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**Kalthoff et al.**

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[54] **METHOD AND MACHINE FOR FLOTATION OF MINERALS OR THE LIKE**


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[51] **Int. Cl** .......................................... **B03d 1/26**

[58] **Field of Search** ............................ 209/162–168, 170, 211; 55/22, 459, 417; 261/126



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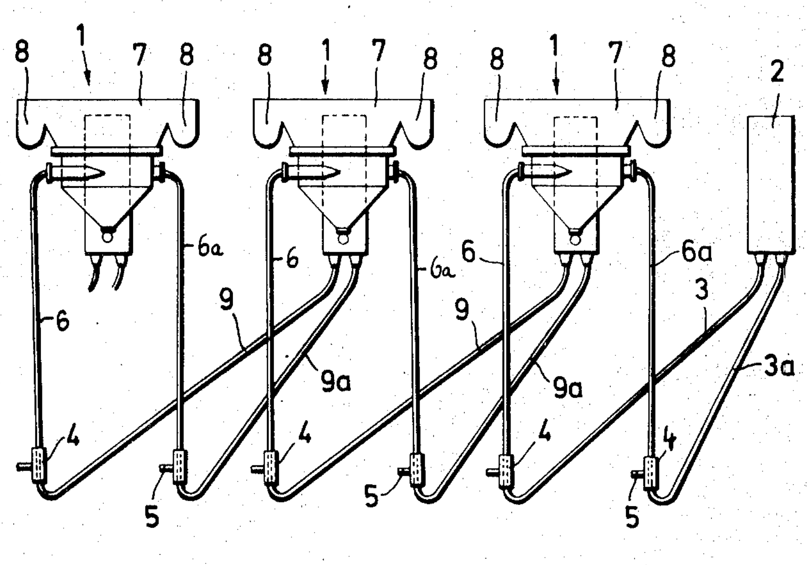
[57] **ABSTRACT**

A flotation machine having a battery of centrifugal cells which are disposed at the same level. The first cell receives a continuous stream of reagent-containing slurry from a receptacle and each other cell receives a continuous stream of slurry from the bottom part of the preceding cell. Each cell has a sealed annular cyclone chamber which receives slurry from the bottom part of the preceding cell or from the receptacle, and a froth collecting chamber which is surrounded by the respective cyclone chamber. The slurry rises into the cyclone chambers under the action of compressed air which is pumped into the slurry in such quantities that the surplus of air forms in each cyclone chamber a cushion from which air is withdrawn in controlled amounts for introduction into slurry which is being drawn from the bottom part of the respective cell. Compressed air serves to convey as well as to be dispersed in the slurry with attendant formation of froth which rises in and is withdrawn at the top of the corresponding froth collecting chamber.

**24 Claims, 3 Drawing Figures**

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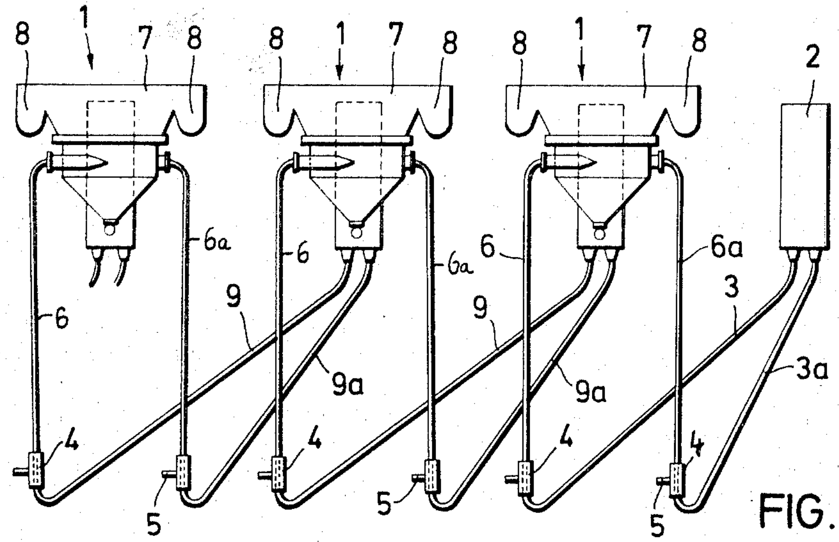


