Nov. 2, 1954 H. R. BRAMEL 2,693,280

SEPARATING APPARATUS

Filed Nov. 8, 1949 2 Sheets-Sheet 1

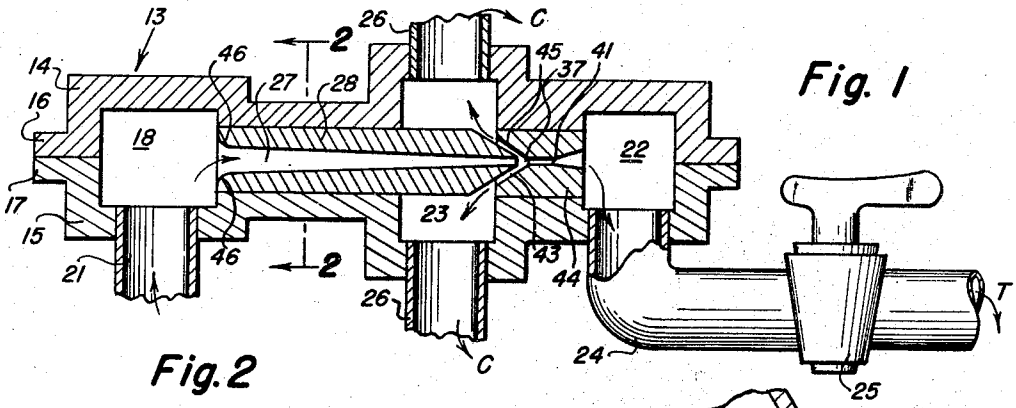


Fig. 1

Fig. 2

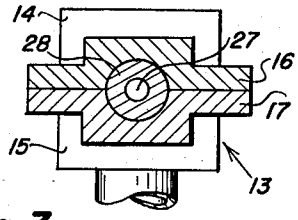
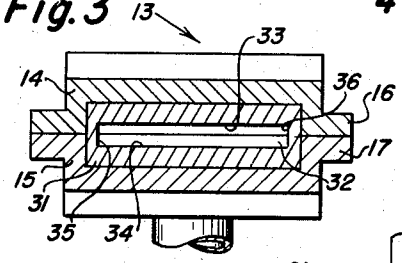


Fig. 3



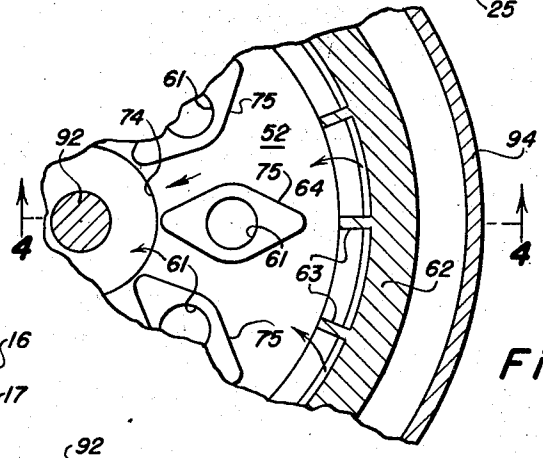


Fig. 5

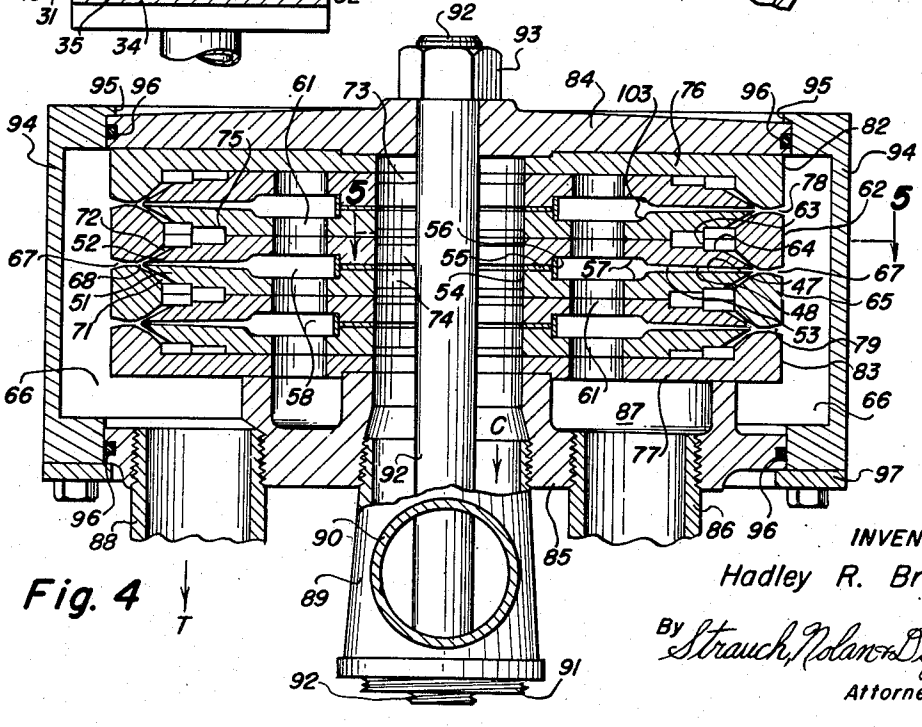


Fig. 4

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SEPARATING APPARATUS

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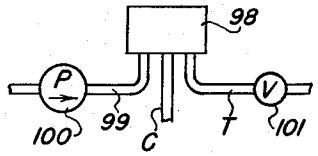


