatus as set out in claim **8,** further comprising a chamber in communication with said separating annulus to receive fluid passing therefrom, a further plurality of vanes in said chamber extracting energy from the rotating fluid and means mechanically connecting the further plurality of vanes with the first-mentioned plurality of vanes.

11. Apparatus as set out in claim 7 wherein the inner of said coaxially positioned cones is formed with a protuberance to avoid increased fluid axial velocity at points adjacent the inner cylinder.

12. A vortical separator for providing heavy and light fractions of a fluid comprising:

an inlet vortex chamber and an outlet vortex chamber each having an inlet and an outlet,

an inner and an outer cylinder rotating in synchronism and defining a separating annulus therebetween,

first and second pairs of coaxially positioned cones, one cone of each pair being connected to the inner cylinder and one to the outer cylinder thereby defining radially expanding flow paths to and from the separating annulus,

a pair of cylindrical members with axially extending circumferentially positioned holes one communicating the outlet of the inlet vortex chamber with the associated radially expanding flow path and the other communicating the inlet of the outlet vortex chamber with the associated radially expanding flow path, said cylindrical members providing a division of the flow path into separate streams,

a first and second plurality of vanes extending between the cones of each pair thereby continuing the division of the flow path into separate streams,

said cones, cylindrical members and vanes being rigidly connected to said cylinders for rotation as a unit.

13. A separator as defined in claim 12 wherein said outer cylinder is perforate and a stationary outer casing is provided to retain separated dense material.

14. A separator as defined in claim 12 wherein said outer cylinder has a re-entrant section for the separation of dense gases.

15. Apparatus as set out in claim 8 further including friction packing between said vanes.

16. Apparatus as set out in claim 8 wherein said means recombining said separate streams comprises a perforated plate extending between said cones and rotating therewith.

17. A method for producing a forced vortex in a fluid contained in a separating annulus defined by two synchronously rotating cylindrical surfaces comprising the steps of:

establishing a rotational flow pattern in said fluid,

providing a flow path for said fluid maintaining said rotational flow pattern and subdivided into a plurality of separate streams corresponding portions of each having substantially equal axial velocity,

providing flow path segments of radial extent increasing up to the dimension of said annulus to impart additional rotational kinetic energy to the fluid, and

recombining the streams at least adjacent the periphery of said separating annulus while maintaining the angular velocities of all portions of the fluid in the annulus substantially equal thereby forming a forced vortex having an axial velocity of predetermined profile.

18. A method as set out in claim 17 wherein the step of providing flow path segments of increasing radial extent includes the step of causing the flow path segments to flow over radial protuberances thereby controlling the profile of axial velocity.

19. A method as set out in claim 18 including the step of providing enlarged protuberances whereby the axial velocity is reduced adjacent the inner cylindrical surface and increased adjacent the outer cylindrical surfaces.

20. Apparatus for producing a forced vortex in a fluid contained in a separating annulus defined by two synchronously rotating cylindrical surfaces comprising:

first means for establishing a rotational flow pattern in said fluid,

second means defining a flow path for said fluid maintaining said rotational flow pattern and subdivided into a plurality of separate streams corresponding portions of each having substantially equal axial velocity,

third means including flow path segments of radial extent increasing up to the dimension of said annulus imparting rotational kinetic energy to each of said separate streams, and

means recombining said separate streams at least adjacent the periphery of said separating annulus while maintaining all portions of the fluid in the annulus with substantially equal angular velocities thereby forming a forced vortex having an axial velocity of predetermined profile.

21. Apparatus as set out in claim 20 wherein the flow path segments of increasing radial extent include a radial protuberance affecting the profile of axial velocity.

22. Apparatus as set out in claim 21 having an enlarged protuberance whereby the axial velocity is reduced adjacent the inner cylindrical surface and increased adjacent the outer cylindrical surface.

23. Apparatus as set out in claim 20 further including vanes extending from the inner cylindrical surface towards the outer cylindrical surface.

24. Apparatus as set out in claim 20 further including rods extending from the inner cylindrical surface towards the outer cylindrical surface.

25. Apparatus as set out in claim 23 wherein said inner cylindrical surface and vanes are arranged for free rotation.

26. Apparatus as set out in claim 25 wherein some of said vanes have scraper blades bearing against the outer cylindrical surface.

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