Dec. 15, 1959 V. RAKOWSKY 2,917,173

CENTRIFUGAL METHOD AND APPARATUS FOR SEPARATING SOLIDS

Filed Aug. 21, 1957

FIG. 1

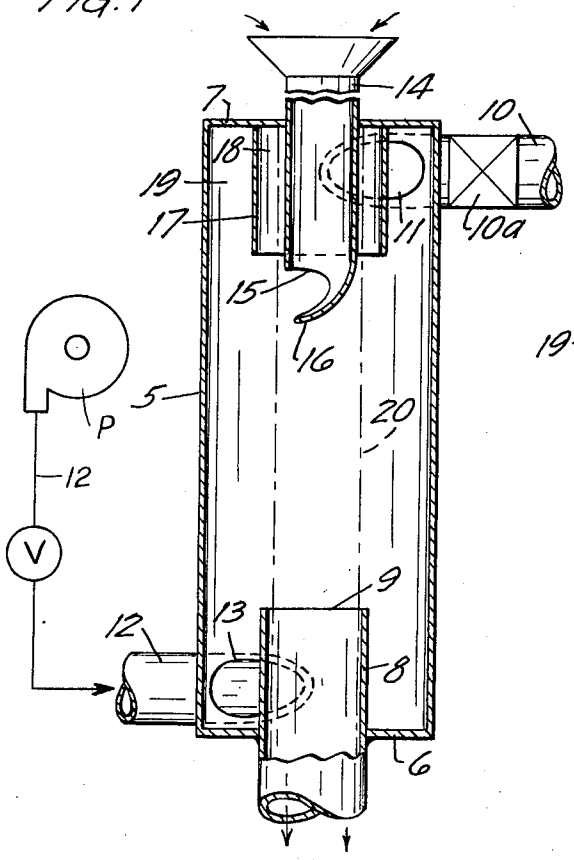


FIG. 3

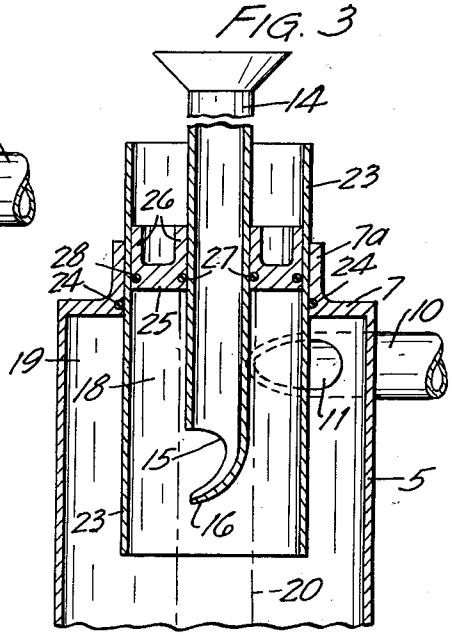


FIG. 2

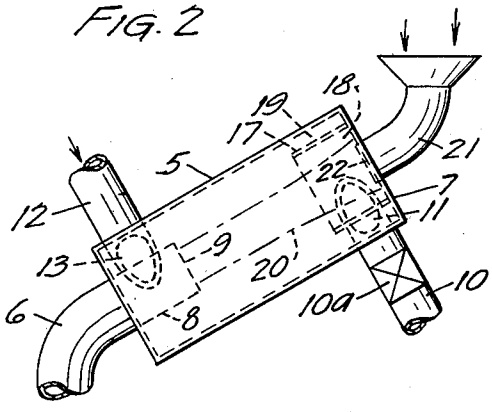
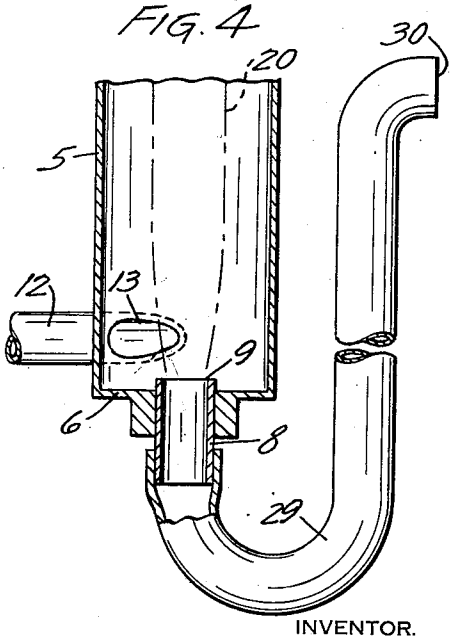