FIG. 1

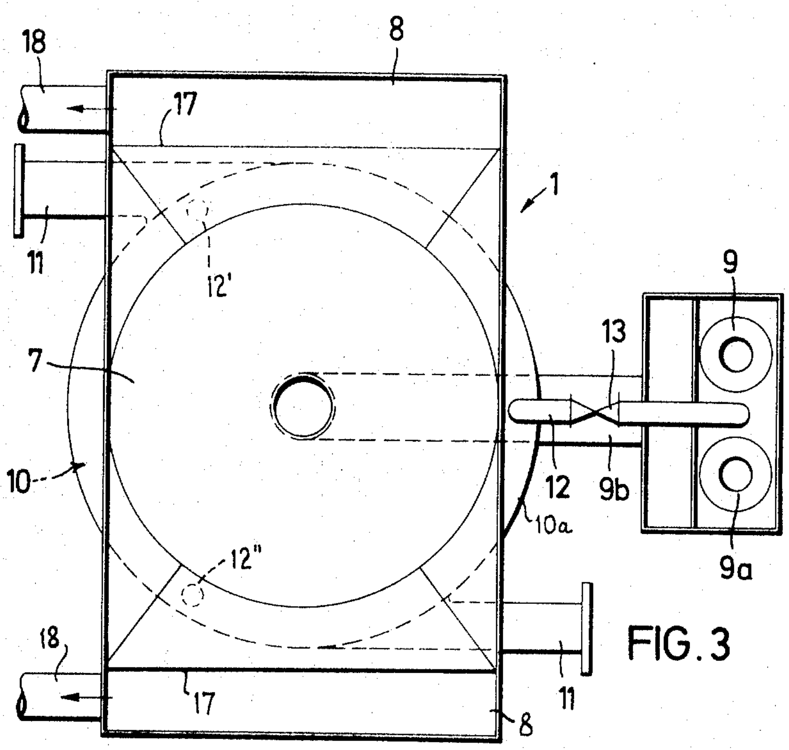


FIG. 3

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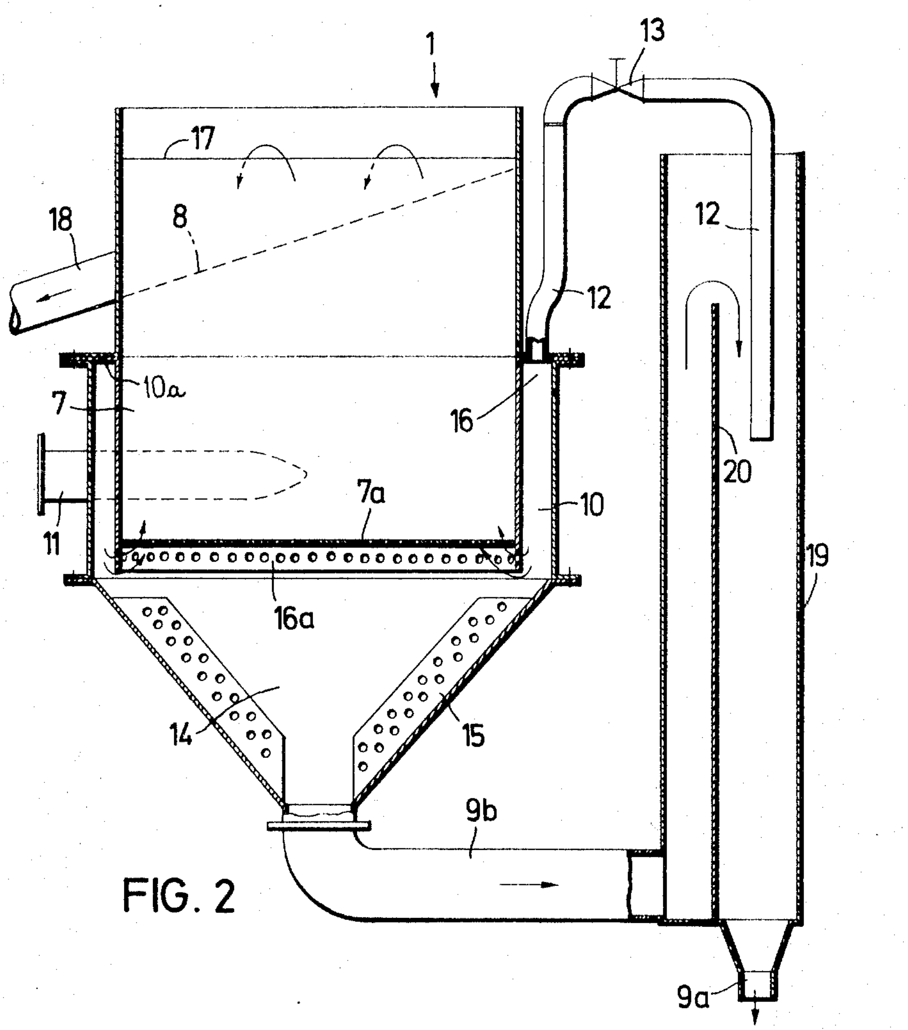


FIG. 2

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# METHOD AND MACHINE FOR FLOTATION OF MINERALS OR THE LIKE

## BACKGROUND OF THE INVENTION

The present invention relates to a method and to a machine for flotation of mixtures of finely comminuted substances, especially minerals. More particularly, the invention relates to improvements in method and machines for flotation of minerals or the like in a plurality of discrete cells.

