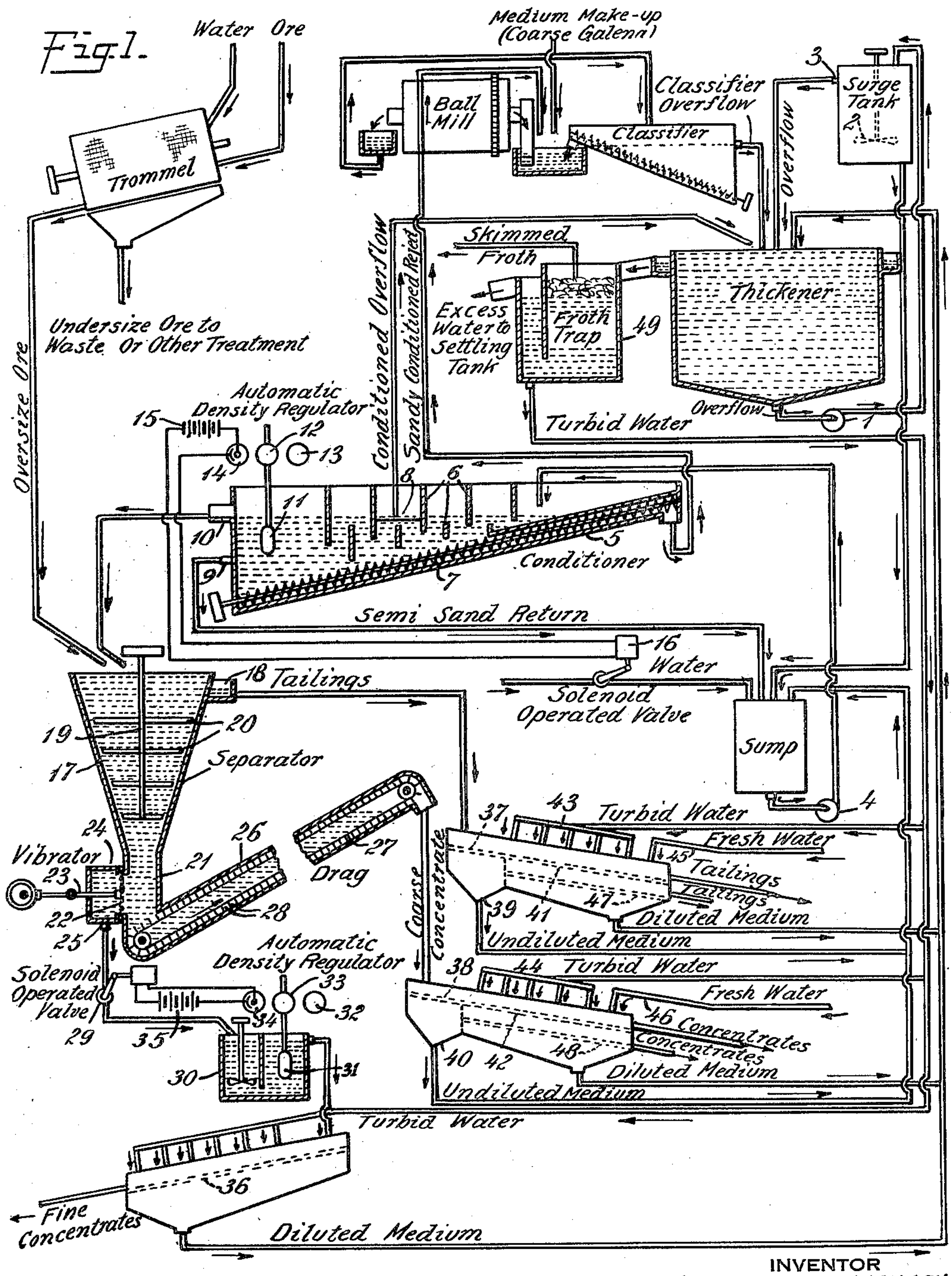
April 12, 1938. C. E. WUENSCH 2,113,609

CONCENTRATION

Original Filed April 8, 1935 2 Sheets-Sheet 1

Fig. 1.