Fig. 6

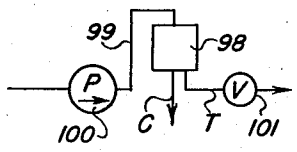


Fig. 7

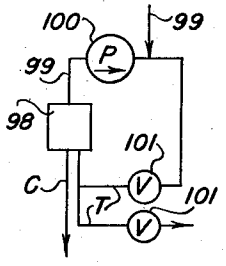


Fig. 8

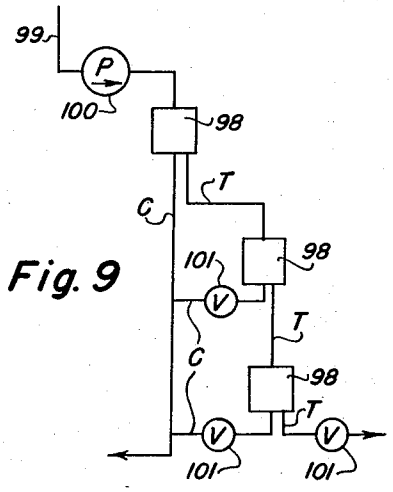


Fig. 9

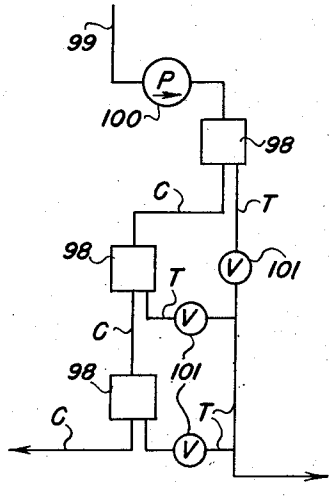


Fig. 10

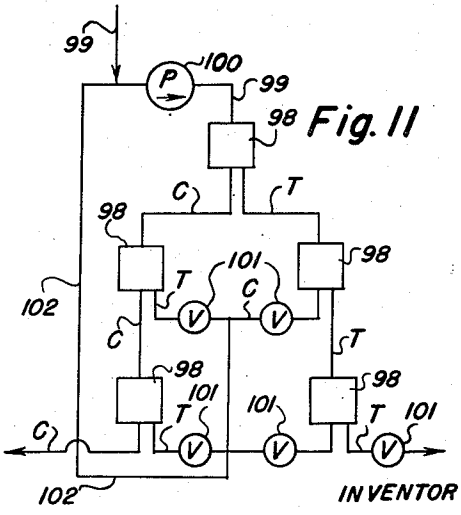


Fig. 11

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SEPARATING APPARATUS

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Application November 8, 1949, Serial No. 126,188

2 Claims. (Cl. 210—51)

My invention is related to the processing of materials, and is particularly suited to the continuous separation of the physical components of fluid suspensions as, for example, slurries, slips, pulps, juices, milks, emulsions, sludges, mists, dust bearing gases, the control of waste products and the like.

The separatory operations to which this invention may be adapted include the classification of suspended solids according to size, sorting according to shape, sorting according to densities, the thickening or concentration of suspended material, the clarification of fluids, and various combinations of these operations as, for example, thickening, together with clarification.

These operations are now commonly performed by machines such as hydraulic, rake and spiral classifiers, elutriators, settling tanks of various forms in which settling may occur quiescently or with stream motion, Dorr type thickeners, batch and continuous centrifuges, cyclones, screens of stationary and dynamic type filters of continuous or discontinuous kind, and various types gravity concentrators and sedimentation devices.

To this broad and intricate technological field my invention is related as an improvement and by contribution of distinctive and unprecedented separatory operations.

With reference to basic physical mechanism the majority of well-known machines for the separation of suspended material primarily belong either to the sedimentation family, including in general the classifiers, elutriators, settlers, tank thickeners, centrifuges, cyclones and gravity sedimentation devices; or to the screen membrane family including the various screening and filtering devices.

A general characteristic and limitation especially of gravity sedimentation devices lies in the fixed pace at which sedimentation takes place with a given product. The achievement of a desired result requires that a certain volume of process fluid be in process for a certain length of time. Since centrifugal equipment is generally operated at or near top speed, similar conditions prevail.

This inflexibility of operation results in several practical disadvantages. Not only must the original selection of equipment be made with great care and with attendant risk of error in choice, but also costly provision must be made to insure steadiness of operation. Furthermore, changes in the scale of operation by addition or subtraction of such equipment must proceed by gross jumps rather than by graduation.

A further limiting characteristic of sedimentation equipment, especially in the commonplace function of classification, lies in the rapid decrease of capacity for a given installation with decrease in the particle size of separation. As a rough rule, an installation which would yield a ton of product at a particle size of unity would yield only a quarter ton at a particle size of half unity. As a result of this limitation the continuous classification by gravity settling of such important products as the majority of mineral raw materials is generally regarded as economically marginal at 50 to 70 micron particle size.

Similarly where the nature and value of the product are such as to allow accommodation to the pecularities and high costs of continuous centrifugation, separations may be practical to a particle size of about 5 microns and only rarely to finer sizes.

The large space requirements of gravity sedimentation equipment is often disadvantageous, especially when

scale of operation must be increased in a crowded, industrial area. A corollary disadvantage may be the large volume of material tied up in process—a condition particularly objectionable in the case of material subject to bacterial deterioration or evaporation.

Effective performance of gravity sedimentation devices in the function of classification often requires a comparatively high dilution of the suspension in process. Such dilution may, in turn, require correction by costly thickening operations.

Screens may be distinguished from filters by both purpose and mechanism. Whereas screens are generally intended to effect separations between particles according to size, or size and shape, filters are generally used to make a more or less complete separation of solids and liquids. In point of mechanism, the screen membrane itself is the effective barrier in a screen, whereas in a filter the screen membrane serves mainly as a foundation for the effective barrier formed autogenously of material in suspension.

The cost of screening operations, as a general rule, like that of gravity classification, increases rapidly with decreasing particle size. The aperture of the finest available screen cloth is 37 microns, although few commercial products in quantity can be economically screened below 100 to 200 micron size.

A further characteristic and limitation of screening operations is determined by the comparative abundance of so-called "difficult particles," or those which approximate the size of the screen aperture. Where such particles are abundant screening is greatly impeded.

Filtration devices used for the purpose of thickening a suspension have the occasional disadvantage of concentrating the suspended material beyond the point desired. This is particularly objectionable where particles subsequently to be dispersed adhere to one another to form indestructible aggregates.

Certain materials as, for example, solids of flaky shape may be impractical to filter by formation of impervious filter cake.

Both gravity thickening and the filtration of fine-sized materials frequently depend on the mechanism of floc formation. Although a few materials, such as certain clays, flocculate naturally, the flocculation of most process materials must be caused artificially by the use of reagents. The large quantity of pasted starch used for this purpose in thickening and filtering the red mud residues from the caustic leaching of aluminum ores furnishes a practical example of reagent costs approaching prohibitive levels.