In certain presently known flotation machines, the pulp or slurry is produced in a receptacle which is located upstream of the cells and wherein the slurry is stirred and receives requisite quantities of one or more reagents. The thus prepared slurry is conveyed by piping to several serially connected centrifugal flotation cells. As a rule, the cells are disposed at different levels to facilitate the flow of slurry from cell to cell. The cell which is nearest to the receptacle is located at the highest level and the remotest cell is located at the lowest level. If the machine contains a large number of cells (for example, 160 cells), the difference between the levels of the first and last cells is very substantial so that the slurry which is to be conveyed from the receptacle to the first cell must be lifted through a considerable distance, normally by means of an air-operated lifting device which blows compressed air into the pipe to cause the slurry to flow upwardly through a riser which delivers the slurry to an equalizing container located at a level above the uppermost cell. The upper end of the equalizing container is open so that air which was used for lifting of the slurry is free to escape into the atmosphere. The slurry is conveyed from the container into the uppermost cell by gravity flow. The supply pipe which delivers the slurry to the uppermost cell contains an injector which admits air before the slurry reaches an annular chamber of the uppermost cell. The annular chamber has a closed upper end and surrounds a cylindrical froth collecting chamber. The slurry which enters the annular chamber is caused to circulate and descends, partly by gravity and partly in response to admission of fresh slurry, into the lowermost part of the uppermost cell whence the froth rises into the cylindrical chamber. Dispersion of air which has been admitted by the injector takes place in response to circulation of slurry in the annular chamber and the resulting bubbles of air adhere to those particles which are to rise with the froth. The froth is withdrawn at the upper end of the cylindrical chamber and the remainder of the slurry flows by gravity through a discharge pipe to enter the next cell. The discharge pipe contains an injector which admits to the slurry air prior to entry of slurry into the annular chamber of the next cell.

A serious drawback of such machines is that the amounts of air which are admitted by the injectors are insufficient to insure an optimum saturation of slurry with dispersed air bubbles. The amounts of air which are admitted by the injectors are drawn into the slurry by suction. That air which is admitted into the slurry by the aforementioned pneumatic lifting device between the receptacle and the equalizing container is lost because the upper end of the equalizing container is open. Unsatisfactory aeration of slurry reduces the efficiency of the cells so that the conventional machines must contain a large number of bulky cells which occupy a substantial amount of space and must be accommodated in enclosures whose construction and maintenance costs are very high. An additional factor which contributes to the operating cost of conventional machines is the consumption of large quantities of highly compressed air which is used to lift the slurry from the receptacle and is thereupon lost by being permitted to escape into the atmosphere. It is well known that the cost of establishing and maintaining a substantial supply of highly compressed air is extremely high. The conventional machines consume large quantities of compressed air not only because the amount of air which is needed to transport the slurry is very high but also because the distance between the levels of the receptacle wherein the slurry is formed and the equalizing container above the uppermost cell is great. It will be readily understood that the uppermost cell must be located well above the level of the lowermost cell if the flotation machine comprises a large number of cells each of which is mounted at a different level in order to insure that the slurry can be conveyed from cell to cell by gravity flow.

Another serious drawback of cells in the just described conventional machines is that the admission of air by way of injectors cannot be regulated with a satisfactory degree of precision. Since the quantity of air influences the formation of froth and hence the separation of heavier and lighter particles, such conventional cells are not suited for accurate regulation of the separating action.

## SUMMARY OF THE INVENTION

An object of the invention is to provide a novel and improved method of froth flotation which is more economical than presently known methods and which can be used for the separation of a wide variety of substances.

Another object of the invention is to provide a novel and improved flotation machine which occupies less room than a conventional machine of identical capacity, which is simpler, more reliable and less expensive than presently known machines, and whose height is but a fraction of the height of conventional machines.

A further object of the invention is to provide the improved machine with a novel cell whose operation can be regulated with a high degree of precision to thereby control the quality and the formation of froth.

An additional object of the invention is to provide a cell which is constructed in such a way that the slurry or pulp which is admitted thereto is invariably saturated with dispersed air.

Still another object of the invention is to provide a cell whose dimensions are but a small fraction of the dimensions of a conventional cell with identical output.

A further object of the invention is to provide a flotation machine wherein two or more or all of the cells can be mounted at the same level.

Another object of the invention is to provide a flotation machine whose energy requirements are a small fraction of the energy requirements of a conventional machine and which can operate properly with relatively small quantities of compressed air which can be obtained by resorting to simple and inexpensive compressing devices, such as blowers or fans.

An additional object of the invention is to provide a flotation machine which can operate without stirrers and/or injectors.

One feature of the invention resides in the provision of a method of separating a first class of particles from a second class of particles which are intermixed with particles of the first class in a pulp or slurry. The method comprises the steps of introducing into the slurry at least one reagent which promotes the adherence of particles of the first class to air bubbles, introducing into the thus treated slurry compressed air to thereby convey the slurry in at least one predetermined direction (preferably from a lower level to an upper level) and thereupon confining the slurry to circulation in an enclosed area (preferably in an annular cyclone chamber of a cell) to prevent uncontrolled escape of air whereby the conveying air is dispersed in the slurry and adheres to particles of the first class with attendant formation of froth which contains at least a substantial percentage of particles of the first class, and separating the froth from the remainder of the slurry.

The air is preferably introduced into the slurry in such quantities that a surplus develops on entry of the slurry into the enclosed area whereby such surplus forms an air cushion which is located above the circulating slurry. The pressure of air in the cushion is preferably less than 1 atmosphere above atmospheric pressure, preferably between 0.4 and 0.6 atmospheres above atmospheric pressure.