FIG. 4



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11 Claims. (Cl. 209—172.5)

This invention relates to the separation of heterogeneous mixtures of solid particles into fractions which differ in specific gravity and contemplates both processes and apparatus therefor. More specifically, the invention is concerned with improvements in making separations by introducing the mixture of particles into a fluid body which is caused to rotate in a confined space by feeding a stream of the fluid tangentially into the space and continuously discharging part of the fluid, together with the lower gravity particles, axially from one end of the space and discharging the remainder of the fluid and higher gravity particles from the periphery near the other end of said space.

The present invention is an improvement on that described in my Patent No. 2,725,983, granted December 6, 1955, for Whirlpool Separation of Particulate Materials. In that patent I have discussed different ways in which gravity separations have been carried out and have disclosed an improved method and apparatus which includes the introduction of a fluid medium into an elongated confined space and causing the fluid to flow spirally around and through the space at an angular velocity sufficient to create an open free vortex. The particulate material to be separated into fractions is fed into the inner face of the vortex and the input pressure and flow rate are maintained sufficiently high to cause two concentric open free vortices rotating in the same direction, the inner one moving longitudinally toward the axial discharge and the outer one moving longitudinally in the opposite direction. Further, according to this method, the particles of feed material of lower gravity than the selected gravity of separation are discharged axially from the confined space at one end thereof, i.e., the lower end, and the higher gravity fraction is discharged with the fluid discharged from the opposite or upper end of the space.

In general, the present invention is similar to that of my Patent No. 2,725,983 in the utilization of two concentric open free vortices rotating in the same direction but with the inner vortex moving longitudinally toward the axial discharge and the outer one moving longitudinally in the opposite direction. Further, according to both inventions, the fluid medium is introduced tangentially near one end of the confined space, the lower gravity particles are discharged axially from the same end and the heavier particles are discharged through a peripheral discharge near the opposite end of the confined space. There are important differences, however, between the present invention and that of my issued patent. In the practice of the latter it developed that when the input pressure and flow rate is increased sufficiently to produce superatmospheric pressure in the upper end of the separatory vessel, the fluid medium will rise in the feed opening or pipe for the particulate material and, under some circumstances, may be discharged from the upper end of the separator. This difficulty is overcome by the present invention. As a further result of these improvements I make it feasible to place the separatory vessel on its side or with its axis in suitable inclined positions.

It also appears that when superatmospheric pressures are developed in the peripheral discharge end of the separatory vessel there is a tendency to intermix the particulate material carried in the inner and outer vortices in the annular zone adjacent to the peripheral discharge. Thus some of the heavier particles may be deflected by the upper end wall of the separator into the inner downwardly flowing vortex and some of the lighter particles may be deflected into the outer vortex to be carried out with the heavy fraction discharge and medium through the peripheral discharge conduit. Such mixing of the particles from the inner and outer vortices adversely affects the sharpness of separation of the lighter and heavier particle fractions.

It is, therefore, an object of the present invention to improve on this method of separation and the apparatus used therefor in such a way as to increase the sharpness of separation and to effectively guard against the discharge of the liquid medium through the feed pipe when pressures substantially above atmospheric are created in the peripheral discharge end portion of the confined space of the separator.

A particular object is to prevent, in a method of the class described, radial flow from causing the mixing of the particles carried in the inner and outer vortices in the annular zone adjacent to the discharge end of the outer vortex.

A further object is to provide in apparatus of the class described an annular baffle surrounding the inlet opening for particulate solid material and so spaced from this opening and from the peripheral discharge opening as to separate the discharge end portion of the outer concentric vortex from the adjacent portion of the inner vortex.

