United States Patent [19]

Hart

[11] **3,834,529**

[45] **Sept. 10, 1974**

[54] **DEVICE AND METHOD OF DENSITY MEASUREMENT AND CONTROL OF FLOTATION SYSTEMS**

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[22] Filed: **Jan. 20, 1972**

[21] Appl. No.: **219,221**

[52] **U.S. Cl.** **209/1,** 209/166, 210/96

[51] **Int. Cl.** **B03b 9/00,** B03b 13/00

[58] **Field of Search** 209/162, 164, 172.5, 166, 209/168, 169, 170; 210/96, 42; 73/438, 439

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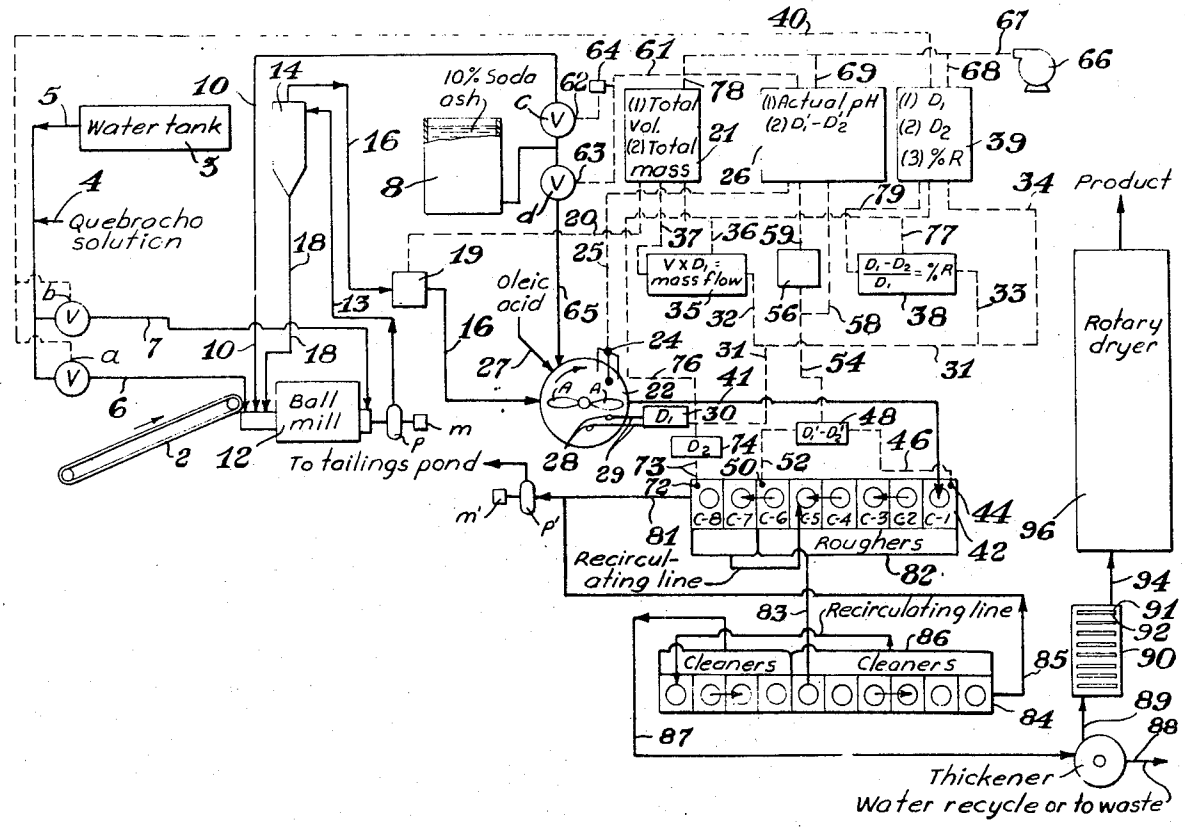
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[57] **ABSTRACT**

Two open-end tubes are vertically immersed, open-end down at substantially the same level, one near the place of entrance of a liquid in process in a series of treating vessels and the other near the outlet of the liquid whereby densities of the liquid at the respective locations are measured by means of a suitable pneumatic assembly, the density values are translated to and recorded as a pneumatic pressure differential and the pneumatic pressure differential is either (1) automatically converted to and recorded in meaningful values and the indicated adjustments manually made to restore and tend to maintain the optimum density differential, or (2) directed to an optimizer whereby optimum adjustments are automatically made to restore and tend to maintain a maximum density differential. Where a fluctuating level of liquid exists, two probes immersed at different depths to define a fixed stratum may be used in cooperation to obtain one density value.