Controlled quantities of air can be withdrawn from the cushion to control its pressure and to insure that the enclosed area can accommodate an optimum quantity of circulating slurry. The air is preferably withdrawn at several equidistant points of the enclosed area and the withdrawal of air can be regulated at each point independently of the rate of withdrawal at the other point or points. The thus withdrawn air can be introduced into the slurry which is withdrawn from the cell upon separation of froth whereby the air can serve for conveying the once-treated slurry to the next cell and/or to form in the once-treated slurry bubbles which adhere to remaining particles of the first class.

Fresh slurry is admitted continuously in the aforementioned direction to enter the enclosed area substantially tangentially of the circulating slurry. Such admission can take place at a single point or at two or more points which are equidistant from each other, as considered in the circumferential direction of the enclosed area.

The novel features which are considered as characteristic of the invention are set forth in particular in the appended claims. The improved flotation machine itself, however, both as to its construction and its mode of operation, together with additional features and advantages thereof, will be best understood upon perusal of the following detailed description of certain specific embodiments with reference to the accompanying drawing.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a schematic partly side elevational and partly sectional view of a flotation machine which embodies the invention and comprises three serially connected cells;

FIG. **2** is an enlarged vertical sectional view of a cell; and

FIG. **3** is a plan view of the cell shown in FIG. **2**.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** illustrates a flotation machine which comprises several series-connected cyclone-like centrifugal cells **1**. The slurry which is to be treated in successive cells **1** and contains one or more suitable reagents is stored in a receptacle **2** which also serves as an equalizing or compensating chamber. The receptacle contains an agitating device, not shown. The outlets of the receptacle **2** are connected with two withdrawing pipes or conduits **3, 3*a*** which convey the slurry to two compressed-air lifters **4** each having an inlet **5** for admission of compressed air from a compressed air conduit not shown in the drawings, which is fed by a suitable blower. Air which is admitted into the slurry delivered by the pipes **3, 3*a*** causes the slurry to rise in supply conduits **6, 6*a*** and to enter a preferably upright cylindrical ring-shaped cyclone chamber **10** (see FIGS. **2** and **3**) of the first or rightmost cell **1**. The pressure of air which is admitted by way of the inlets **5** need not exceed 1 atmosphere above atmospheric pressure; it is preferably in the range of 0.4–0.6 atmospheres above atmospheric pressure.

The upper end portions of the supply conduits **6, 6*a*** are provided with horizontal nozzle-like outlets **11** which are disposed substantially tangentially of the cyclone chamber **10** (see FIG. **3**). The upper end of the cyclone chamber **10** is closed by a ring-shaped top wall **10*a***. The cyclone chamber **10** surrounds the cylindrical lower portion of a froth collecting chamber **7** which is preferably coaxial therewith. The froth which overflows the edges **17** of two opposing side walls of the polygonal upper portion of the chamber **7** (see FIGS. **2** and **3**) enters two parallel intercepting chambers **8** which extend lengthwise of the upper portion of the chamber **7** and are preferably provided with inclined bottom walls (see FIG. **2**) to facilitate the outflow of froth by way of removing pipes **18**.

The residue of once-treated slurry (containing the heavier particles of mineral or the like) leaves the first cell **1** by way of discharge conduits **9, 9*a*** which deliver it to second compressed-air lifters **4** provided with inlets **5** for compressed air so as to cause the slurry to rise in a second pair of supply conduits **6, 6*a*** and to enter the cyclone chamber of the second cell **1**. The cells **1** are preferably of unit construction and the slurry entering the second cell is treated in the same way as described in connection with the first cell. The twice-treated slurry which is evacuated from the lower part of the second cell **1** by way of discharge conduits **9, 9*a*** is caused to flow to compressed-air lifters **4** which cause it to rise into the cyclone chamber of the third cell **1**. It is clear that the flotation machine can comprise a single cell, two cells or more than three cells. The cells may be arranged in groups or batteries which are connected in series and/or in parallel.

FIG. **1** shows that the illustrated cells **1** of the flotation machine are disposed at the same level, i.e., in a common horizontal plane. Consequently, all of the lifters **4** may be of identical construction and each thereof is preferably mounted in such a way that the slurry flowing upwardly through the supply conduits **6, 6a** covers the same distance. The lifters **4** serve the additional purpose of effecting a desirable aeration of the slurry. The distance which the slurry must cover from the respective lifter **4** to the next-following cyclone chamber has been exaggerated in FIG. **1** for the sake of clarity. In actual practice, such distance need not exceed 2–3 meters.