The following example from practice illustrates several of the foregoing points.

In the blending and firing operations of the wet process for cement manufacture a finely ground cement rock slurry of high solids concentration is required. Although the grinding of the rock in ball mills is accomplished at approximately the solids concentration desired for blending, considerable dilution of the ball mill product is essential to the efficiency of the subsequent hydraulic classification. Dewatering the classified fine product then requires two further operations: first, thickening in Dorr type thickeners, and finally filtration by continuous filters. Since the resulting filter cake is too dry for direct blending it must be suitably diluted.

This brief review of the prior art brings out the considerable need and long unsatisfied demand for a generally flexible, compact and inexpensive separatory method, particularly suited to the accomplishment of the various separatory functions in the range of finer particle size for example in approximately 50 micron size and finer.

A series of problems of long standing concerns the separation of suspended particles of non-granular shape. Such problems include the classification of flexible fibers according to length, the sorting of fibrous and flaky materials and the separation of these irregular bodies from associated compact particles. Furthermore, the degree of difficulty in separations of this kind is often increased by the association of particles into aggregates. Separation must therefore be accompanied by mild disintegrating action.

Certain problems in the paper manufacturing industry may be cited as examples. The control of fiber length

is essential in paper making. Since no machine has heretofore been available which can satisfactorily classify fibers in pulp slurries, fiber length must be controlled by the type of wood used and more particularly by controlling the thickness of chips cut from the solid wood.

Furthermore, for lack of adequate classifying means, the beating or mechanical disintegration step in paper making remains a batch process which must be continued for each batch for a sufficient duration to assure the complete disintegration of the most refractory materials present. The slotted screens which are used following beating in an attempt to eliminate non-fibrous solids, such as knot fragments are only partially effective.

Industries using reclaimed paper fiber are similarly handicapped. In order to provide fibers of desired length the used paper, at considerable cost, must be hand-sorted into various grades. An additional problem is that of removing from the beaten pulp the numerous flakes of undisintegrated paper which inevitably escape the beating process and are deleterious to the quality of finished paper and fiber products. As in the manufacture of virgin paper, slotted screens having high maintenance costs and requiring much manual effort are used with indifferent success to reject undesirable particles.

Similar unsolved problems of fiber classification and speck removal exist in the fruit juice industries.

The separation of clay and clay-like product such as weighted and unweighted rotary drilling mud from sandy impurities and the separation of the weighting materials such as barytes and iron oxides, afford examples of separation and classification requirements in which processing at high solids consistency would be desirable. Clays are often of extremely flocculent nature so that even comparatively dilute suspensions form a rigid floc structure which entraps sand grains and prevents satisfactory separation by relatively inexpensive gravitational methods.

A further general problem of long standing is that of fractionating a fine-sized product comprising a wide range of particle sizes into groups of closely similar size. The preparation of abrasive powders, is a practical example of this kind and a similar example is the close sizing requirements of certain radioactive solids. Heretofore the slow and expensive laboratory elutriation method in air or liquid media has been the principal means of effecting such separations. A method capable of conducting such operations at high production rates is very desirable.

In certain dredging operations silt is pump into barges and towed for dumping into deep water. If it were economically practicable to classify the dredgings into slow settling and fast settling fractions it would be possible to dump the slow settling fraction at the site to be dispersed by tidal or river currents and thereby effect enormous savings in disposal transportation. A method of sufficient compactness and overall economy for this purpose would so alter the practice as to be regarded as a far reaching economic development.

In general my invention solves the foregoing problems by application of my discovery that solid particles entrained with a confined fluid stream, as between plates or in a tube tend to migrate in course of passage from regions adjacent the boundaries toward the center of the stream. In applying my discovery in the preferred embodiments of my invention I provide apparatus of various types to move fluid suspensions of the materials to be separated in confined streams while transforming potential energy to kinetic energy, and continuing the movement of certain components of the stream in the same direction, while removing other components in angular directions, and then convert the kinetic energy of the separated components substantially to potential energy by reducing their speeds.

Among the advantages of my invention are (1) its ability to disperse aggregates of fibrous or other material in suspension and to classify such materials according to size or to sort them according to shape; (2) its ability to separate oversize materials from thixotropic flocculent fine materials such as clay. A similar advantage is its ability to classify materials without need for excessive dilution; (3) its adaptability to separations of materials in the sub-size range of particle sizes. A related but specialized advantage is its ability to classify sub-sieve materials into fractions of closely identical size; (4) the thickening and clarification of fine material may be accomplished without the use of flocculating or other reagents; (5) performance characteristics such as selectivity and intensity of effect in separatory operations may be varied over a wide range simply by the variation flow rate; (6) wide range of through-put capacities which may be accommodated by a given installation without appreciable change in quality of performance; (7) relative compactness of the equipment for a given capacity range; (8) relatively small quantities of material are in process at one time; (9) entire separatory operations may be conducted hermetically sealed and, if desired, under lowered or elevated pressures and temperatures, advantages of considerable importance in the treatment of foaming or volatile fluids, fluids sensitive to oxidation, or materials of sensitive thermodynamic equilibria; (10) most of the parts of the separator are subject only to small mechanical stresses and may therefore be fabricated from a wide variety of corrosion-resistant or abrasion-resistant materials; (11) ease with which the separatory units may be opened for inspection, cleaning, or for the substitution of parts; (12) the fluid undergoing separation is kept continuously in motion with little opportunity for the accumulation or stagnation of material in process; (13) and by appropriate choice of the pump which provides the flow through the separatory system the products of the separation may be elevated or piped to remote destinations without additional pumping equipment. Additional advantages will be apparent to those skilled in the art from the following.

Accordingly a primary object of my invention is to employ, as a means of separation of materials in fluid suspension, novel hydrodynamic effects, which have proved adaptable to systematic utilization for that purpose.

Another object is to provide a pressure-actuated separatory mechanism of compact unitary character and which functions continuously according to novel hydrodynamic principles requiring the use of no moving mechanical parts.