8 Claims, 6 Drawing Figures



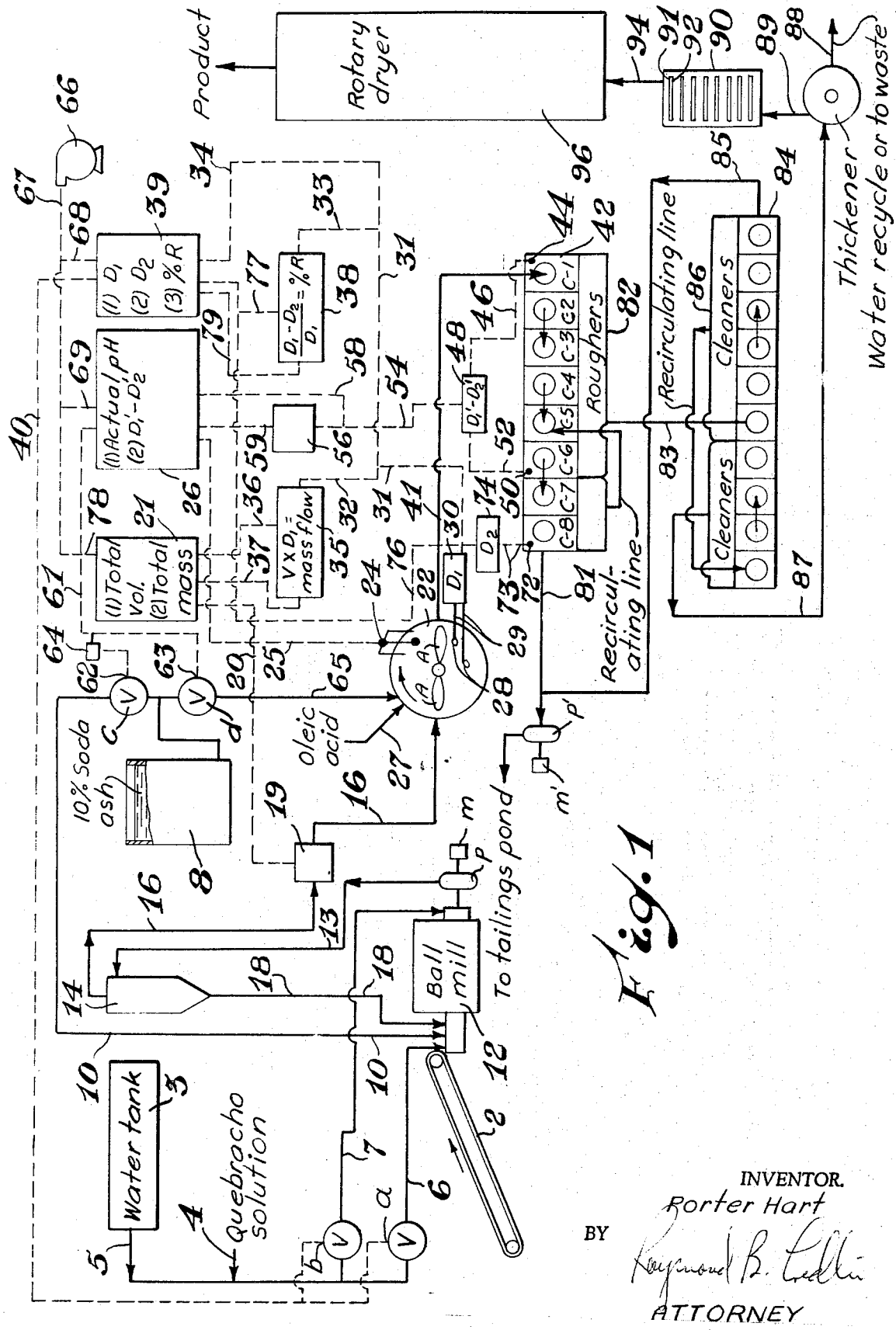


Fig. 1

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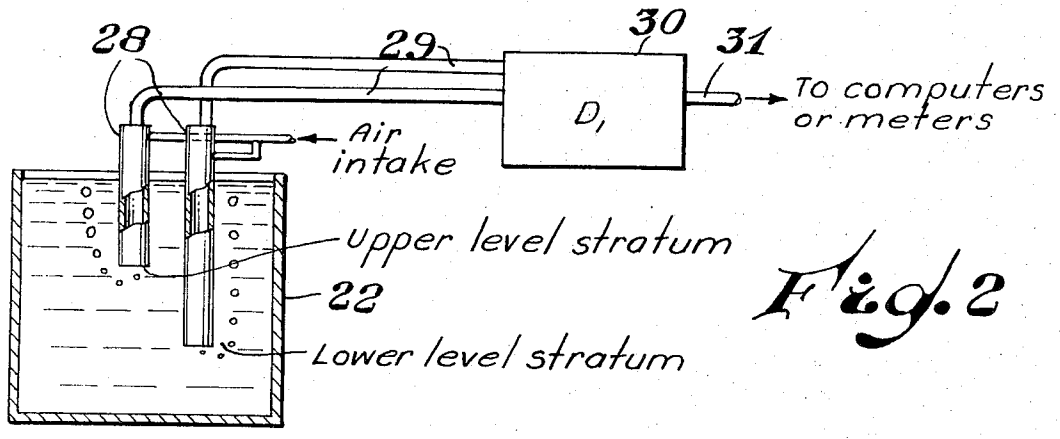