FIGS. **2** and **3** illustrate the details of one of the cells **1** on a larger scale. The circular shape of the cyclone chamber **10** can be seen in FIG. **3**. The horizontal nozzle-like outlets **11** of the supply conduits **6, 6**a are disposed diametrically opposite each other and discharge the slurry tangentially of the cyclone chamber **10** so that the slurry circulates prior to entering the inverted pyramid shaped lower end portion or tank **14** below the froth collecting chamber **7**. The slurry which enters the cyclone chamber **10** contains a large quantity of air some of which forms relatively large bubbles. At least the majority of such large bubbles are broken up during circulation of slurry in the cyclone chamber **10** so that the latter contains finely dispersed and relatively small air bubbles whereby the surplus of air accumulates above the exposed surface of the slurry (below the top wall **10***a*) and forms a cushion **16**. As the operation progresses, the thickness of the cushion **16** would unduly increase and, therefore, each cell **1** is provided with means for evacuating or effecting removal of a certain amount of separated air from the upper portion of the respective chamber **10**. Such evacuation is necessary because an unduly thick air cushion **16** would cause premature expulsion of slurry from the chamber **10** or would prevent entry of sufficient quantities of slurry. The means for evacuating a certain amount of separated surplus air may comprise a single evacuating or removing device but preferably two or more discrete evacuating devices each of which can be adjusted independently of the other(s). It is preferred to place the evacuating devices at equal intervals around the circumference of the lower portion of the chamber **7**. FIGS. **2** and **3** merely show a single complete evacuating device which comprises an air evacuating pipe **12** provided with an adjustable regulating valve **13** which renders it possible to regulate the evacuation of air with a **150** degree of precision. The pipe **12** extends substantially vertically through and upwardly beyond the top wall **10***a* and is thereupon curved to convey the evacuated air in a desired direction. The setting of the valve **13** is preferably such that the air cushion **16** above the slurry which circulates in the chamber **10** is maintained at a pressure which is less than one atmosphere above atmospheric pressure, preferably 0.4–0.6 atmospheres above atmospheric.

The slurry which enters the cyclone chamber **10** by way of the outlets **11** expels the previously admitted slurry into the funnel-shaped inverted pyramid-shaped lower end portion or tank **14** of the cell **1**. The inclined wall of the tank **14** is provided with apertured stabilizing baffles **15**. The reagent or reagents which are admitted to the slurry in the receptacle **2** cause the air bubbles in the tank **14** to adhere to those grains or particles which are to rise into the chamber **7**. The rising particles must pass through a filter or sieve **7***a* which separates the tank **14** from the lower portion of the chamber **7**. The lowermost part or skirt **16***a* of the lower portion of the chamber **7** extends downwardly from the filter **7**a and also constitutes an apertured baffle through which froth can pass from the chamber **10** into the chamber **7**. The diameters of apertures in the baffles **15, 16**a and in the filter **7***a* greatly exceed the maximum transverse dimensions of largest particles which are contained in the slurry. Therefore, all particles are free to pass through the apertures of these baffles and at least such particles which adhere to air bubbles are free to pass through the filter **7***a*. The froth which rises in the chamber **7** overflows along the parallel horizontal top edges **17** of the upper portion of the chamber **7** and enters the aforementioned intercepting chambers **8** to be evacuated by way of the respective removing pipes **18**.

The once-treated slurry flows from the tank **14** by way of an intermediate conduit **9***b* which conveys it into the left-hand compartment of a container or vessel **19**. The left-hand compartment is separated from a right-hand compartment by a vertically adjustable partition **20** over which the slurry flows into the right-hand compartment and thence into the pipes **9, 9***a*. The vertically adjustable partition **20** serves to regulate the level of slurry in the cyclone chamber **10** of the cell **1**. Each of the evacuating pipes **12** discharges air into the right-hand compartment of the container **19** so that such air promotes the flow of slurry toward the next cell, namely, toward the next-following lifter **4**.

The polygonal outline of the upper portion of the chamber **7** is clearly shown in FIG. **3**. Such configuration is desirable in order to provide the aforementioned straight overflow edges **17**. This contributes to more satisfactory separation of froth from the residue of slurry. Portions of two additional air evacuating pipes **12′, 12″** are indicated in FIG. **3** by broken-line circles. Each of these pipes extends substantially vertically upwardly beyond the maximum levels of slurry and froth in the chambers **10** and **7**.

If desired, the air cushions **16** in the upper portions of the cyclone chambers **10** can be at least partially separated from the circulating slurry in the lower portions of such chambers. The liquid in each of the chambers **10** preferably extends to a level which is located above the discharge ends of the respective outlets . It is also possible to replace at least some of the evacuating pipes **12** with simple openings which discharge the surplus of air into the atmosphere. Such openings are then controlled by suitable flaps or other types of valves which can terminate and otherwise regulate the outflow of surplus air in order to maintain the pressure of the cushion **16** above the circulating slurry within the desired range, preferably 0.4–0.6 atmospheres above atmospheric pressure. However, the illustrated air evacuating devices **12–13** are preferred at this time because the evacuated air can be used to promote the flow of slurry into the next-following cell **1**. As mentioned above, each valve **13** is preferably adjustable and closable independently of the other valves. This enables the operators to regulate with a high drgree of accuracy the pressure of the air cushion **16**, the amount of air in the slurry which circulates in the lower portion of the respective chamber **10**, and the development of froth in the chamber **7**. It is equally within the purview of the invention to connect all of the pipes **12** or all of the aforementioned openings (which replace the pipes **12**) to a single collecting pipe which discharges air into the corresponding container **19**. The intakes at the lower ends of those portions of the pipes **12** which extend into the chamber **10** are located at a level above the axes of the outlets **11**, preferably at a distance of about 50 millimeters and most preferably at a distance of about 100 millimeters above the plane of such axes. This insures that, when the valves **13** are open, the escaping air is unable to entrain the slurry from the chamber **10** into the respective container **19**. As shown in FIG. **2**, the illustrated pipe **12** extends vertically or nearly vertically from the top wall **10**a and to a level above the topmost level of froth in the chamber **7**. The uppermost portion of the pipe **12** is bent so as to convey the evacuated air in a desired direction, namely, into the container **19**. Such configuration and mounting of the pipe **12** prevent penetration of slurry into its intake and the entry of slurry into the container **19**.