Still another object is to provide, for operation of the separatory mechanism described, a choice of practicable circuit arrangements adapted to the performance of a wide range and combination of separatory operations including sorting, classification, thickening, and clarification of diverse fluid suspensions.

A further object is to provide novel separatory mechanism and circuit systems for its practical application to fluid suspensions whose separation in a desired manner by machines heretofore available has proved partially or wholly unsatisfactory.

Another object is to provide separatory units whose through-put capacity can be materially increased or decreased, as desired, by simplified manipulations involving the addition or subtraction of standard interchangeable parts.

Still another object is to provide separatory units whose performance characteristics, particularly as these concern accommodation to differences in the nature of materials to be separated, may be adjusted over a wide range by simplified procedures involving the substitution of standardized parts.

Other objects will become apparent as the description proceeds in connection with the accompanying drawings, and from the appended claims.

As shown in the drawings:

Figure 1 is a section in a plane parallel to the principal direction of fluid motion and illustrates an aspect of one embodiment of apparatus for carrying out my invention;

Figure 2 is a cross-section on the line 2—2 of Figure 1, and supplements Figure 1 to define one form;

Figure 3 is also a cross-section on the line 2—2 of Figure 1 and supplements Figure 1 to define another form;

Figure 4 is a view partially in elevation and partially in section along line 4—4 of Figure 5, and illustrates another form;

Figure 5 is a partial section along the line 5—5 of Figure 4 and supplements Figure 4 to illustrate the duct system and other features of Figure 4;

Figure 6 is a circuit diagram illustrating one system in which my invention is utilized.

Figure 7 is a more conventionalized representation of Figure 6;

Figure 8 is a circuit diagram illustrating another system utilizing my invention;

Figure 9 is a circuit diagram illustrating another system;

Figure 10 is a circuit diagram illustrating still another system;

Figure 11 is a circuit diagram illustrating another system.

Referring to Figures 1 to 3 which illustrate perhaps the most simplified embodiment of my invention, a casing **13** may be assembled of two similar parts **14** and **15** having mating flanges **16** and **17** by which the parts may be held together by screws or bolts, etc., not shown. Opposing facing cavities in the parts **14** and **15** form a fore-chamber **18**, to which an inlet **21** is connected, to admit the fluid suspension to the fore-chamber. Spaced from the fore-chamber **18** in the parts **14** and **15** is a first after-chamber **22** also formed by oppositely facing cavities in the parts **14** and **15**. Between the fore-chamber **18** and the first after-chamber **22** is a second after-chamber **23**, similarly formed by oppositely facing cavities in the parts **14** and **15**. An outlet pipe **24** for the thickened fraction T is connected to the first after-chamber **22**, the flow through the pipe being controlled by a suitable valve **25**. A pair of outlet pipes **26** are connected to the oppositely facing cavities forming the second after-chamber **23**, to carry off the clarified fraction C of the separation, in a manner to be explained.

Clamped between the parts **14** and **15**, and extending from the fore-chamber **18** almost to the first after-chamber **22** is a converging nozzle or passageway which forms a separatory duct **27** (Figures 1 and 2). This converging separatory duct **27** may be formed in a cylindrical member **28** as shown in Figure 2, the member being clamped between the parts **14** and **15**. In this case the converging separatory duct is in the form of a long tapered cone. Alternately, the converging separatory duct may be formed within a rectangular member **31** clamped between the parts **14** and **15** as shown in Figure 3, in which case the separatory duct, here identified by the reference number **32** has converging facing spaced walls **33** and **34** to define the separatory duct, the side walls **35** and **36** being either parallel, or slightly converging in the direction of fluid flow.

In either case, whether the separatory duct is conical as in Figure 2 or merely converging as in Figure 3, it terminates in what may aptly be termed a splitting chamber **37**, shown in Figure 1. This splitting chamber **37** is formed by the junction of diverging discharge duct **41** and **43**. The discharge duct **41** is coaxial with the separatory duct **27**, whether it be of the form of Figures 2 or 3, and it discharges into the first after-chamber **22** for the thickened fraction T. If the device be in the form of Figure 2 the discharge duct **41** is of diverging conical shape within a cylindrical member **44**. Also, in this form, the diverging discharge duct **43** may be formed between the conical end of cylindrical member **28** and a conical recess **45** in the inlet end of the cylindrical member **44**, the angles of the cones being dissimilar so that the clarified fraction discharge duct **43** is of expanding cross-section with its outlet at the second after-chamber **23**, and in the form of an annulus surrounding the cylindrical member **28**. In the form of Figure 3 the cylindrical member **44** of Figure 1 is replaced by a rectangular member similar to the member **31** of Figure 3 except that it is shorter, and the thickened fraction expanding nozzle corresponding to duct **41** of Figure 1 is of rectangular cross-section throughout its length, and the clarified fraction discharge duct, corresponding to duct **41** of Figure 1, instead of being in the form of an annulus, may be in the form of two divergent discharge passageways, extending on opposite sides of the outlet end of the rectangular member **31** and toward the second after-chamber **23** in the manner shown in Figure 1. In either form, whether the separatory duct is circular in cross section as shown at **27** in Figure 2 or rectangular as shown at **32** in Figure 3, the entrance to the separatory duct is rounded or streamlined as best shown by the rounded corners **46** of Figure 1.

The rectilinear longitudinal contours of separatory duct **27** and similarly **32** may be modified by curved forms or by tangents connected by curves without essential deviation from the general forms illustrated and described. Likewise the clarified fraction duct **41** shown in Figure 1 as rearwardly directed may be at any angle to the axis of separatory duct **27** or **32**. Also when utilized with gaseous carriers it will be understood that the contours of the passages **27** and **32** may be modified to take full advantage of the thermodynamic factors involved, as for example by making the separatory ducts of converging-diverging form in a manner that will be apparent to those skilled in the art.

In operation, the embodiments shown in Figures 2 and 3 in conjunction with Figure 1 operate in the same manner and in accordance with principles which will be explained later. In either case the mixture enters the fore-chamber **18** and passes through the separatory duct **27**, emerging into the splitting chamber **37**. From there the thickened fraction passes through the discharge duct **41** to the first after-chamber **22** and the clarified fraction passes through the discharge duct or ducts **43** to the second after-chamber **23**. The separated fractions pass thence to the outlet pipes **24** and **26** as is obvious.