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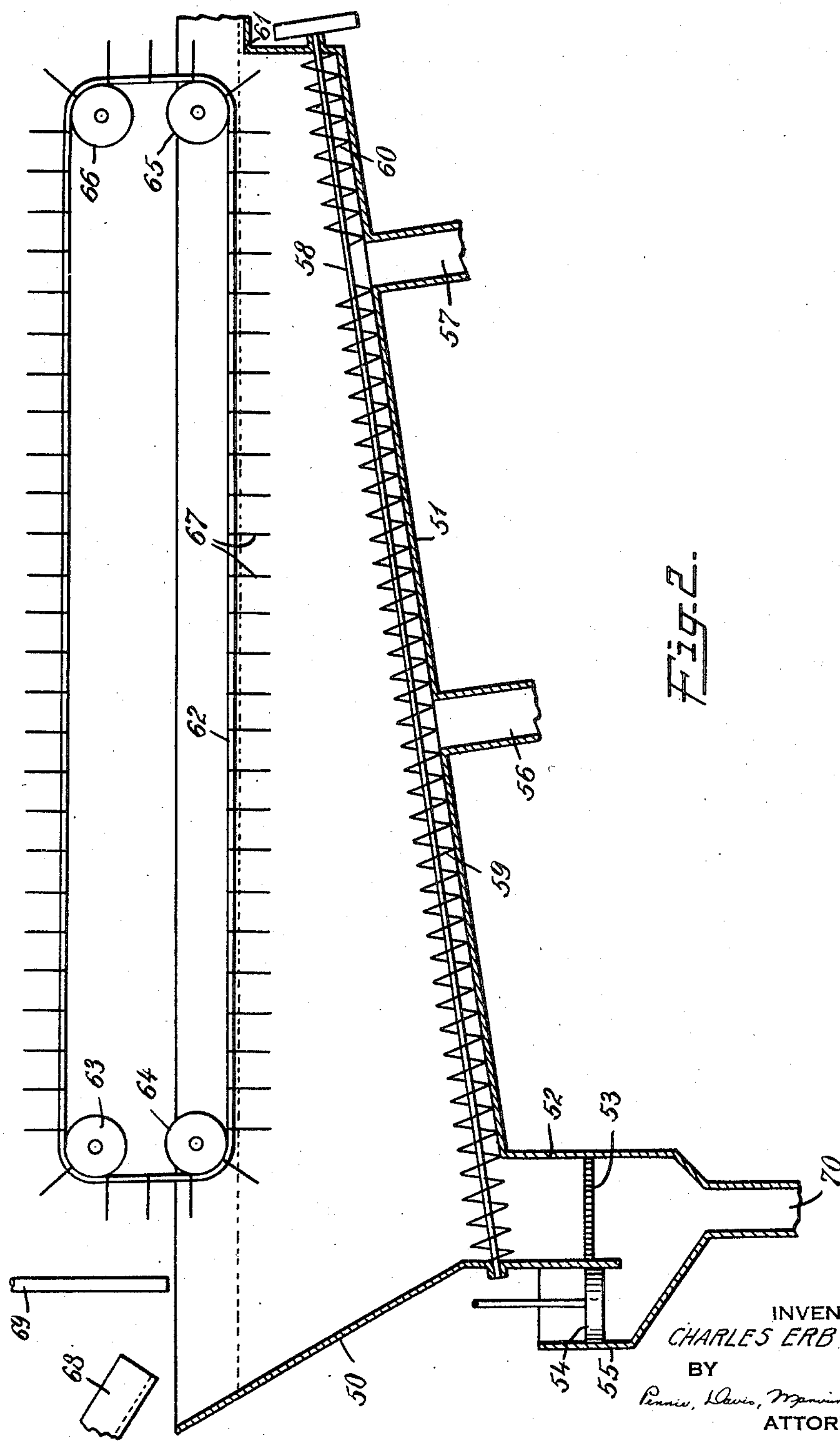

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2,113,609

CONCENTRATION

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Original application April 8, 1935, Serial No. 15,217. Divided and this application February 8, 1936, Serial No. 63,020

7 Claims. (Cl. 209—173)

This invention relates to the separation of heterogeneous mixtures of solid particles having different densities, and contemplates the provision of an improved method of and apparatus for effecting such separation. More specifically, the invention contemplates improvements in the separation of two or more minerals or other solids having different specific gravities by employing gravitational forces in the presence of a heavy fluid.