The openings in the baffles **15, 16***a* need not be of circular shape. Such openings can constitute slots or the baffles may be provided with two or more different types of openings. The baffles **15, 16***a* serve to break up larger air bubbles before the froth rises through the filter *7a* and into the lower portion of the chamber **7**. This insures that the rising froth contains a very high percentage of those particles which are to be separated from the particles entering the container **19**. The bubble-breaking action of the baffle **16***a* is particularly intensive because at least a substantial percentage of the slurry must pass through the openings of this baffle on its way from the chamber **10** into the chamber **7** and/or tank **14**. The openings of the baffle **16**a cannot prevent entry of particles into the tank **14** but are very effective in reducing the size of air bubbles.

As stated before, all of the cells **1** shown in FIG. **1** are disposed at the same level. This brings about substantial savings in material, labor and time. Moreover, the operating cost of a flotation machine wherein all of the cells (or at least the cells of each of several batteries of cells) are disposed at a common level is much less than the cost of machines with cells disposed at different levels so as to permit gravitational flow of slurry from cell to cell. The height of supply conduits **6, 6***a* need not exceed 2–3 meters so that the expenditures in energy for the lifting of slurry in such relatively short supply conduits are rather low because the lifters **4** require relatively small quantities of compressed air.

Another important advantage of the improved machine is that proper aeration of the slurry can be carried out without resorting to injectors which are employed in conventional machines to effect admission of air into the slurry. The lifters **4** convey the slurry directly into the cyclone chambers **10** and supply all of the air which is needed for the formation of bubbles. Thus, the air which is admitted by inlets **5** serves for transport of slurry as well as for diffusion of air therein. Since the upper ends of the chambers **10** are sealed (by the walls **10***a*), the air which is admitted by the inlets **5** cannot escape before the slurry reaches such chambers. The evacuating pipes **12** are necessary because the quantities of air which are needed for the transport of slurry into the cyclone chambers **10** exceed the quantities which are necessary to form the froth. This insures that the slurry which enters the chamber **10** invariably contains sufficient quantities of dispersed air, i.e., such quantities which are amply sufficient to carry out the flotation of lighter particles. Consequently, the number of cells which are needed in the machine of the present invention is substantially smaller than the number of cells in a conventional flotation machine. Also, the capacity of the novel cells is much less than the capacity of conventional cells despite the fact that the overall number of cells **1** is less than the number of cells in presently known machines. For example, a conventional flotation machine with 160 cells each having a volume of 1.5 cubic meters can be replaced with a machine having 100 cells **1** each with a volume of 0.5 meters. Furthermore, the cells **1** operate properly without any stirrers which are standard parts of presently known cells. The omission of stirrers brings about additional savings in material, manufacturing cost and energy. It was found that the manufacturing cost of a cell **1** which is constructed in a manner as shown in FIGS. **2** and **3** is but a small fraction of the cost of a conventional cell. Such lower cost is attributed to smaller dimensions of the cells **1**, to the absence of stirrers and also to the simplicity of cells **1**.

The space requirements of our flotation machine are a small fraction of those for a conventional machine with the same output. This reduces the construction cost for the building which accommodates the improved machine. Moreover, the distribution of cells **1** can be varied as desired so that the machine can be readily installed in the space which is available in an existing industrial plant. The energy requirements of our flotation machine constitute about 40–45 percent of energy requirements of a conventional machine with the same output. The cells **1** are less prone to malfunction than the cells of presently known machines so that the maintenance cost of the improved machine is surprisingly low. It was found that the cells **1** can operate properly without any maintenance for very long periods of time.

Another important advantage of our machine is that it can dispense with equalizing and deaerating containers of conventional machines. Such machines are installed upstream of the first cell in a conventional machine and are provided with means for withdrawing air before the slurry is caused to enter the cells. The absence of such containers renders it possible to reduce the distance between the lifters **4** and the associated cells **1** with attendant savings in compressed air.

Still another important advantage of our machine is that the treatment of a certain quantity of slurry in each of the cells **1** can be completed within a short period of time. This is due to the fact that the slurry which enters a cyclone chamber **10** invariably contains an optimum amount of dispersed air which is needed for flotation of certain sizes of particles. The time required to treat a unit quantity of slurry in a cell **1** of our machine is only about one-fifth of the time which is necessary to treat the same quantity of slurry in a conventional cell. This renders the improved machine particularly suitable for the so-called Rougher and Scavenger flotation.