Another particular object is to provide a separatory vessel having an elongated tubular body and an end closure wall formed with a central opening through which the material to be separated is fed axially into the body in combination with a coaxial tubular baffle surrounding the feed opening and spaced from both this opening and the tubular body, whereby fluid under superatmospheric pressure in the vessel is prevented from passing out through the feed opening when the vessel is disposed with its axis in any selected angular position.

In the drawing cylindrical separatory vessels are shown by way of example but it is to be understood that the vessel may be substantially conical or of truncated cone shape, or of partially conical and partially cylindrical shape within the spirit of my invention.

Further discussion of the present invention may be more easily followed by reference to the accompanying drawing in which:

Figure 1 is a central vertical sectional view showing, diagrammatically, one form of separator;

Fig. 2 is a diagrammatic side elevational view showing modifications of the separator which adapt it for use with its axis substantially horizontal or at an angle having a vertical component;

Fig. 3 is a diagrammatic central vertical sectional view showing certain modifications of the upper portion of the separator; and

Fig. 4 is a diagrammatic vertical sectional view showing modifications of the lower portion of the separator.

Referring to Fig. 1 illustrating one form of separator utilizing the principles of my invention, a tubular element 5 defines a confined space in which the separating action takes place. Element 5 is preferably circular in cross section but may vary otherwise in proportions and shape. A first end closure 6 is suitably secured to the tubular element 5 at its normally lower end, and a second end closure 7 is secured to the opposite end of the element 5. Communicating with the confined space through a central opening in the end closure 6 is a second tubular element 8 having an intake opening 9 coaxially disposed in relation to the element 5 for discharging fluid medium and solids. Adjacent the end closure 7 a peripheral discharge conduit 10 has a port 11 communicating with the confined space. The rate of discharge through the conduit 10 may be controlled by a flow control device 10*a* which may be an elastic iris diaphragm, valve or other suitable means. For installations where coarse ore is to be discharged through the conduit 10 constriction of this conduit may not be feasible. For such installations valve means 10*a* may be eliminated and control of flow through the peripheral discharge may be effected by providing a flexible conduit 10 of the gooseneck type such as that shown in Fig. 4 for the axial discharge control. By changing the elevation of the outlet end of the flexible conduit the rate of discharge may be adjusted.

Fluid medium is introduced into the confined space through a conduit 12 and port 13. This port is preferably located near the end closure 6 and is disposed to introduce the medium tangentially into the confined space. Medium is thus supplied at such pressure and flow rate as to cause two concentric open free vortices rotating in the same direction in the confined space, the inner one having a longitudinal movement toward the intake opening 9 of the element 8 and the outer one a longitudinal movement toward the end closure 7. Means for supplying the fluid medium at a controlled rate and under suitable pressure to the conduit 12 are shown schematically in Fig. 1 as a pump P and a valve V interposed in an extension of the conduit 12.

Mixtures of particulate solid materials to be separated into fractions of differing average specific gravities are introduced into the confined space through a feed pipe 14 which is preferably coaxially disposed in relation to the tubular element 5 and communicates with the confined space through a centrally located opening in the end closure 7. For installations where the separator is supported with its axis substantially vertical, as shown in Figs. 1 and 3, the lower end of the feed pipe 14 is provided with an opening 15 and a deflecting element 16 adapted to direct the feed material into the inner face of an open free vortex extending along the axis of the separator.

Projecting into the confined space from the end closure 7 in coaxial relation to the feed pipe 14 and tubular element 5 is a third tubular element 17. This element 17 constitutes an annular baffle which is spaced radially outward from the feed pipe 14 and inward from the peripheral discharge port 11. Element 17 thus separates an annular chamber 18 surrounding the feed pipe 14 from an annular chamber 19 at the outer side of the baffle, the latter chamber being in continuous communication with the port 11. End closure 7 coacts with element 17 to reverse the direction of flow of the inner vortex longitudinally of the separator while element 17 prevents direct radial flow between chamber 18 and chamber 19.