This application is a division of my co-pending application Serial No. 15,217, filed April 8, 1935.

In the heretofore customary practice of ore dressing and allied arts, mixtures of mineral particles having different densities have been separated by adding the mixture to a fluid having a density intermediate the densities of the minerals to be separated. Under these conditions the mineral particles having a density greater than that of the fluid tend to sink, whereas mineral particles which are lighter than the fluid tend to float. The products are thus separated, and may be withdrawn separately from different zones in the fluid medium.

The term "fluid" is used here to include true liquids, such as aqueous salt solutions of high specific gravity and heavy organic liquids such as tetrabromethane ($C_2H_2Br_4$), as well as multiphased mixtures of finely divided solids with liquids, usually referred to as "suspensions".

Mineral separating processes employing heavy fluids have presented attractive possibilities because of their apparent simplicity, and promising results have been obtained when some of these processes have been employed in the laboratory under carefully controlled conditions. However, duplication of these results in commercial practice has been impossible except in rare instances. Processes employing heavy organic liquids such as tetrabromethane have not come into commercial use because the relatively high cost of such liquids usually requires a high initial investment and excess replacement costs, for in commercial operations a substantial loss of the separating medium is almost inevitable. Commercial application of processes that employ heavy salt solutions for mineral separation has been handicapped by the presence of at least three outstanding disadvantages:

(1) The capital expenditure involved in employing large volumes of such solutions.

(2) The cost of solution losses in the operation of the process.

(3) The fact that such solutions become contaminated or diluted in commercial use. In order to restore the solutions to the proper concentration, evaporation is necessary, and this entails large expense. Furthermore, removal of contaminants without removing the necessary salts which impart the necessary increase in density to the solutions is frequently impossible, and costly in any event.

Commercial examples of processes employing aqueous suspensions of finely divided solids in place of true heavy liquids have met with some success. Aqueous suspensions of finely ground clay, galena, hematite, barytes, silica, and mixtures of these and other materials have been prepared. Such suspensions are not subject to the aforementioned objections in that they are less expensive, so that first cost and the cost of losses are relatively less. Suspensions possess a further advantage over true liquids in that they may be restored from a diluted state by settling or filtration, which are less expensive than the evaporation required to remove excess liquid from true solutions.

Accompanying these advantages which the use of suspensions afford there are, however, serious disadvantages. Unless the suspended solid particles are so fine as to be practically colloidal, they tend to settle out, so that the density through a column of the suspension varies. Unless means are taken to prevent such settlement, the delicacy of the separation is deleteriously affected, not only by the variation in density from top to bottom of the column, but also by the fact that the particles crowd into the bottom of the column, where instead of exerting an unimpaired and delicate buoyant effect, they form a mat which prevents separation of the heterogeneous mixture. Lastly, for any given density, a suspension is usually considerably more viscous than an equivalent true liquid, so that hinderance to separation may be excessive.

Separating processes employing suspensions have been at least partially successful in separating constituents having a marked difference in density. Thus, such processes have been employed for the separation of coal from slate and pyrite, but have failed to accomplish an adequate separation in commercial practice when there was but a slight difference in the density of the minerals to be separated. This failure may be attributable to the following and other factors:

1. Improper average density of the suspension.
2. Variation in density throughout the suspension.
3. Excessive viscosity of the suspension.

4. Coarse particle size of the solids comprising the suspension.

5. Insufficient size of the mineral particles undergoing separation.

6. Adhesion between the particles of the suspension and the particles of the mineral aggregate undergoing separation.

7. "Crowding", i. e. a tendency of particles of the minerals aggregate or particles of the separating medium (suspension) to collect in zones in the separating chamber and act as a mat or screen through which heavy mineral particles fail to penetrate in their fall.

8. Contamination of the suspension with solids of improper particle size or density, soluble impurities, and oleaginous substances.