Figures 4 and 5 illustrate an embodiment wherein the capacity and separatory characteristics, although operating under the same principles as those of Figures 1 and 2, may be widely varied by the addition, subtraction, or substitution of interchangeable parts.

Referring to these Figures 4 and 5, the converging separatory ducts corresponding to the ducts **27** and **32** of Figures 1 to 3 are formed between facing annular surfaces **47** and **48** of a pair of ring elements **51** and **52**, the aforesaid annular surfaces being spaced to provide an annular convergent separatory duct **53** through which the mixture passes to be separated. The ring elements of each pair have aligned central openings or holes **54**, and the axial distance between two facing ring elements **51** and **52** that define a pair is adjusted by varying the number or thickness of shims **55** therebetween. Thus the number and thickness of shims **55** determine the effective spacing of the oppositely facing annular surfaces **47** and **48** that define the converging separatory ducts **53**. Each pair of ring elements **51** and **52** is held in coaxial alignment by means of coupling rings **56** which are of insufficient thickness axially to affect the axial spacing of the ring elements.

The aforesaid ring elements each have annular channels **57** surrounding the coupling rings **56**, the channels in the ring elements facing each other to provide circular fore-chambers **58** communicating directly with the rounded or streamlined entrance ends of the annular separatory ducts **53**. A series of substantially equiangularly spaced holes **61** arranged around and parallel to the axes of the pair of ring elements **51** and **52** provide passages for the entrance of the separable mixture to the annular fore-chamber **58**.

Referring to Figure 4, it will be seen that an outer ring element **62** surrounds the ring element **52** and has a series of short radial spokes **63** (Figure 5) that rest upon an annular shoulder **64** on the upper ring element **52**. A similar outer ring element **65** has short radial spokes resting against a similar annular shoulder on the underside of the lower ring element **51**. The two outer ring elements **62** and **65** define between them an annular divergent passageway **67** communicating at its outlet end in a first annular after-chamber **66** for the thickened fraction. The same outer ring elements **62** and **65**, in conjunction with the ring elements **51** and **52**, define an annular splitting chamber **68** similar in principle to the splitting chamber **37** of Figure 1. From the splitting chamber **68** lead divergent annular passageways **71** and **72** which conduct the clarified fraction of the liquid to the lower surface of ring element **51** and the upper surface of ring element **52** respectively. It should be appreciated at this point that since the outer ring elements **62** and **65** rest against shoulders on the ring elements **51** and **52**, that the size of the thickened fraction divergent passageway **67** is adjusted in accordance with and at the same time as the separatory duct **53** when the number or size of the shims **55** are changed.

A clarified fraction passageway **73** is provided by aligned central openings **74** in the ring elements **51** and **52**. The ring elements **51** and **52** are provided on their outer surfaces with raised bosses **75** surrounding the equiangularly spaced holes **61** therethrough. These raised bosses provide supports for adjacent identical ring elements, which form between them and the ring elements **51** and **52** a series of radial passageways for the passage of the clarified fraction from the divergent passageways **71** and **72** to the central openings **74**. These central openings **74** form the discharge passageway **73** for the clarified fraction.

Any number of pairs of such ring elements **51** and **52** together with their outer ring elements **62** and **65** may be stacked in the above manner to provide a separator having the desired capacity and characteristics. The top and bottom of the stack is completed by closure elements **76** and **77** respectively (Figure 4), which mate with the upper and lower of the ring elements forming the stack to form the uppermost and lowermost thickened fraction divergent passageways **78** and **79** respectively, it being seen that these closure elements **76** and **77** include outer peripheral portions **82** and **83** that have parts corresponding to the outer ring elements **62** and **65**. The closure elements **76** and **77** are similar except that the upper element **76** lacks the series of equiangularly spaced holes that lead to the fore-chambers **58**.

The entire described assembly is assembled and compressed between an upper closure **84** and a lower closure **85**, the latter having an inlet pipe **86** leading to an annular inlet channel or manifold **87** that places it in communication simultaneously with all of the holes **61** that lead to the fore chambers **53**. Also, the lower closure **85** has an outlet pipe **88** which discharges the thickened fraction from the first after-chamber **66**. A control valve (not shown) similiar to the valve **25** of Figure 1 is incorporated in this outlet pipe. The clarified fraction discharges from the central clarified fraction passageway **73** downwardly into a fitting **89** threaded into the lower closure **85** and then passes through a suitable discharge pipe **90** that is threaded into the fitting **89**. This fitting **89** is closed at its lower end by a threaded plug **91** and a central bolt **92** is threaded into the plug **91**, passing up through the clarified fraction passage **73** and through the upper closure **84**. A nut **93** securely clamps the assembled ring elements between the upper and lower closures **84** and **85**. The enclosure of the assembled ring elements is completed by an annular casing **94** that may be positively located by a flange **95** seated upon the upper closure **84**. Sealing between the casing **94** and the closures **84** and **85** may be by any suitable device such as the packings **96**. As illustrated the end surfaces of housing **94** are hydrostatically balanced. However the tensile strength of housing **94** may if desired be utilized by use of retaining ring **97** seated against the rim of closure **85** by suitable cap screws.

The principle of operation of the embodiment of Figures 4 and 5 is the same as those of Figures 1 to 3, in that the converging separating ducts, splitting chambers, the divergent passageways for the thickened fraction T and the rearwardly directed divergent passageways for the clarified fraction C are similar. These passageways may be modified as herein before set forth to take advantage of thermodynamic factors when utilizing gaseous carriers.

Figures 6 to 11 illustrate in schematic form several systems or flow circuits in which the separators illustrated in Figures 1 to 5 may be used to obtain a desired separatory effect. In each of the Figures 6 to 11 the rectangular shaped elements **98** represent a separator constructed in accordance with my invention, of which three embodiments are illustrated in Figures 1 to 5. Conduits or pipes carrying thickened fractions are identified by the reference character T. Those carrying clarified fractions are identified by the reference character C. In each case the pipe line carrying the fluid to be separated is identified by the reference character **99**, and includes a pump **100** for delivering the fluid at the desired pressure to the separator **98**. Control valves having the purpose of the valve **25** of Figure 1 are identified by reference character **101**.