In the operation of the separator shown in Fig. 1, separatory medium is introduced into the confined space defined by the element 5 through the conduit 12 and port 13 tangentially. This imparts rotary motion to the fluid medium as it passes into and upwardly within the confined space. The medium is introduced under sufficient pressure and in sufficient volume to fill the confined space and produce pressure at least slightly above atmospheric pressure in the end of the confined space adjacent to the end closure 7. That portion of the rotating fluid medium which enters the annular chamber 18 is deflected from the end closure 7 and caused to reverse its direction of flow thereby forming the inner of the concentric vortices which moves longitudinally toward the axial discharge opening 9. The inner face of the inner vortex, indicated by the numeral 20, coincides with the outer face of an open column of air which normally extends from the axial discharge opening 9 to the end closure 7 in radially outwardly spaced relation to the feed pipe 14 or open discharge end thereof. At least a portion of the outer concentric vortex is discharged through the port 11 and conduit 10 while the remainder is directed inwardly and then downwardly along the baffle element 17 to join the inner vortex below element 17. The inner or core portion of the inner vortex is discharged through the axial opening 9.

A further and surprising result of the coaction between the baffle element 17 and end closure 7 within the chamber 18 is the exclusion of the fluid medium from the feed pipe even when pressures substantially above atmospheric are created in the fluid medium adjacent to the feed pipe or in the feed receiving end of the separator. This has been demonstrated by operation of my improved separator with its axis in various angular positions causing relatively high hydrostatic pressure in the feed pipe end. Specifically the separator may be operated with its axis at various oblique angles as indicated in Fig. 2, or with its axis horizontal, or even in an inverted position wherein the feed pipe inlet opening to the confined space is at a lower elevation than the axial discharge opening 9.

In the modification shown in Fig. 2 the tubular element 5 is disposed with its axis at approximately 30 degrees to the horizontal. Particulate material to be separated is fed into the separator through a feed pipe 21 discharging into a central opening 22 in the end closure 7. Opening 22 is coaxial with and spaced radially inward from the tubular baffle element 17. It will be evident that the other elements of the separator shown in Fig. 2 are similar to those shown in Fig. 1 including the axial discharge opening 9, tubular element 8, conduit 10 and port 11, constituting the peripheral discharge, means for supplying medium under pressure comprising conduit 12 and port 13 and means 10*a* for controlling the rate of discharge through conduit 10.

During operation of the modification shown in Fig. 2, medium is introduced through conduit 12 under sufficient pressure and in sufficient volume to fill the confined space and produce superatmospheric pressure in the end of the confined space adjacent to the end closure 7. The medium is thereby caused to form inner and outer open free vortices surrounding a central core of air similar to the vortex having the inner face 20 of Fig. 1. The rate of flow is adjusted to properly proportion the flow through the axial discharge opening 9 and peripheral discharge port 11. Particulate material to be separated is then fed through the feed pipe 21 and enters the confined space through the opening 22. Since the separator is in an inclined position, the feed material passes by gravity into the inner face 20 of the inner vortex.

Baffle element 17 prevents radial flow of medium and feed material from the chamber 18 directly into annular chamber 19 communicating with the peripheral discharge port 11. The heavier fractions of feed material upon reaching the lower periphery of baffle element 17 are free to move radially outward into the outer vortex flowing upwardly into the chamber 19. At the same time a major portion of the lighter material and medium received in the chamber 18 is deflected from the end closure 7 within this chamber to reverse its direction of flow

and to form the inner vortex moving toward the axial opening 9. Since the lighter material cannot move directly outward into the outer vortex until such material has been carried past the lower periphery of the baffle element 17, a minimum of the lighter feed material is discharged with the heavier fractions through the peripheral discharge port 11. By suitable adjustment of the flow control means 10*a* the proportions of material which pass out through the peripheral discharge and through the axial discharge may be regulated.