Fig. 2

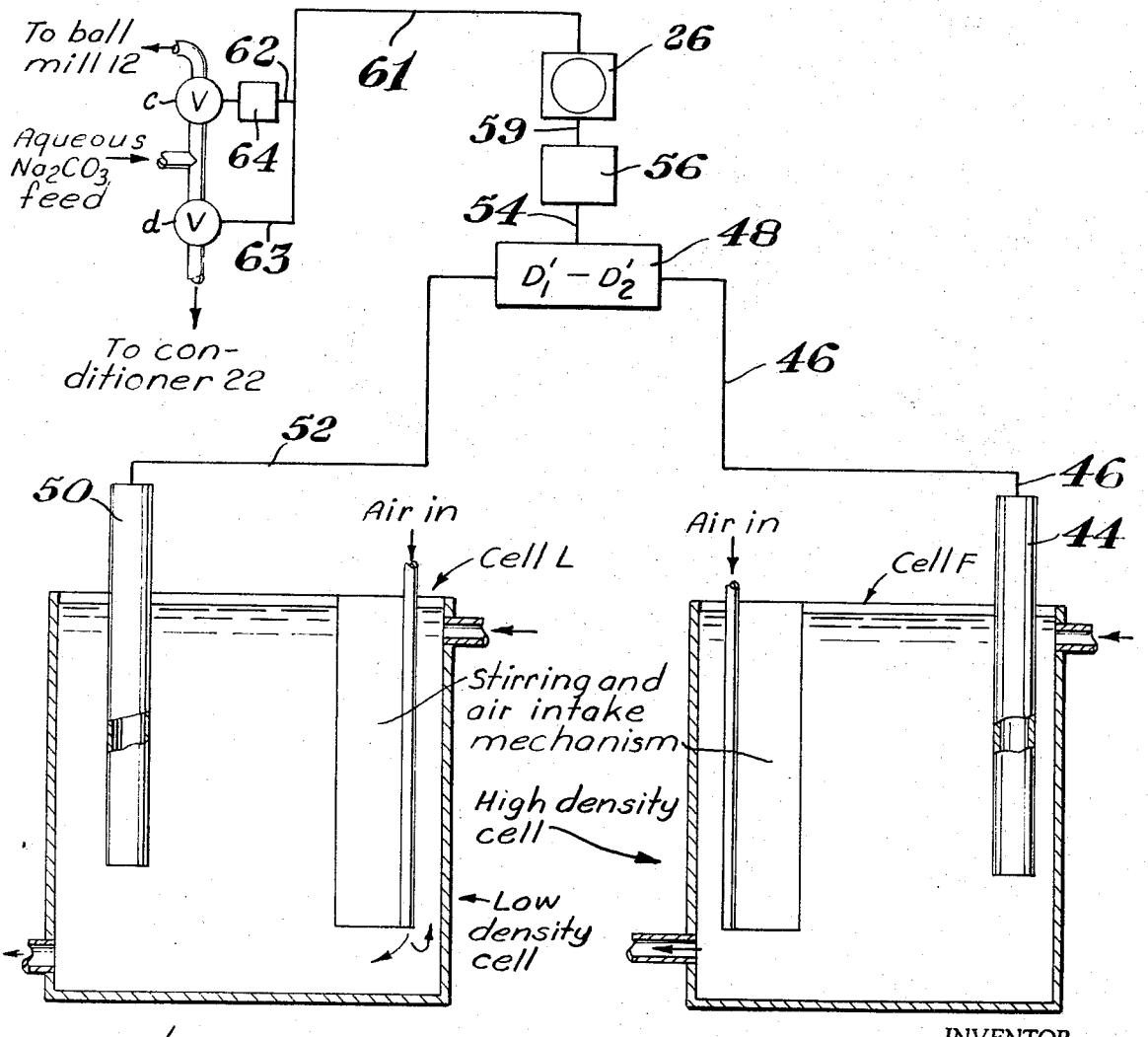


Fig. 3

42

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