Evacuation of surplus air from the upper portions of the cyclone chambers **10** is further desirable on the ground that it contributes to such calming of the circulating slurry which is best suited for the development of froth. Excessive turbulence in the chambers **10** could result in socalled boiling of slurry. The froth collecting chambers **7** receive only such quantities of air which are necessary to carry out the flotation; the surplus of air is withdrawn by the pipes **12** and is used for pumping of the slurry toward the next-following cell.

In some instances, the operation of cells **1** is sufficiently predictable to insure the evacuation of requisite quantities of surplus air by employing one or more pipes **12** having a predetermined internal diameter. However, the valves **13** are normally desirable because they enable the operators to regulate the operation of cells **1** with a high degree of precision. The aforementioned values for the preferred pressure of air cushion **16** can be exceeded or reduced, depending on the nature of the slurry and the exact design and dimensions of the cells. Since the pressure of the cushion **16** is preferably less than one atmosphere above atmospheric pressure, the pressure of air which is admitted by the inlets **5** need not exceed 1 atmosphere. Such pressure can be achieved by resorting to relatively simple and inexpensive blowers.

The aforediscussed evacuation of surplus air from the air cushions **16** by way of the pipes **12** is not analogous or equivalent to evacuation of air which takes place in conventional flotation machines in order to convey the slurry into the equalizing containers. In conventional machines, all or nearly all of the air which is contained in the slurry is permitted or caused to escape. Fresh air is thereupon admitted by way of injectors before the slurry enters a cell. Air which is admitted by such injectors is not sufficient to insure the formation of optimum quantities of froth. The pipes **12** of our improved cells **1** withdraw a certain amount of that air which cannot be absorbed by the slurry in spite of the fact that the slurry is caused to circulate in the chambers **10.** Thus, the pipes **12** withdraw air which cannot be accepted by the slurry in the respective cells whereas the withdrawal of air in conventional machines takes place efore the slurry even reaches a cell.

The cells of the present invention insure that the slurry is saturated with air before it leaves the respective chambers. This is due to the fact that diffusion takes place during transport of slurry from the lifters **4** into the respective chambers **20,** that the air which enters the chambers **10** cannot escape freely into the atmosphere, and that the cushion **16** constitutes a secondary supply of air from which the circulating slurry withdraws such quantities as are needed for optimum saturation prior to entry of slurry into the tank **14.** Such saturation is an important requisite for satisfactory operation of the cell.

When a cell **1** is relatively small, the admission of slurry can take place by way of a single supply conduit **6** or **6***a*. Two or more supply conduits (and an equal number of tangential outlets **11**) are utilized for admission of slurry to the cyclone chambers **10** of relatively large cells. The outlets **11** are preferably equidistant from each other to insure uniform circulation of slurry in the lower portions of the chambers **10.** A large cell will be provided with two or more equidistant evacuating pipes **12** or openings; this insures that the pressure of the air cushion **16** is uniform in all zones of the cyclone chamber **10** and guarantees greater uniformity of froth formation in the chamber **7.** An air cushion which is maintained at a uniform pressure further prevents undesirable turbulence in the chamber **7.** Since the air which is withdrawn by the pipes **12** enters the container **19,** the cell operates practically without any losses in compressed air; this contributes to the economy of operation. The air which is admitted into the right-hand compartment of the container **19** shown in FIGS. **2** and **3** serves to aerate the slurry as well as to convey the slurry toward the next lifters **4.** Such air is normally not sufficient to insure a saturation of the slurry and its entry into the next-following cell. Therefore, the improved machine preferably comprises a separate lifter **4** for each supply conduit.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features which fairly constitute essential characteristics of the generic and specific aspects of our contribution to the art and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended

We claim:

**1.** A flotation method of separating a first class of particles from a second class of particles which are intermixed with the particles of said first class in a pulp and wherein the particles of said first class exhibit the tendency to adhere to gas bubbles, particularly of separating one class of minerals from another class of minerals, comprising the steps of lifting said pulp by means of a compressed gas which is supplied in a quantity exceeding the maximum quantity capable of being dispersed in said pulp so that only a portion of said compressed gas becomes dispersed in the pulp together with gas in excess and forms bubbles therein; introducing the thus lifted pulp tangentially into an at least substantially enclosed circular area and confining the thus introduced pulp to circulation in said enclosed area to prevent uncontrolled escape of undispersed gas and at least to maintain the dispersion of said portion of gas in the circulating pulp whereby the particles of said first class adhere to said bubbles with attendant formation of froth containing at least a substantial percentage of particles of said first class and with simultaneous formation of a residue containing the particles of said second class; transferring said first and second particles to a collecting chamber spaced within said enclosed area and separating the froth from said residue; and effecting a controlled removal of undispersed gas from said enclosed area.

**2.** A method as defined in claim **1,** wherein said undispersed gas forms in the enclosed area a cushion above the circulating pulp.

**3.** A method as defined in claim **2,** further comprising the step of maintaining the gas of said cushion at a pressure of less than 1 atmosphere above atmospheric pressure.