By employing the baffle element 17, I obtain sharper separation between the lighter and heavier fractions and also prevent the fluid in the feed pipe end of the separator from rising in or passing out through the feed pipe 21. These desirable results are obtained even when the opening into the confined space at the delivery end of the feed pipe is located flush with the inner surface of the end closure 7 and irrespective of the angular position of the axis of the separator. As long as the feed inlet opening is spaced radially inward from the annular baffle element 17, the annular end closure 7 within the chamber 18 deflects the inner vortex away from the feed inlet opening and toward the axial discharge opening 9.

In Fig. 3 I have illustrated modifications of the normally upper portion of the separator wherein the positions of the annular baffle member, end closure for chamber 18 and feed pipe may be adjusted along the axis of the separator. An elongated tubular baffle element 23 is slidably supported in a bearing 7*a* formed in the end closure 7. To seal this joint a resilient pressure seal ring 24 is confined in an annular recess formed in the end closure 7 to slidably engage the outer periphery of the element 23. Thus the extent of the tubular element 23 within the tubular element 5 may be adjusted for separations of various types of materials and under various operating conditions, including various pressures and flow rates of medium and rate of feed of particulate material.

Another modification shown in Fig. 3 comprises a movable annular wall member 25 of the chamber 18 which is adjustable axially of the inner periphery of the tubular element 23 and in engagement with the outer periphery of the feed pipe 14. This end wall member 25 has annular elongated bearing portions 26 adapted to slidably engage the element 23 and feed pipe 14. An elastic pressure seal ring 27 is provided for engagement with the periphery of the feed pipe 14 and a similar ring 28 seals the sliding joint between the wall member 25 and inner periphery of the tubular element 23. By this modification I provide an end closure member 25 which is adjustable axially of the separator independently of the adjustable tubular element 23 and feed pipe 14. The length of the chambers 18 and 19 may thus be changed, one independently of the other, and discharge opening 15 and deflector 16 may be located at selected positions either within the baffle element 23 or at or below the lower periphery thereof. Fig. 3 shows the separator with its axis vertical, but it will be understood that it may be supported with its axis in various angular positions with only minor changes in the feed pipe and axial discharge conduit, e.g., as indicated in Fig. 2.

Fig. 4 illustrates diagrammatically modifications of the the lower end portion of the separator wherein the axial discharge opening is located approximately flush with the inner side of the lower end closure 6 and the port 13 for introducing the fluid medium is located at an elevation above the axial discharge opening. A further modification is the provision of suitable means for adjusting the rate of flow through the axial discharge conduit. Exteriorly of the separator the axial discharge pipe 8 is fitted with a flexible conduit 29 having an outlet end 30 adapted to be placed at various elevations to control the rate of discharge through the opening 9. Tubular element 8 may be made adjustable longitudinally in a bearing formed in the end closure 6 to provide adjustment of the elevation of the axial discharge opening. Such adjustment is more fully described in my Patent No. 2,725,983.

Sharpness of separation is improved by proper selection of the diameter of the tubular baffle element 17 or 23 interposed between the point of feed or feed pipe and peripheral discharge. When the particulate material to be separated is preponderantly of the lighter fraction to be discharged through the axial discharge a tubular element 17 (or 23) of relatively large diameter should be provided. Otherwise when the feed material is preponderantly of the heavier fraction the baffle element should be of relatively small diameter, being relatively close to the feed pipe and relatively widely spaced from tubular element 5 and port 11. When thus properly proportioned the annular baffle element prevents the mixing by radial flow of selected portions of the outer and inner vortices within the upper or feed end of the separator.

The several advantageous features of the invention described in my Patent No. 2,725,983 are embodied in the present invention. Both inventions make it feasible to operate with feed material of a wide range of sizes. For example, feed particle sizes of minus 1½ inches, plus 40 mesh may be treated successfully. In this respect the present invention is comparable with the prior sink and float systems wherein a large static body of relatively quiescent separatory medium is employed. However, such systems possess several inherent disadvantages which are not common to the present invention. Among these are the physical size and quantity of apparatus required and relatively expensive medium solids required for high density separations, i.e., those substantially above s.g. 2.5.

As a result of the forces exerted by the spiral flow in my process, it is possible to accomplish a separation of the particulate material into fractions at an apparent parting density higher than the specific gravity of the incoming separatory fluid. These forces also reduce the viscosity of the separatory medium and thus increase the rate of separation into the light and heavy fractions.