As a result of my investigations, I have invented a method and apparatus for mineral separation whereby the aforementioned difficulties heretofore involved in the use of suspensions are largely obviated or at least greatly reduced. As a result of my invention, it is now possible to effect a clean separation of mineral particles in commercial operation, even when the difference in specific gravity between two minerals is less than 0.10.

In accordance with my invention, the separating medium or suspension is conditioned prior to its introduction into the separating apparatus, and the proper density and consistency of the medium is maintained by controlling the size of the solid particles, the amount of liquid in the medium, or the ratio of the amounts of various sizes of particles in the medium.

During the separation operation the occurrence of excessive "bottom densities" and "crowding" of particles within the separator is prevented by withdrawing a portion of the medium substantially continuously from the lower portion of the separator (together with sandy material from other sources) and varying the amount of material so withdrawn in proportion to its density, thus maintaining the density and consistency of the contents of the bottom of the separator substantially constant.

The cycle of flow throughout the process of my invention is so arranged as to provide for a gradual removal of deleterious contaminants, both liquid and solid, so that at no time need there be a departure from optimum operating conditions due to these causes. Furthermore, the accumulation of coarse particles at points in the circuit where they would interfere with proper separating conditions is effectively prevented.

These and other features of my invention will be more readily understood if reference is made to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a diagrammatic flow sheet of an ore concentration plant of my invention, and

Fig. 2 is a schematic representation of a modified mineral separating apparatus of my invention.

Referring to Fig. 1, it will be seen that the suspension employed (in the instance illustrated, an aqueous galena slime) is prepared by wet grinding in a ball mill operating in closed circuit with a classifier, which may be of the rake type, the interrupted screw type or other appropriate design. A screw or bowl type classifier will probably be preferable in the grinding of the solid particles to make up the suspension or separating medium in most instances, in that the relatively quiescent state which exists in the overflow end of classifiers of these types permits the production of a very slimy material. The ball mill circuit and classifier preferably should be operated to produce a classifier overflow having a maximum particle size minus 100 to 150 mesh. Under these conditions the majority of the particles in the classifier overflow will be considerably finer than 100 mesh, and a large amount of impalpable slime will be present.

The classifier overflow, together with the diluted medium returned from subsequent stages of the process is sent to a thickener of conventional design. The underflow or spigot product of the thickener is transported by a pump 1 to a surge tank, which is provided with an agitator 2 and with an overflow 3 back to the thickener. The density of the thickener underflow should be greater than the required density of the conditioned medium sent to the separator so that density control may be effected by adding liquid to the material during the conditioning treatment as hereinafter described.

From the surge tank the dense medium flows to a sump. Water and medium returned from later stages of the process are also added in the sump. The medium in the sump is pumped by means of a pump 4 to the shallow end of a conditioner which comprises a sloping trough 5, provided with baffles 6, and a rotatable screw 7 adapted to move sandy material upward to the discharge or shallow end of the trough, from whence the sandy material is returned to the ball mill circuit for further grinding. For convenience in operation, and to provide for surges in the delivery of galena slime from the pump, an overflow 8 is provided on the side of the conditioner at about the middle of the length of the trough. Slime overflowing at this point returns to the thickener. In practice there is a tendency for relatively coarse material to build up in the deep end of the conditioner trough and to overflow in surges. If such an accumulation is allowed to occur there is, of course, a lack of uniformity in the density and ratio of particle sizes of the conditioned slime overflowing from the deep end of the apparatus, with consequent deleterious effect upon the subsequent mineral separating operation in which the slime is employed. To prevent this effect an outlet pipe 9 is provided about midway up the deep end of the conditioner trough through which the relatively coarse material is returned to the sump. The sandy material removed from the shallow end of the conditioner carries with it considerable material of the kind which tends to overflow in surges from the deep end of the conditioner, so that an excessive circulating load of this relatively coarse material (semi-sand) is prevented.