Figures 6 and 7 illustrate a simple flow circuit comprising an inlet pipe **99** having a pump **100** delivering the mixture to the separator **98**. The thickened fraction issues through pipe T and is controlled by valve **101**, while the clarified fraction issues through the pipe C. Figure 7 is a flow circuit identical to Figure 6 but having the pipes or conduits indicated by single lines.

In the circuit shown in Figure 8 a fluid suspension passes through pipe **99** and pump **100** to separator **98**. The C outlet from the separator is discharged from the circuit. The T product line from the unit has two branches, each containing flow regulating means or valves **101**. One branch is discharged from the circuit; the other branch returns to join the incoming fluid in pipe **99** at a point upstream from the pump **100**.

Figure 9 represents the use of three separatory units **98** in what might be termed a "T series circuit" or "thickened fraction circuit." Any number of units beyond two could be so-employed. A pressure elevating means **100** delivers fluid through pipe **99** to the inlet of the first separator **98**. The T outlet of the first unit communicates with the inlet of a second separator **98**, and similarly the T outlet of the second with the inlet of a third separator **98**. The T outlet line of the final separator contains flow regulating means **101** which discharges from the circuit. Similarly the C outlet lines of all but the first separator contain flow regulating means **101** following which the lines may, if desired, be joined as shown for single discharge from the circuit.

Figure 10 represents the use of three separators in what might be called a "C series circuit" or a "clarified fraction circuit." Two or more separators **98** are so employed. A pump delivers fluid via pipe **99** to the inlet of the first separator **98**. The C outlet of the first unit communicates with the inlet of a second separator **98** and similarly the C outlet of the second with the inlet of a third separator **98**. The C outlet line of the final separator is discharged from the circuit. The T outlets of each separator contain valves **101**, following which the lines may be joined as shown to a common line discharging from the circuit.

Figure 11 represents a combination of the circuit principles of Figures 9 and 10, and might be called a "compound circuit." Although a symmetrical arrangement of five separatory units is shown in Figure 11, any number above two could be so employed. Fluid is delivered to the inlet of the uppermost separator **98** via pipe **99** and pump **100**.

The T outlet of the uppermost separator communicates with the inlet of a second separator; the T outlet of the second with the inlet of a third separator and the T outlet line from the final "T leg" separator contains a valve **101** which discharges from the circuit. Similarly the C outlet of the uppermost separator **98** communicates with the inlet of a fourth separator; the C outlet of the fourth with the inlet of a fifth separator; and the final C outlet from the "C leg" is discharged from the circuit. The C lines from the "T leg" as well as the T lines from the "C leg" each contain flow regulating or valve means **101**, following which all join a common return line **102** leading to the inlet pipe **99** at a point upstream from the pump **100**.

As hereinbefore pointed out, my invention operates in part by virtue of my discovery that solid particles entrained with a fluid stream confined, as between plates or in a tube tend to migrate in course of passage from regions adjacent to the boundaries toward the center of the stream.

With reference to Figure 1 the essence of the invention is applied: first, by the use of separatory duct **27** of appropriate characteristics to bring about an accumulation of a prescribed fraction of the process material in the central region of the stream approaching the splitting chamber **37**, and, second by appropriate characteristics of this splitting chamber and diverging ducts **41**, **43** and **45**, and by suitable control of flow through regulating means, such as valve **25**, of effecting a symmetrical three-way division of the segregated stream and diversion of its parts intact as of the instant preceding the splitting event. Suitable passages and discharge openings provided for the products complete the desired physical separation.

Although the peculiar hydrodynamic effect on which my separatory method is in part based has not to my knowledge heretofore been isolated or analytically described, certain aspects of the flow configurations used in the method have been rationalized in engineering terms and their brief discussion is therefore in order.

The sectional configuration of separatory duct **27** in combination with discharge duct **41**, resembles the familiar venturi tube which is used for metering fluids and which is notable for its efficiency in the energy transformation cycle of potential to kinetic to potential energy. As in the venturi tube a substantial portion of the potential energy available in the fluid at fore-chamber **18** reappears as potential energy at the first after-chamber **22**, and if the outlet to this chamber is stopped by valve **25** a somewhat reduced quantity of potential energy becomes available in the second after-chamber **23**. Similarly the flow may be divided, each stream of the division containing a proportionate share of the available energy. This characteristic of the separatory

units makes it practicable to use various flow circuits employing the interconnection of several units with flow maintained by a single pressure generating means.

Part of the energy in flow between boundaries, as in duct **27** is transformed by the mechanism of viscous friction into heat. One of the primary factors determining the scale of this transformation is the degree to which the flow follows a systematic pattern. Flow at low velocities between relatively stationary boundaries is characterized by a uniformly laminar pattern in which adjacent layers of fluid parallel with the boundaries, slip frictionally over one another and with velocities increasing uniformly toward the center of the stream. The frictional energy transformed in such flow is proportional to the average velocity of the stream, and with velocity held constant, is inversely proportional to the dimensions between boundaries. This form of flow may be described as having a uniform shearing gradient.

At certain higher fluid velocities the flow pattern tends to become unstable and to pass more or less abruptly into transient complex configurations in the aggregate known as turbulence. The frictional energy transformation in turbulent flow, depending on the degree of turbulence, is proportional to some power of velocity between one and two. The shearing pattern which in extreme turbulence can only be regarded as a composition of averages is of a general form not unlike that of laminar flow. The shearing gradient and its energy relations in flow between boundaries have been particularly mentioned because it is reasonable to associate with them the observed segregation phenomena. Tentatively it may be assumed that the segregation action in the separatory ducts is in some wise proportional to the prevailing systematic shearing intensity.

Since fluid turbulence is by nature a mixing action, an objective in the design of the separatory duct would be to employ means not only for retarding the onset of turbulence but also of suppressing so far as possible the magnitudes of such irregularities of motion as must inevitably arise at extreme flow velocities. The rounded entrances **46** of Figure 1 and **103** of Figure 4 and converging walls of separatory ducts **27** and **53** are consistent with this objective.