**4.** A method as defined in claim **2,** further comprising the step of maintaining the gas of said cushion at a pressure of 0.4–0.6 atmospheres above atmospheric pressure.

**5.** A method as defined in claim **1,** wherein said step of effecting controlled removal of undispersed gas comprises removing unidispersed gas from the enclosed area at several points which are equidistant from each other, as considered in the direction of circulation of pulp in the enclosed area.

**6.** A method as defined in claim **5,** further comprising the step of independently regulating the withdrawal of gas at each of said points.

**7.** A method as defined in claim **1,** further comprising the step of introducing the removed undispersed gas into said residue subsequent to a separation of said froth so that the thus introduced gas is dispersed in said residue.

**8.** A method as defined in claim **1,** further comprising the step of continuously lifting into said enclosed area fresh pulp so that the fresh pulp enters the enclosed area by flowing in the direction of circulation of pulp in said enclosed area.

**9.** A method as defined in claim **8,** wherein the pulp is admitted into the enclosed area at several points which are equidistant from each other as considered in the direction of circulation of pulp in the enclosed area.

**10.** In a flotation machine for the separation of a first class of particles from a second class of particles which are intermixed with particles of said first class in a pulp and wherein the particles of said first class exhibit the tendency to adhere to gas bubbles, particularly for the separation of a first class of minerals from another class of minerals, a combination comprising a receptacle for a supply of pulp; a cell having an annular chamber and a flotation and froth collecting second chamber surrounded by said annular chamber, said chambers having communicating lower portions and said annular chamber being at least substantially sealed from the surrounding atmosphere; conduit means connecting said receptacle with said annular chamber and having at least one outlet disposed substantially tangentially of said annular chamber to promote the circulation of pulp therein; pneumatic lifter means for admitting into said conduit means a compressed gas at such pressure and in such quantities that the thus admitted gas conveys the pulp into said annular chamber and a portion thereof is dispersed in the pulp during lifting of pulp into said annular chamber whereby the undispersed portion of said gas accumulates in said annular chamber and the circulating pulp contains bubbles of gas to which particles of said first class adhere to form a froth not later than on entry into said second chamber; and means for effecting a controlled removal of undispersed gas from said annular chamber.

**11.** A combination as defined in claim **10,** wherein said annular chamber is an upright chamber and said cell further comprises a lower end portion which establishes the communication between the lower portions of said chambers.

**12.** A combination as defined in claim **11,** wherein said lower end portion is a funnel which is coaxial with and diverges upwardly toward the lower portions of said chambers.

**13.** A combination as defined in claim **10,** further comprising at least one additional cell disposed at least substantially at the level of said first mentioned cell and additional conduit means connecting said cells, each additional conduit means containing a lifter means.

**14.** A combination as defined in claim **10,** wherein said means for effecting controlled removal of undispersed gas comprises a plurality of discrete gas removing devices each of which is arranged to remove undispersed gas from said annular chamber independently of each other gas removing device.

**15.** A combination as defined in claim **10,** wherein said means for effecting controlled removal of undispersed gas comprises a plurality of discrete gas removing devices each having means for adjusting the rate of gas removal.

**16.** A combination as defined in claim **10,** wherein said means for effecting controlled removal of undispersed gas comprises a plurality of discrete gas removing devices, said gas removing devices being uniformly distributed as considered in the circumferential direction of said annular chamber.

**17.** A combination as defined in claim **10,** wherein said means for effecting controlled removal of undispersed gas comprises at least one adjustable regulating valve which controls the removal of gas from said annular chamber.

**18.** A combination as defined in claim **10,** wherein said cell further comprises a lower end portion which establishes communication between the lower portions of said chambers and collects the residue of pulp which is not converted into froth, and further comprising a vessel and conduit means for admitting said residue from the lower end portion of said cell into said vessel, said means for effecting controlled removal of undispersed gas from said annular chamber being arranged to introduce the removed undispersed gas into the residue in said vessel.

**19.** A combination as defined in claim **18,** wherein said vessel comprises two compartments one of which receives residue from the lower end portion of said cell, and an adjustable partition over which the residue flows into the other compartment.

**20.** A combination as defined in claim **10,** wherein said outlet means comprises at least one substantially horizontal nozzle, said means for effecting controlled removal of undispersed gas from said annular chamber comprising at least one upwardly extending pupe having at its lower end an inlet located in said annular chamber at a level disposed at least **50** millimeters above the axis of said nozzle.

**21.** A combination as defined in claim **20,** wherein said pipe extends substantially vertically upwardly to a level above the maximum levels of pulp and froth in said chambers.

**22.** A combination as defined in claim **10,** wherein said cell further comprises a lower end portion which communicates with the lower portions of said chambers and the lower portion of said second chamber is apertured so that froth must pass through said apertured lower portion while flowing from said annular chamber into said second chamber.

**23.** A combination as defined in claim **22,** wherein said apertured lower portion constitutes the bottom wall of said second chamber.

**24.** A combination as defined in claim **22,** wherein the size of each aperture in said lower portion of said second chamber substantially exceeds the maximum size of particles in the pulp.

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