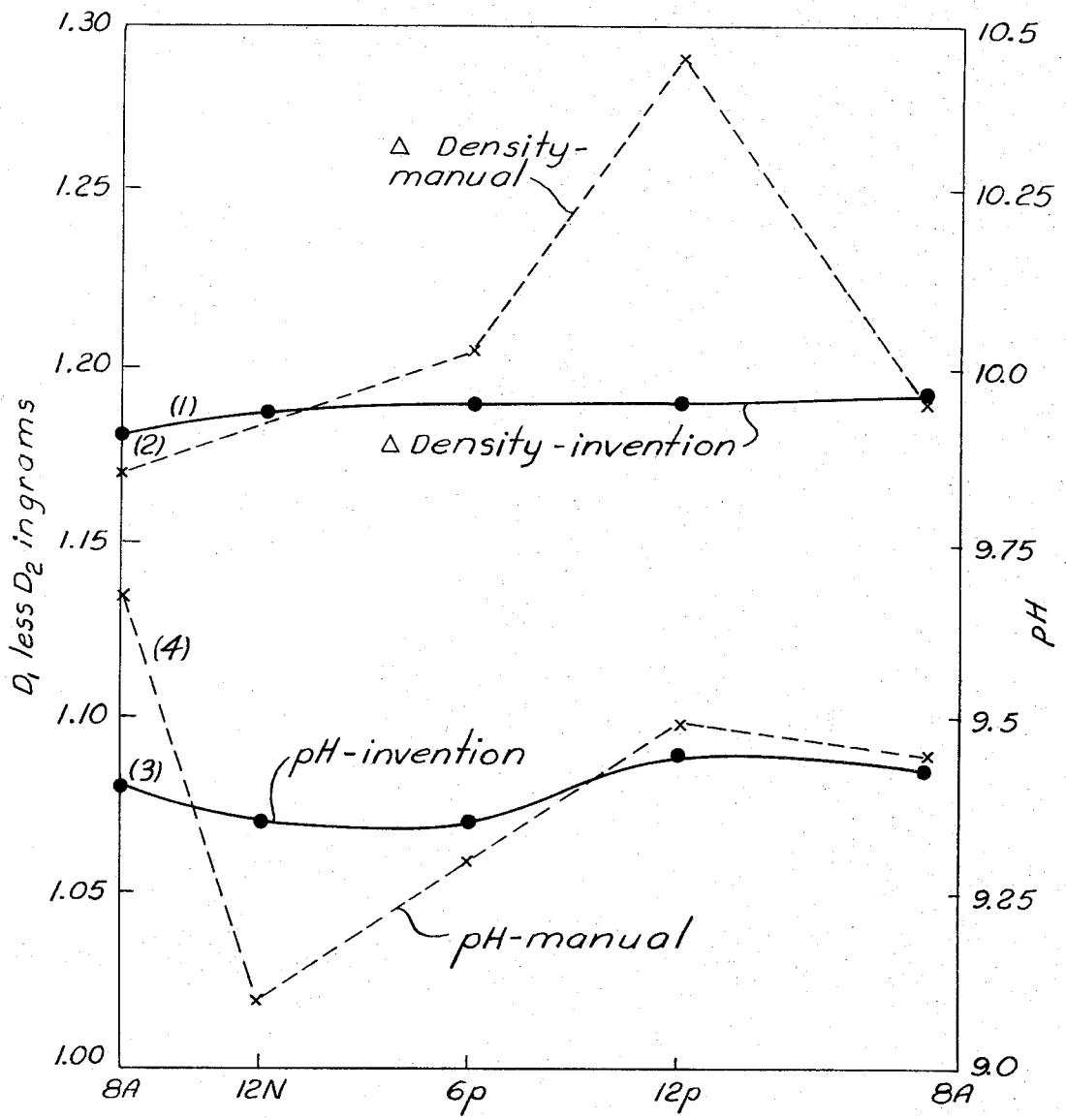
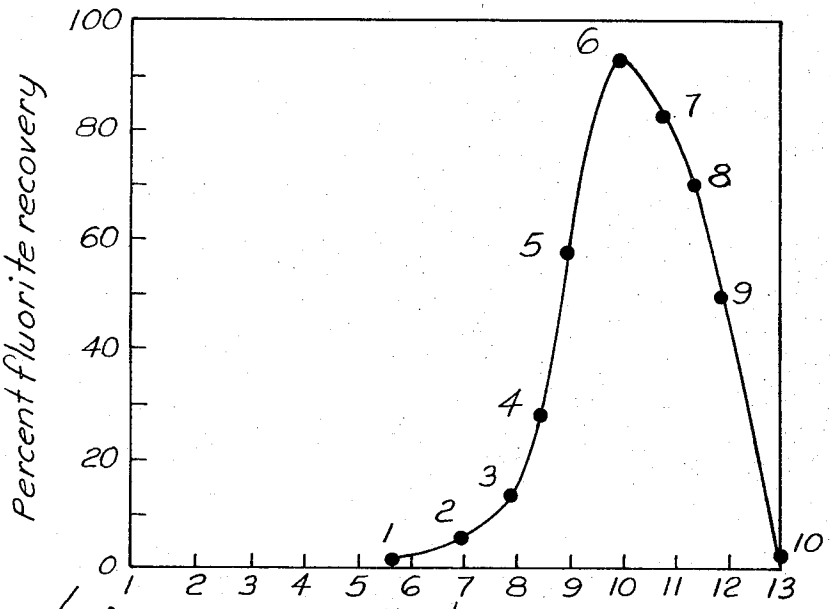