In order to insure that the density of the galena slime (to be used as the separating medium) is of a uniform and appropriate density when it overflows from the conditioner at a lip 10 a novel density regulator is employed. The density regulator comprises a hydrometer 11, equipped with a shield 12, positioned between a light 13 and a photoelectric cell 14 at the discharge end of the conditioner, where the hydrometer floats in the relatively quiescent medium. The photoelectric cell is connected in series with a source of direct current 15 and a solenoid operated valve 16 which controls the amount of water introduced into the sump. Should the density of the medium overflowing the lip of the conditioner become too high, the hydrometer rises and the shield between the light and the photoelectric cell is displaced, so that the light increases the conductivity of the conductor in the photoelectric cell permitting it to pass current and energize the solenoid to open the water valve. Because of the fact that the galena slime delivered by the thickener will ordinarily be denser than is required for the separating medium leaving the lip of the conditioner, no automatic means for increasing the amount of solids added to the conditioner feed is required. In the event that such a procedure were necessary the hydrometer could be provided with a second shield (not shown), movement of which would actuate a second photoelectric cell circuit (not shown) which would in turn control the amount of solids admitted to the sump.

The requisite delicacy of the automatic density control will depend, of course, upon the difference in specific gravity between the minerals to be separated. When this difference is small the density regulator may be made correspondingly delicate by increasing the sensitivity of the hydrometer employed.

The mineral aggregate to be separated (designated on the flow sheet as "ore") is first screened and washed with water in an appropriate device such as a trommel, to remove the bulk of the fine material. The size of the material retained on the screen will depend in some measure upon the nature of the mineral aggregate. In the treatment of Joplin jig tailings containing about 1.5 to 2.0 percent of zinc in the form of sphalerite, it has been found that the material should range in size from ½ to ¾ inch down to 20 mesh (Tyler scale). The fines produced by the trommel may be wasted, or if the practice is economically justified they may be ground and treated by flotation or other appropriate methods. The oversize from the trommels in a clean and slightly moist condition is transported to a separator of novel design as shown on Fig. 1.

Washing the aggregate and supplying it to the separator in a slightly moist condition is desirable for several reasons, viz.

(1) Soluble contaminants are thus removed.

(2) Materials are removed which are too fine to be separated by heavy fluid methods because of the excessive surface exposed per unit of volume.

(3) The wet surfaces of the aggregate reduce any deleterious effect of adhesion between particles of the mineral aggregate and the particles comprising the suspension or medium, at the same time facilitating removal of entrained medium from the products made in the separator.

(4) The presence of a slight amount of moisture dilutes the medium in the top of the separator, thus permitting light minerals to be immersed in the medium in the first instance so that they do not form a floating mat which would block the fall of heavy particles which follow.

When only two products are to be separated, I prefer to employ a separator of the type illustrated in Fig. 1, comprising an inverted conical chamber 17, having a peripheral tailing trough 18 tangential to its upper edge and a concentric rotatable agitator 19 equipped with horizontally adjustable blades 20 positioned within it. The lower end of the conical chamber terminates in a substantially cylindrical pipe 21. A fine meshed screen 22 (say 25 mesh) is affixed on the side of the cylindrical pipe, and may be vibrated by an arm 23 which extends through a hutch 24. A drain pipe 25 is provided at the bottom of the hutch. The bottom of the pipe 21 is connected to a housing 26, which is inclined upwardly and extends to a point slightly above the top of the conical chamber. A conveyor 27 provided with scrapers 28 is positioned within the housing and serves to drag out coarse concentrates falling through the pipe 21.

The drain pipe 25 is equipped with a solenoid operated valve 29 and drains into an agitator box 30 in which a hydrometer 31 of an automatic density regulator is located. This density regulator is similar to that located at the conditioner outlet and comprises a light 32, a shield 33, a photoelectric cell 34, a current source 35 and the solenoid operated valve 29. The agitator box should be so constructed as to provide a quiescent zone for the hydrometer without, however, providing a space in which substantial settlement of solids can occur.