When compared with the practice in cyclonic systems where velocities must be maintained sufficiently high to produce an upwardly rising inverted vortex, much lower velocities are sufficient for the present process. I thus reduce the cost of pumping and cleaning equipment for the medium and greatly reduce the abrasive effect of the medium solids and ore particles on the interior surfaces of the separator. My invention has the further advantage over cyclonic systems in that the separations may be made with feed material of a wider range of sizes. It is not considered feasible to treat ores coarser than ¼" in a cyclone separator but ores of particle sizes up to 1½" or coarser may be treated without difficulty according to my invention.

The present invention has large capacity for an installation of any selected size. For example, a small pilot plant having a separatory vessel 8" in diameter and 19" long is capable of treating than than 5 tons of ore per hour. For this separator the annular baffle element 17 is 4" in diameter and extends down from the peripheral discharge end approximately 4", the axial discharge opening is 3" wide, the concentrated discharge conduit a 2" pipe and a 2" feed pipe for the particulate material has a lateral deflector at its lower end, as indicated in Fig. 1. A 3" Wilfley pump driven by a 15 h.p. variable speed motor was used to feed medium to the inlet conduit 12. This unit was used in obtaining the results shown in the several examples hereinafter described.

EXAMPLE 1

Mesabi iron ore

Tests were run on Mesabi iron ores using ferrosilicon mixed with magnetite as the medium solids. The ore samples tested were in the size range, minus ⅞" plus 3/16" and had been treated by the static heavy media proc-

ess employing drag receptacles. These tests were made with the object of raising the iron content and reducing the silica content. The following illustrative results were obtained:

Test No.	Ore Feed, Percent Fe	Specific Gravity			Concentrates, Percent			Percent Fe Recov.	Tailings, Percent		
		Inlet Med.	Conc.	Tail	Wt.	Fe	SiO_2		Wt.	Fe	SiO_2
1	51.30	2.86	3.14	2.74	68.15	59.33	10.28	78.81	31.85	34.13	45.63
2	51.41	2.86	3.14	2.74	77.61	59.82	11.16	85.77	22.29	32.83	47.84

EXAMPLE 2

Anaconda manganese ore

Another series of tests were conducted using a similar separator on Anaconda manganese ore. The following illustrative results were obtained:

Test No.	Feed, Percent Mn	Specific Gravity			Percent Mn		Percent	
		Med.	Conc.	Tail	Conc.	Tail	Extraction	Discard
3	5.30	2.53	2.54	2.50	10.22	1.39	35.43	55.63
4	5.69	2.57	2.84	2.52	18.48	1.52	79.85	75.41
5	5.61	2.57	2.58	2.56	10.78	1.39	86.39	55.00
6	5.57	2.57	2.58	2.56	10.78	1.08	89.50	53.85

For tests 3, 5 and 6 the medium solids were minus 200 mesh magnetite and for test No. 4 minus 200 mesh ferrosilicon. The ore sample used as feed for test No. 3 was sized at minus ½" plus 40 mesh and for the other tests of this series the feed was minus ½" plus 2 mm. It will be noted that the specific gravity of the medium inlet ranged from 2.53 for test 3 to 2.57 for the other tests. For comparison, heavy liquid tests conducted on this same ore in a static separator indicated that a medium having a specific gravity of 2.8 was required to obtain comparable results.

EXAMPLE 3

Using the same separator another series of tests was run on zinc-lead ores and on a low-grade zinc ore with the following results:

Test No.	Feed Ore Assay, Percent	Specific Gravity			Percent Weight		Extraction	Percent Discard
		Med.	Conc.	Tail	Conc.	Tail		
7	2.27 Zn .51 Pb	2.53	2.54	2.52	Zn 15.30 Pb 6.02	0.18 .15	86.84 Zn 75.73 Pb	92.79
8	1.54 Zn 0.44 Pb	2.53	2.55	2.52	Zn 21.56 Pb 8.08	0.42 0.01	74.12 Zn 97.83 Pb	94.71
9	1.22 Zn .588 Pb	2.52	2.53	2.51	Zn 5.00 Pb 2.83	0.30 .04	80.33 Zn 94.55 Pb	80.31
10	.754 Zn	2.55	2.58	2.52	Zn 5.34	0.34	5.864	91.72
11	.86 Zn	2.52	2.53	2.51	Zn 4.40	0.32	67.83	86.16