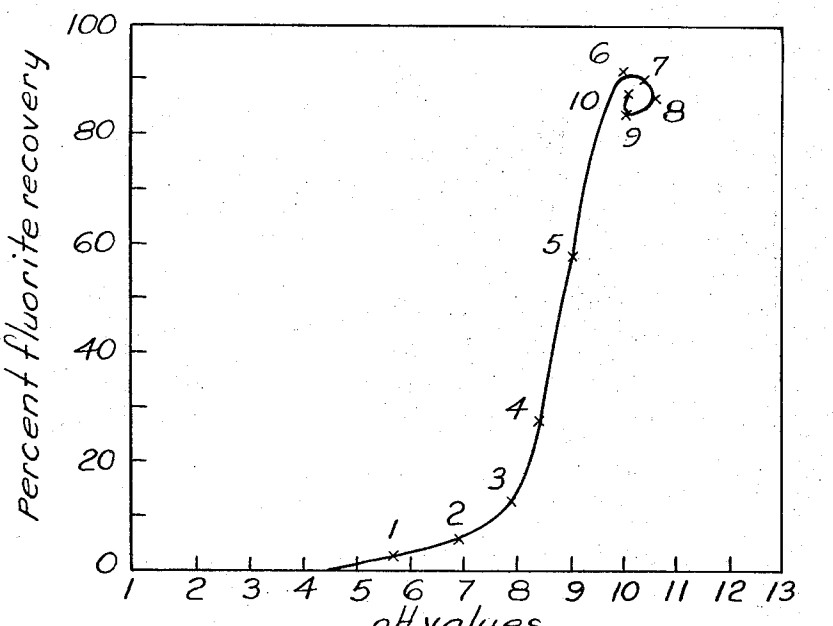
Fig. 4

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Lack of alkalinity control

Fig. 5



Alkalinity control attained by optimizer density probe

Fig. 6

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DEVICE AND METHOD OF DENSITY MEASUREMENT AND CONTROL OF FLOTATION SYSTEMS

BACKGROUND OF THE INVENTION

In many processes conducted in liquid phase, it is essential for control thereof to ascertain and control the density at various stages. Density differential very often is also indicative and sometimes an accurate measurement of the efficiency of the process. Illustrative of the latter are ore flotation systems wherein a mineral is separated by passing an aqueous slurry of finely ground ore containing conditioning agents through a series of open-top chambers or vessels (usually called cells), positioned substantially horizontally to each other, each provided with an upwardly directed air supply and troughs or trays along the upper edges thereof to collect and drain away the desired mineral which is frothed off, sometimes aided by additional water supplied to the collection system, and usually thereafter thickened and dried. For specific consideration the separation of fluorite (which term will herein be used interchangeably with substantially pure CaF_2) from fluorspar ore is illustrative. Fluorite which is the principal component of the ore and which is of greatest density, is frothed off as the slurry moves through the vessels, commonly called rougher cells. Accordingly, the density of the slurry is lessened as it passes from cell to cell. The efficiency of the system is indicated by the difference in density of the slurry in the successive cells and particularly between the first and last cells of a series. In general, the greater the difference in density, the more of the desired heavier mineral is being floated off.

Heretofore, density values have been obtained by manually taking samples of the slurry as it enters the first cell and again as it leaves a subsequent cell, weighing the samples, and calculating the density differential. Although this has long been done by a convenient liter vessel attached to one end of a balance arm and having a calibrated spring scale attached to the other, such measurements are only roughly accurate, and also provide only periodic values; they do not provide adequate information for satisfactory control of the system. Not only is such method of measurement done only at intervals so that conditions between measurements are unknown, but the time lag between the time that awareness of an undesirable change in density is known and a correction is made and becomes effective leads to erratic results.

A need, therefore, exists for a method of continuous density differential measurement and for prompt correction and particularly for automatic correction to effectuate the greatest differential conducive to frothing off a high quality product. The invention fulfills this need to a most gratifying extent.