In operation, moist oversize from the trommel and medium of substantially constant density and consistency are run continuously into the top of the separator near its center. The agitator 20 is revolved slowly by a chain or other appropriate means. The peripheral speed of the blade tips should not exceed 150 feet per minute. Separation begins immediately, the light minerals tending to rise and flow outwardly due to buoyancy exerted by the medium of galena slime and to the slight centrifugal force induced by the agitator. Under the influence of these forces the light minerals, designated on the flow sheet as "tailings", pursue an ascending spiral path and overflow into the peripheral tailings launder accompanied by a portion of the medium. The heavier minerals or "concentrates" sink through the cone into the pipe 21, and come within the influence of the vibrating screen, the function of which is to prevent "crowding" or matting of the concentrates and of the galena particles. Unless the washing of the material from the trommel has been perfect and the ore is unusually hard so that no attrition occurs in the separator, a small amount of relatively fine heavy mineral particles will tend to settle along with a portion of the galena in the medium, thus increasing the "bottom density", aggravating the tendency for crowding, and thus interfering with the separation. The vibrating screen 22 is sufficiently coarse to permit the fine mineral particles (due to attrition or imperfect washing) together with coarse galena particles to pass out into the hutch 24 and thence through the drain pipe 25 and the valve 29 into the agitator box 30. The valve 29 is so constructed that it is never completely closed. When the density of the material draining out of the hutch rises to a predetermined point which indicates that crowding or excessive bottom density is about to occur in the pipe 21 or in the bottom of the conical chamber, the density regulator operates to open the valve still further and permit the outflow of the material which is about to cause the crowding. When the density of the material leaving the hutch returns to normal the hydrometer drops; the circuit of the density regulator is broken; and the valve, under the influence of an appropriate spring or counterweight, resumes its normal opening. It will be apparent that the feature of the invention whereby a portion of the medium contaminated with fine concentrate is continuously withdrawn from the separator at a rate depending upon the density of the material withdrawn is also applicable to processes in which the separating medium or heavy fluid is a true heavy liquid instead of a suspension.

When the amount of fine concentrate drained out of the hutch warrants recovery, or when the contamination which would result from the presence of the concentrate in the galena slime returned to the separating circuit cannot be tolerated, outflow from the agitator box is washed in a screen **36** of appropriate mesh (say 50 to 80). The concentrate is retained on the screen and the undersize, consisting chiefly of dilute galena slime is returned to the thickener. If contamination of the medium equal in amount to this fine concentrate can be tolerated, and if the amount of this fine concentrate does not warrant recovery, the screen **36** can be eliminated and the outflow from the agitator box may be returned to the ball mill for further grinding, or to the thickener.

The coarse concentrates falling through the conical chamber and the pipe **21** are picked up by the conveyor and dragged out above the level of the medium in the drag housing. Some galena accompanies these coarse concentrates, so that drainage and washing on a screen are necessary. The coarse concentrates are removed from the upper surface of the screen and sent to further processing. The galena is returned to the circuit as hereinafter described.

The tailings are removed from the peripheral trough at the top of the separator and subjected to screening and washing to remove galena. The galena is returned to the separating circuit. The tailings (assuming that further treatment is not economical) are transported to the dump.

As shown on Fig. 1, the draining and washing of the concentrates and tailings in order to produce clean products and to recover the galena slimes are subjected to the following treatment:

The concentrate and tailings are transported respectively across screens **37** and **38** of appropriate mesh. Such medium as will drain off without the addition of water is permitted to pass through the screens into separate receptacles **39** and **40**, and is returned in an undiluted condition to the sump. The drained concentrates and tailings next pass respectively over screens **41** and **42** under water sprays **43** and **44**. The water for these sprays is the slightly turbid overflow from the thickener. The partially washed concentrates and tailings are given a final washing under fresh water sprays **45** and **46**, and are discharged respectively from the screens **41** and **42** in a slightly moist condition, i. e. containing about 3 to 5% of water. The dilute medium products resulting from the dual washing treatment of concentrates and tailings are passed respectively through finer screens **47** and **48** (say 50–80 mesh) in order to remove any coarse material which would contaminate the medium circuit, i. e. the circulating suspension of galena. Because the screening of the ore is not perfect and because the screening and washing are advantageously conducted on moving or vibrating screens, some attrition occurs and a secondary screening of the dilute medium is usually necessary before it is returned to the circuit. In this way, the sandy material will not prevent the maintenance of optimum conditions in the separator. The sandy concentrates removed in this secondary screening operation are recovered. The sandy tailings are wasted, or subjected to further treatment. The dilute medium from which the sand has been removed is returned to the thickener.