On the assumption, as suggested, that the segregative action is associated with the energy systematically transformed in fluid friction the following may be predicted as to certain operating characteristics of my separatory unit.

With flow velocities held constant more intense segregative action would be expected with decrease in the clearance of the separatory ducts:

Since at all velocities within the regime of laminar flow the frictional energy expended per unit of fluid passing would be constant, the net segregative effect over this velocity range will be constant also.

Some change in the separatory characteristics would be expected as velocities increased beyond the incipience of streamline turbulence;

Since the frictional energy per unit of fluid passing increases with velocity in the turbulent regime within this regime some increase in segregative intensity should accompany an increase in velocity.

Such reasonable expectations have been substantially verified by observation. I have found, for example, that fluids containing very fine suspended material can be more effectively thickened at flow rates within the laminar regime, although thickening action with such material can be produced over an unrestricted range of velocities. The laminar regime of operation is entirely consistent with economic rates of throughput and coincides in the cases of many separation problems with convenient and economical pumping pressures. The choice of operation above or below critical flow rates affords for certain separations a usefully selective operating control.

It should be particularly noted that this segregative mechanism whose operation has been visually observed in transparent apparatus is unique in that the forces effectively utilized, as distinct from inertial or gravitational effects are of fluid origin and mode of action. It is also noteworthy that these forces take effect on the external surfaces of suspended materials in a new and peculiarly selective fashion.

The effect might aptly be termed the "shearing effect" to distinguish it from other effects with which the inertial properties or body forces of matter are more closely associated.

Suspended matter whose density is closely similar to that of the suspending medium, a condition sometimes approached with process materials such as certain synthetic as well as animal and vegetable substances, reacts to gravitation or acceleration as if it were part of the suspending fluid. Thus a suspended particle in precise hydrostatic equilibrium would have no tendency to move with respect to the neighboring fluid whether the system were at rest or subject to accelerated motion as in a centrifuge. The successful application of my invention to materials in approximate hydrostatic equilibrium, by way of isolating the shearing effect from possible inertial effects has further demonstrated its existence and intensity.

The densities of most process materials, however, differ perceptibly from and are usually greater than those of the suspending media. Also, since both rectilinear acceleration and curvilinear motion take place in the duct systems of my invention, inertial effects both assisting and opposing the action of the shearing effect are known to exist. Two of the more important inertial effects will be discussed.

In the splitting chamber of my invention, side fractions of a stream, often moving at high velocity, are turned aside into lateral ducts while the central portion, usually simultaneously checked and expanded continues in generally forward motion. Since the arc of curvature followed by the diverted lamina is of small radius, the inertial forces developed, although covering a duration of say only a few microseconds may be sufficient to transfer dense particles from streamlines entering the lateral ducts to those continuing forward. Since the more common separations involve suspended substances of densities above those of the suspending media the intertial action accompanying the splitting event more often assists than hinders the separatory purpose. When the density differential is extreme, as in the case of a dust-laden gas, this inertial action may predominate to effect separation.

It should be noted that analysis of the character of confined flow around bends shows the elements of fluid near the inside of a bend to be accelerated while those travelling longer arcs are decelerated. Therefore, the inertial forces tending to shift those particles entrained with lamina close to the separatory duct boundary may, during the splitting event, reach considerably greater intensities than approach velocities would indicate. In general and in the light of familiar principles, the hydrodynamic action in the splitting chamber nicely supplements the preparatory action of the shearing effect.

Another inertial effect and one generally capable of acting with some degree of hindrance to the purposes of separation is apparently present under certain circumstances. The shearing effect may be identified with fluid forces tending to move suspended particles from regions of higher to regions of lower shearing intensity; that is in the case of flow through the separatory duct from boundary lamina toward central lamina. Such cross-stream motion traverses lamina of increasing axial velocity and a particle which makes this traverse is therefore subject to considerable axial acceleration. When the density difference between particle and medium is small inertial resistance to such a lateral shift is also small, but when the density difference is large the inertial resistance to lateral shift may approach the magnitude of the shearing effort and effectively cancel it in the simpler types of converging separatory duct. Even with such ducts the inertial effects opposing segregation toward the axis of the stream can be minimized by appropriate choice of duct length and convergence angle. Modifications in the entrance section of the separatory duct may be so employed as to bring all elements of the stream to high velocity and the shearing and inertial effects thereafter employed in concert.

It should be pointed out that the several hydrodynamic effects discussed and their interaction are subject to a wide range of control by comparatively minor mechanical adjustments in the embodiments of my invention, as illustrated and described. Furthermore, the existence of controllable inertial effects increases the range of possible application of the separatory system to include separation of materials into classes according to density.

The separatory mechanisms shown in Fig. 1 in con-

junction with Fig. 3 and in Figs. 4 and 5 are alike in having symmetrically opposed parts including clarified fraction ducts. The objective of this symmetry is partly to make an efficient fractionation of the dissimilar parts of a stream whose components are symmetrically disposed. It is noteworthy that separatory action still takes place when the symmetry is absent as for some special purpose. Thus where one of the opposing boundaries comprising a separatory duct and splitting chamber system is formed as a flat unbroken surface, separatory action suitable for certain purposes is still secured.

The principal means by which control may be exercised over selectivity and intensity of separatory action include: the form and angle of convergence of the separatory ducts, the clearance dimensions of the separatory ducts, the relative magnitudes of the product fractions as set by the flow regulating means, **25**; the velocity of the streams as mainly determined by the pressure drop between fore-chamber **18** and splitting chamber **37** or **68**, the nature and concentration of the suspension in process; and the circuit by which the units are operated.

In a typical case using a substance such as a potato starch suspended in a liquid carrier, in order to assure the capture of a particle of given size in the thickened product of separation, the clearance of the separatory duct near the splitting chamber should be not in excess of say 10 or 15 times the effective diameter of the particle, and separatory duct length of one to three inches with a converging angle of about ½° gives excellent results. In a pneumatic dust collecting system the relative sizes of particles and duct clearances may be much smaller. Since the range of particle sizes encountered in separatory problems is extremely wide, provision of means for the adjustment of duct clearance is desirable and, although duct systems having fixed convergence angles can be effectively used over a comparatively wide range of clearances, special forms may be employed to suit extreme cases. Adjustment of clearance between the ring elements **51** and **52** forming separatory duct **53** in Figure 4 is obtained by interchanging shims **55**. Major adjustments of duct form involve substitutions of the ring elements themselves. It is noteworthy that the units are made accessible to changes simply by removal of nut **93**. Alterations in the number of separatory chambers require substitutions also of parts **92** and **94**.