SUMMARY OF THE INVENTION

Broadly, the invention is a method of continuously measuring density, and particularly the concurrent measurement of density values at two stages of progress in a liquid system to ascertain the density differential, and the apparatus necessary for performing such method. The preferred mode of practicing the invention consists of a method and apparatus which measures such densities and density differential and promptly and automatically corrects the density differential to provide optimum conditions. Particularly the invention is a method and apparatus which continuously measures the differential between density values, converts such values instantly to a pressure differential, optionally relates the density differential to a calibrated recording instrument, to guide manual changes if desired, and/or simultaneously makes proper changes in one or more components of the source material being introduced into the system, whereby the density differential is optimized to maintain maximum recovery of product of improved quality.

Although the term pH (which strictly means only the reciprocal of the logarithm of the hydrogen ion concentration) is used herein to designate E.M.F. or electric potential produced in the slurry, it is to be borne in mind that such potential may be due in part to other contributing causes.

DESCRIPTION OF THE INVENTION

The invention is an improvement in flotation processes generally, and apparatus necessary for the practice thereof. To better understand the invention, conventional flotation, applicable to the recovery of CaF_2 product from fluorspar, is set out below.

Ore is pulverized, as by passing it through a rock-crusher, grizzly, or the like and then, after admixture with water to produce a slurry, some or all of the following treating agents are admixed therewith: a surface tension improving agent (known sometimes as a collector) to increase surface tension and to encourage bubble formation and stabilized froth, a suppressant to lessen the tendency of undesirable minerals present in the ore to rise in the froth, and an alkalinity-control agent to maintain desirable ionic potential in the slurry, and passing the so treated slurry in sequence: through a ball mill to reduce particle size; from the ball mill to a conditioning tank (conditioner) for thorough mixing and usually admixture of additional treating agents to attain a desired slurry composition for processing conditions; from the conditioner to a series of rougher cells wherein the slurry is agitated and into which are fed upwardly directed air to produce a mass of bubbles or froth, to which the desired mineral is attracted and adheres and which is caused to overflow out into collecting troughs positioned along the outer edges of the cells; from the collecting troughs (usually some additional water being admixed with the froth at this point) optionally into a second series of similarly designed cells (often called cleaners) by which the so collected foam is again subjected to air flotation and refined to a higher content of desired mineral; from the cleaners (or directly from the roughers) into a slowly agitated moderately heated tank (usually called a thickener) during which entrapped air escapes and considerable water separates as an upper layer and overflows to waste (or is recycled back to the ball mill to be used to slurry additional ore) leaving in the thickener a high viscosity but easily pumpable slurry; from the thickener the so thickened slurry of recovered mineral passes from the bottom thereof to a filter system which is preferably a vacuum dewatering type which comprises envelopes connected to an internal vacuum system to provide interior low pressure, arranged on a wheel which rotates on a horizontal axis so as to define an arc passing below the upper surface of the body of the thickened mineral slurry, causing slurry to adhere to

the outside as a wet cake and water to be removed therefrom through the internal vacuum system, and to rotate through a second arc above the surface of the slurry where the envelopes scrape against fixed blades which remove the cake as wet crumbles; from thence the cake crumbles drop onto a conveyor and are conveyed to dryers which produce a dehydrated commercially acceptable CaF_2 product.

All necessary crushers, ball mills, conveyors, treating compound inlet and feed lines, transfer lines, control valves and pumps, rougher cells equipped for mechanical agitation, aerating and collection means, conditioning and thickener tanks, vacuum dehydration means, and dryers (all of which are known in the art) are located in accordance with a recommended lay-out suggested by advanced technology of ore treatment processing.

The improvement, in broad terms, of the above conventional general procedure and equipment which is the instant invention, comprises a method and means of continuous measurement of density differential of a mineral slurry at selected successive stages in a flotation system which differential is continuously recorded and serves as a basis for judicious adjustment of at least one component or condition of the process and provides for prompt adjustment thereof, e.g., a component of the feed composition in accordance with the density differential, to provide optimum recovery and improved quality of product. This is attained inherently in the novel system by converting the density differential to a pressure differential which is transferred as a pneumatic impulse. This may be done by directing the impulse to a recording instrument which is observed and acted on. The impulse preferably, however, is directed to an optimizer which automatically directly adjusts an ingredient in the feed to that proportion which results in the highest per cent recovery which is consistent with good quality. This is a peak-seeking optimizer which continuously changes the selected ingredient to result in optimum density differential.

The novel aspects and mode of operation of the improved process of the invention include cooperating mechanisms (the most critical of which are identified immediately below by small letters) for obtaining continuous density values converted to pressure differential employing (a) open-bottomed tubes (called hereafter density probes) positioned substantially vertically in the slurry at selected successive stages of the process, which connect at the top with tubing filled with dead air which terminate in (b) a two-chambered density cell, against a flexible diaphragm therein, which forms the density cells where, by density variations, the densities are converted to corresponding pressure variations in each chamber, called herein D_1 and D_2, respectively, for the selected stages. The differential between D_1 and D_2 is either calculated and a pneumatic impulse sent to a recording meter for quick reading and manual adjustment made or an impulse is sent directly to (c) an optimizer which optimizer continuously seeks the greatest D_1-D_2 or peak value possible and automatically relays this directly to a control which adjusts a component or condition so as to maintain the highest D_1-D_2 value.