Appropriate reagents to promote settling, such as lime or alum, may be added to the pulp in the thickener. In commercial operation, a small amount of oil almost inevitably leaks into the suspension or separating medium at some point in the circuit. If the solid or solids in suspension are amenable to flotation (as in the case with galena and many other minerals with metallic surface) there is a tendency for a mineral bearing froth to form on the surface of the thickener or at other points in the circuit. Froth formation is objectionable, but it may be minimized by adding appropriate depressing agents to the circuit.

The thickener overflow is run into a trap **49** from the top of which any froth may be skimmed. After appropriate treatment to remove oleaginous substances, the solid constituents of the froth may be returned to the medium or suspension. Water for the sprays employed in the first washing of the concentrate and tailings is withdrawn from the bottom of the trap. The controlled excess water overflows from the trap and is sent to settling ponds (not shown) or to other appropriate treatment, if the amount of suspended galena or other valuable solid is such as to warrant recovery. The bleeding off of this controlled excess water at this point prevents an undue accumulation of deleterious soluble contaminants in the circuit.

In the event that the mineral aggregate undergoing treatment is such that more than two classes of products should be separated from each other, I prefer to employ a novel separating apparatus of my invention as illustrated in Fig. 2. This apparatus comprises a trough **50** having a gently sloping bottom **51**, and adapted to be partially filled with the separating medium or suspension employed. Underneath the deep end of the trough is located a jig chamber **52** equipped with a screen **53** of such mesh that a jig bed of concentrates will be retained thereon. A movable piston **54** operating in a box **55** which communicates with the jig chamber serves to pulsate the bed on the screen. Two middling traps **56** and **57** are located in the bottom of the trough intermediate the ends thereof. A screw conveyor **58** extends lengthwise along the bottom of the trough and is provided with a helix **59** on its lower portion and a helix **60** on its upper portion. The helix **59** is adapted to move aggregate which settles to the bottom of the trough following the jig upwardly to middling traps **56** and **57**. The helix **60** is adapted to move material settling in the upper portion of the trough downwardly to the middling trap **57**. An overflow **61** is provided at the shallow end of the trough. A drag conveyor **62** supported by pulleys **63**, **64**, **65**, and **66** and provided with blades **67** is positioned within and above the trough. The blades on the lower portion of the drag conveyor are adapted to be partially immersed in the contents of the trough and are adapted to move continuously and slowly toward the shallow end thereof.

Mineral aggregate is supplied to the lower end of the trough through a chute **68** located at a point such that the aggregate will tend to fall into and not beyond the pulsating current induced by the jig. The separating medium (an aqueous suspension of galena, for example) is supplied to the deep end of the trough through a conduit **69** in amount sufficient to maintain the level of the contents of the trough approximately constant. Concentrates fall into and through the jig chamber and the screen into a concentrate trap **70**, from which they are withdrawn together with some of the separating medium or suspension. Middlings fall to the bottom of the trough and are moved to the middling traps by the screw conveyor. Tailings overflow into the shallow end of the trough together with some of the medium.

The function of the drag conveyor is to supplement the natural current in the shallow end of the trough and to prevent "crowding".

In the event that only three products are desired, the middling trap 56 may be omitted. Should more than three products be desired, additional product traps may be provided in the bottom of the trough.

The separating apparatus illustrated in Fig. 2 is adapted to be substituted for the conical separator shown in Fig. 1, when a multiple separation is desired. The automatic density regulator associated with the hutch of the conical separator may also be connected to the hutch of the jig in the apparatus of Fig. 2 or to the other traps.

It will be understood that my invention is not limited to the use of a separating medium of suspended galena. Any appropriate solid may be substituted for galena. Thus, an aqueous suspension of hematite, barytes, pyrite, silica, clay, etc. or combinations thereof may be employed depending upon the respective densities of the minerals to be separated.

It will also be understood that the application of my invention is not limited to a case in which the specific gravity of the medium is intermediate the specific gravity of two minerals which are to be separated. By appropriate control, a plurality of minerals which are either heavier or lighter than the medium may be separated from each other for the reason that these minerals will rise or fall in the medium with different velocities and thus become separated. The apparatus illustrated in Fig. 2 is particularly adapted to such practice.