For test 7 the ore feed was sized at minus ¾" plus 2 mm., that for tests 8 and 9, minus ¾" plus 40 mesh and for tests 10 and 11, minus ½" plus 2 mm. It will be evident that the ore treated in tests 10 and 11 was a low grade zinc ore. These feed samples were tailings that had been discarded after treatment in a standard zinc field jig plant. Heavy liquid tests on these ores in a static separator indicated that a medium of 2.63–2.65 is required to obtain comparable results.

Additional tests were made with my separator supported with its axis horizontal and inclined at various angles. These tests demonstrated the surprising effectiveness of my annular baffle element in preventing the discharge of the separatory fluid through the feed pipe and in preventing the mixing of the particles carried in the inner and outer vortices near the peripheral discharge end of the separator when pressures above atmospheric are created in the feed end of the separator. Early tests indicate that excellent results are obtained with the axis at an incline of 45 degrees whereby the outer vortex has a substantial upward component of movement and the feed flows by gravity into the inner face of the inner vortex.

I claim:

1. A device for separating mixtures of particulate solid materials into fractions having different rates of flow through fluids under contrifugal force which device comprises, a first tubular element defining an elongated confined space having a longitudinal axis and first and second end closures, a second tubular element communicating with said confined space through an opening in said first end closure and having an intake end opening to said confined space coaxially with said first tubular element for discharging fluid medium and solids, said first tubular element having a first port communicating with the periphery of said confined space near said first end closure and a second port communicating with said confined space near said second end closure, means for introducing fluid medium tangentially into said confined space through one of said ports whereby to produce outer and inner concentric open end free vortices rotating in the same direction in said confined space, means for discharging fluid medium and solids through the other of said ports, said second closure having a centrally located feed opening, feeding means for introducing a mixture of particulate materials into said confined space through said feed opening, and a third tubular element projecting from said second end closure, in radially outwardly spaced relation to said feed opening and in radially inwardly spaced relation to said second port, said third tubular element extending a substantial distance axially from said second end closure and constituting a baffle between the outer concentric vortex and the adjacent portion of the inner concentric vortex.

2. A device according to claim 1 in which said means for introducing fluid medium tangentially into said confined space is connected to said first port and said means for discharging fluid medium and solids is connected to said second port.

3. A device in accordance with claim 1 in which said third tubular element extends a substantial distance axially within said first tubular element from said second end closure.

4. A device according to claim 2 in which said feeding means comprise a feed conduit having a lateral deflecting element at the lower end thereof formed to impress a lateral component to the materials on introduction.

5. A device according to claim 1 in which said feeding means project into said confined space a distance at least equal to the extent of said third tubular element along said space.

6. A device according to claim 1 in which said means for introducing fluid medium includes means for maintaining the input pressure and flow rate of the medium sufficiently high to create superatmospheric pressure at the inner side of said second end closure.

7. A device according to claim 1 in which said third tubular element is slidably connected to said second end closure for movement axially of said first tubular element whereby the extent of said third tubular element within said confined space may be adjusted.

8. A device according to claim 1 in which said feeding means are elongated axially within said first tubular element and slidably connected to said second end closure for movement axially of said first tubular element whereby the extent of said feeding means within said confined space may be adjusted.

9. A device in accordance with claim 7 in which an annular portion of said second end closure between said feed means and third tubular element is movable along the axis of the confined space whereby the position of said annular portion relative to the third tubular element and feed means may be adjusted.

10. A device in accordance with claim 1 in which said first, second and third tubular elements are circular in cross section and have a common axis which is inclined, the second end closure being at a higher elevation than the first end closure.

11. A device according to claim 1 wherein the axes of said tubular elements are substantially vertical.

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