If desired, the pneumatic impulse from the density pressure cell may go both to the recording meter and to the optimizer whereby the potential difference in the slurry (which as aforesaid for practical purposes may be thought of as the pH value) is made of record but wherein the change is promptly made automatically by the peak-seeking optimizer. To attain this latter end, an electric line or pneumatic conduit leads from the optimizer (or continues from the meter) to an electric motor which actuates the valves that control that component of the feed which must be changed to result in the desired optimum condition, viz. optimum electric potential in the slurry being processed which in turn maintains a large density differential which results in increased product recovery.

It is to be understood that the invention may be practiced by employing variations and modifications of the above procedure so long as the concept of density measurement and automatic optimum adjustment of density, in accordance with the invention, is practiced.

The optimizer is available from instrument specialists e.g., Model 571 Syncro Optimizer MS-276701, as described and illustrated in "Operating Instructions" for said model published by Moore products Co., Spring House, Pennsylvania.

DESCRIPTION OF THE DRAWING

The drawing schematically illustrates an embodiment of the apparatus of the invention and that used to practice the method of the invention.

FIG. **1** shows the various parts of the assembled apparatus and the working relationship of a flotation system for carrying out the process of the invention.

FIG. **2** is a schematic view of an embodiment of the density measuring instrument of the invention wherein a fixed level is established between the lower ends of two cooperative probes which constitute one instrument to obtain a single reading. It is used where the surface level of the liquid under control fluctuates.

FIG. **3** is a schematic view of two instruments from which D'_1 and D'_2, and the differential thereof, of successive stages of a flotation operation, including the instrumentation referred to as (*a*) to (*c*) above, are shown.

FIG. **4** is a graph whereon the ΔD, i.e. $D'_1-D'_2$ density differential as read on the recorder and guided by the optimizer, is curve (**1**) and as obtained manually is curve (**2**); and the pH values as established by automatic adjustment according to the invention is curve (**3**); and the pH values as taken manually are curve (**4**).

FIGS. **5** and **6** are percent recovery values plotted against pH values of the slurry.

In the drawing the word "conduit" is used for tube connections filled with air which effectuate desired changes by pneumatic impulses. The word "line" refers to flow lines for liquids. Electric connections are referred to as wires or wiring.

In more detail, the significant members of the assembled flotation system of FIG. **1** are represented by the following designations:

Item **2** is a moving endless apron for conveying crushed ore from a mine or storage pile. Item **3** supplies water (which need be neither deionized nor softened for use in the invention). Line **4** supplies a suppressant, e.g., an aqueous solution of quebracho. Both **3** and **4** lead into line **5** which bifurcates, through control valves (*a*) and (*b*), into lines **6** and **7**, respectively. Tank **8** supplies an alkalinity control agent, e.g., an aqueous solution of soda ash, which connects with line **10**. Lines **6** and **10** supply water and conditioning agents to the

ore as it enters, and line 7 as the ore leaves, ball mill 12 (i.e., a drum rotating on a substantially horizontal axis or inclined slightly towards the outlet end, and containing freely moving steel balls for grinding ore). Item 13 is the outlet line from 12 which by means of pump (*p*) powered by motor (*m*) conveys slurry to 14 which is a cyclone separator of coarser and finer grind ore (in aqueous slurry containing the additives). Item 16 is an outlet line for finer grind ore from 14 leading directly to further processing and line 18 is an outlet line for coarser grind ore from 14 leading back to 12 for regrinding. Instrument 19 positioned in line 16 is a total ore volume measuring instrument which is connected by electric wire 20 to the first of two pens on recording instrument 21 which records hourly total ore volume thereon. Line 16 terminates in conditioning tank 22 known as a conditioner for finely ground ore slurry from the ball mill, provided with a high speed agitator (A). Positioned in 22 are electrodes T and S comprising electrode pair 24 made of erosion-resistant material (as described in co-pending application Ser. No. 219,230, entitled "METHOD OF CONTINUOUS MEASUREMENT AND CONTROL OF FLOTATION CONDITIONS", of Porter Hart, filed concurrently herewith) which are provided with electric wiring 25 connected thereto and leading to a first recording pen which records continuously the electrode potential, which for simplicity may be considered to be the alkalinity of the slurry, on meter 26 (which for practical purposes may be considered a pH meter). Electrodes 24 are not essential to the practice of the invention but give an accurate slurry EMF (which for simplicity as indicated may be called pH value) at any time and serve as an independent source of knowledge of the conditions of operation.