Once an appropriate selection of units, working pressures and internal dimensions has been made to suit a particular problem one of the chief operating controls is in flow regulating means **25**. By its use the segregated stream in the separatory ducts may be symmetrically fractionated as desired through variation of the amount of thickened fraction drawn off. Normally the draw-off of thickened fraction will range from ten to ninety percent of the total flow. In general, to increase the degree of selectivity toward coarser particles of thickening the thickened fraction is reduced by increased throttling at **25**. Conversely to increase the degree of selectivity toward finer particles the clarified fraction is decreased.

Although the throughput volume of a given unit with a given product may be varied over a wide range with little change in separatory results, certain separations may be more effectively made by operating within certain regimes of flow as defined by such hydrodynamic criteria as Reynolds number. With given dimensional settings the volume of through-put, as determined by the pressure drop between chambers **18** and **37** (Figure 1) is the chief means of controlling this condition.

When the fluid admitted to the separatory ducts contains a high concentration of suspended material the effect is similar to a decrease in duct clearance and the separatory intensity is increased. This fact may be used advantageously to expedite certain separations. Introduction of appropriate neutral materials preliminary to and as an aid to separation may be used, removing the neutral materials following the primary separation.

The elementary flow circuit shown in Figure 6 or Figure 7 is adequate for numerous separatory functions including thickening, clarification, classification and sorting. Since all the process fluid delivered by the pump is discharged from the circuit directly following separation this circuit is the most economical one with respect to installation and operating costs.

The circuit shown in Figure 8 embodies the principle of recirculation of a portion of the T or thickened product of separation whose function is to increase the thickening effect or the selectivity of sorting or classification. For a given through-put this circuit requires a larger pump and may require a separatory unit of larger capacity than that of Figure 7.

As shown, the circuit of Figure 9, like that of Figure 8 is especially suited to thickening, sorting and classification. The operation of this circuit in certain applications might be improved by drawing off the final clarified fraction product C from the first unit and recirculating the C products of remaining units.

The circuit in Figure 10 is especially suited to the purpose of delivering a highly clarified C product. In the circuits of Figures 7, 8 and 9 the minimum clearances of the separatory ducts are largely determined by the size of the coarse particles in the process fluid. In Figure 10, however, each successive unit of the series may be set to a smaller clearance. Extremely fine suspended material may therefore be removed from the final C product.

Figure 11 represents a combination of the specialized thickening circuit of Figure 9 and the specialized clarifying circuit of Figure 10. The combination circuit is therefore adapted to effective thickening and clarification of process fluids whose suspended material comprises a wide range of sizes. The separatory ducts in the T leg are set to pass the coarser suspended materials whereas the ducts in the "C leg" are set successively closer to remove the finer suspended materials.

The complete fractionation of a product of wide particle size range into groups of relatively uniform size may be accomplished as a semi-batch operation utilizing the circuit of Figure 8 modified by addition of a storage tank in the return line ahead of the pump. During operation the valve in the T discharge line is kept closed and make-up liquid comprising clear suspending medium is added to the tank in place of fresh suspension.

The procedure of the fractionation operation is that successively deeper cuts of the peripheral zones of the segregated stream are taken by progressive closure of the valve in the T return line. Each adjustment is maintained until the supply of suspended material represented in a particular zone of the segregated stream is exhausted by discharge as a C product. The process may be carried out rapidly by virtue of the large through-put capacity of the separatory unit.

Flow regulation in circuits comprising the interconnection of two or more units derives from the principles described in discussing the analogy between the flow in separatory units and in venturi tubes. In general, each unit exerts a characteristic back pressure, depending mainly on flow rates and internal clearances. The hydraulic resistance of the T and C discharge ducts can in fact be so selected as to yield automatically T and C fractions of any relative magnitudes. Partial closure of the T discharge openings in any case results in increased flow from the C discharge openings but does not substantially alter the pressure at the inlet to the unit. To elevate this pressure and thereby control flow in upstream units, both outlets to the downstream unit must be regulated.

As an example, control of flow in Figure 11 would begin at the final T outlet of the T leg, then the final C outlet of this leg, then the T outlet of the second unit in the T leg, then the T outlet of the second unit in the C leg, then the T outlet in the third unit of the C leg.

In cases where the separatory ducts are liable to stoppage by occasional oversize material in the process fluid a separatory unit with wide clearances and in closed circuit, as in Figure 8, may be added as a protective device at the head of the various circuits shown. Rotation of one of the opposing duct surfaces may also be utilized for this purpose.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein. The phrase "laminar pattern of flow" as used herein includes true viscous flow as well as stream-line flow, and is not limited to laminar flows as designated technically by Reynolds number.

What is claimed and desired to be secured by United States Letters Patent is:

1. A fluid separating device, comprising means forming a converging passageway having an inlet at its larger end and a splitting chamber at its smaller end; a first after-chamber; a second after-chamber; a first diverging passageway having an inlet smaller than the outlet of said converging passageway and centrally aligned therewith, said first diverging passageway extending between said splitting chamber and said first after-chamber, and in alignment with said converging passageway; means adopted to effect varying of the size of said converging passageway and said first diverging passageway simultaneously; a second passageway between said splitting chamber and said second after-chamber; and outlets from said first and second after-chambers.

2. A fluid separating device, comprising converging passageway forming a separatory duct and having an inlet at its larger end and a splitting chamber at its smaller end; a first after-chamber; a second after-chamber; a first diverging passageway having an inlet smaller than the outlet of said converging pasageway and centrally aligned therewith, said first diverging passageway extending between said splitting chamber and said first after-chamber and in alignment with said converging

passageway; means adapted to effect varying of the size of said converging passageway and said first diverging passageway simultaneously; a second passageway between said splitting chamber and said second after-chamber; outlets from said first and second after-chambers; and flow control means in one of said outlets.

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