I claim:

1. In a process of separating coarse heavy solid particles from coarse light solid particles in a mixture thereof in the presence of a medium comprising a suspension of fine solid particles in liquid in a chamber in a circuit involving the withdrawal of the separated coarse particles from the chamber, the removal of medium from the coarse particles thus withdrawn and the return of the medium thus removed to the chamber, the improvement which comprises washing the coarse particles withdrawn from the chamber to remove the medium therefrom in a diluted condition, settling the diluted medium in a thickener, withdrawing from the top portion of the thickener and removing from the circuit liquid containing finely divided solids, withdrawing thickened medium from the lower portion of the thickener, then classifying the thickened medium and removing sandy and semi-sandy material therefrom, returning the semi-sandy material to the classification step and returning the medium from which the sand has been removed to the chamber.

2. A process according to claim 1 in which a portion of the medium is drained from the coarse particles withdrawn from the chamber prior to washing said coarse particles, the medium thus drained being returned to the chamber without thickening, and the coarse particles withdrawn from the chamber are countercurrently washed first with a portion of the liquid containing finely divided solids withdrawn from the top portion of the thickener and then with fresh water.

3. A process according to claim 1 in which solids and liquids in the form of froth are skimmed off the liquid withdrawn from the top portion of the thickener and removed from the circuit.

4. In a process of separating coarse heavy solid particles from coarse light particles in a mixture thereof in the presence of a medium comprising a suspension of finely divided solid particles in liquid in a chamber in a circuit, said process involving the withdrawal of coarse heavy particles from a lower portion of the chamber and of coarse light particles from an upper portion of the chamber and the removal of medium from the coarse particles thus withdrawn and the return of the medium removed to the chamber, the improvement which comprises washing the coarse particles withdrawn from the chamber to remove the medium therefrom in a dilute condition, settling the dilute medium in a vessel, withdrawing from the top portion of the vessel liquid containing finely divided solids, returning a portion of the liquid containing finely divided solids to the washing step, removing another portion of the liquid containing finely divided solids from the circuit, withdrawing the thickened medium from a lower portion of the thickener, adjusting the density of the thickened medium to a predetermined point by the addition of liquid thereto, and thereafter returning the medium to the chamber.

5. In a process of separating coarse heavy solid particles from coarse light solid particles in a mixture thereof in the presence of a medium comprising a suspension of finely divided solid particles in liquid in a chamber in a circuit, said process involving the withdrawal of coarse heavy particles from a lower portion of the chamber and of coarse light particles from an upper portion of the chamber and the removal of medium from the coarse particles thus withdrawn and the return of the medium removed to the chamber, the improvement which comprises washing the coarse particles withdrawn from the chamber with turbid liquid and thereafter with clear liquid to remove the medium from the coarse particles in a dilute condition, settling the diluted medium in a vessel, withdrawing from the top portion of the vessel turbid liquid, removing a portion of the turbid liquid from the circuit, returning a portion of the turbid liquid to the washing step, withdrawing thickened medium from a lower portion of the vessel, diluting the thickened medium to a predetermined density and removing sandy material therefrom, and returning the medium of predetermined density from which the sand has been removed to the chamber.

6. In a process of separating coarse heavy solid particles from coarse light solid particles in a mixture thereof in the presence of a medium comprising a suspension of finely divided solid particles in liquid in a chamber in a circuit, said process involving the withdrawal of coarse heavy particles from a lower portion of the chamber and of coarse light particles from an upper portion of the chamber and the removal of medium from the coarse particles thus withdrawn and the return of the medium removed to the chamber, the improvement which comprises draining the coarse particles withdrawn from the chamber to remove a portion of the medium therefrom in an undiluted condition, thereafter washing the coarse particles withdrawn from the chamber to remove the rest of the medium in a diluted condition, settling the diluted portion of the medium in a

vessel, withdrawing from the top portion of the vessel and removing from the circuit liquid containing finely divided solids, mixing the undiluted portion of the medium with the thickened portion of the medium, adjusting the density of the resulting mixture to a predetermined point and removing sandy material therefrom, and returning the mixture of predetermined density from which the sand has been removed to the chamber.

7. Process according to claim 6 in which froth containing finely divided particles is skimmed from the liquid from the upper portion of the vessel and removed from the circuit.

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