Feeding into 22 is a surface tension improver or collector agent, e.g., oleic acid, by means of system 27.

Also in conditioner 22 there are shown a pair of cooperating vertical tubes 28, open at the bottom and containing air as shown in FIG. 2. They are, as shown on FIG. 2, immersed to different depths in the slurry, e.g., a difference in depth of about twenty to thirty inches between the open lower ends, thereby defining a fixed stratum or layer of slurry upon which to calculate the slurry density. By means of conduits 29 and instrument 30 (a pressure-density cell) there is provided an accurate density reading D_1 by reason of corresponding pressure changes. This D_1 value is conveyed through conduit 31 into three conduits, viz: 32, 33, 34: conduit 32 leads to computer 35 where the volume (V) value from meter 21 through conduit 36 is received and the calculation $V \times D_1 =$ mass flow is made and the result sent by pneumatic signal through conduit 37 to a second pen on meter 21 for recording mass flow thereon. Conduit 33 leads to computer 38 to provide the D_1 value to the computer. Conduit 34 leads to a first pen on meter 39 which records the D_1 value continuously. Conduit 40 leads from meter 39 to valves (*a*) and (*b*): valve (*a*) provides automatic control of water containing quebracho into line 6 for entrance to ball mill 12 and valve (*b*) provides automatic control of water containing quebracho into line 7 as the slurry leaves ball mill 12.

Line 41 leads conditioned ore from 22 to cell C-1, the first of the series of rougher cells designated collectively item 42. Density probe tube 44 (similar to the longer tube of 28 and described more fully hereinbelow), is submerged in cell C-1. Via air conduit 46 the density D'_1 of the slurry in cell C-1 (converted to corresponding pressure) deflects a flexible diaphragm in accordance therewith, in two-chambered density-pressure instrument 48. Cell C-6, the sixth of rougher cells 42, is provided with density probe 50 (similar to probe 44 of cell C-1) which by way of conduit 52 converts the density D'_2 of the slurry in cell C-6 to pressure which also tends to deflect the flexible diaphragm in density-pressure instrument 48 (against the opposing pressure responsive to the density of C-1) in accordance with the pressure changes. By means of the pressure-activated diaphragm positioned between the two chambers in 48, a pneumatic impulse, responsive to the pressure differential, is passed along conduit 54, sending one signal into optimizer 56 and a second signal through conduit 58 to a second pen on meter 26 which continuously registers the actual, i.e., existing, D'_1–D'_2 or $\Delta D'$ value for purposes of record.

Optimizer 56 continuously and automatically seeks the greatest density differential (D'_1–D'_2), since the greater differential in density indicates the greatest efficiency of the rougher cells. An important condition for high recovery is the correct amount of alkalinity control agent (usually soda ash solution) added. Exact and quick adjustment of soda ash is accomplished by the optimizer passing optimum desired pH value signals, via conduit 59, to a pointer on meter 26 where they are continuously indicated for reference purposes and which the pH recording pen thereon tends to follow. However, by means of conduit 61, the optimizer-guided pneumatic impulses are promptly passed on through branching conduits 62 and 63 to valves *c* and *d*, respectively which, by means of gap controller 64, control two branch flows from soda ash supply system, of the alkalinity control additive (e.g., an aqueous solution of soda ash). Valve *c* regulates flow through line 10 to ball mill 12 and valve d regulates flow through line 65 to conditioner 22 in desired proportions, usually about twice as much being directed to 12 as to 22. It should be understood that soda ash is used here for illustrative purposes. For some ores it is necessary that flotation be conducted in a neutral or acid medium, i.e., at a relatively low pH and an acidifying agent would be added.

An air supply system is represented by source 66, main conduit 67, and branches 68, 69, and 70, which system provides available pneumatic pressure as needed in the various conduits for automatic control.

As the slurry is moved from cell to cell in roughers 42, leaving each preceding cell and entering the next succeeding cell, while being agitated and while air is blown upwardly therethrough foam is produced which carries CaF_2 to the top of the cells and froths it off into the collecting troughs 82.

A third density probe 72 (of the type designated 44 and 50) is immersed in cell C-8 whereby density D_2 value is obtained by means of conduit 73 leading to pressure-density diaphragm cell 74. The D_2 value of C-8 is conveyed therefrom via conduit 76 to a second pen on meter 39 whereby D_2 is recorded. Branching off of conduit 76 is conduit 77 which feeds the D_2 value into computer 38 for calculating D_1–D_2/D_1 = percent recovery (percent R). This percent R value is conveyed by pneumatic signal via conduit 79 to a third pen on meter 39 whereby it is recorded.

The slurry which has not been frothed off in roughers 42 passes from a point near the bottom of cell C-8 through line 81 and, by means of pump p' and motor assembly m', is forced to a tailings pit or pile.

The high CaF_2 content material, i.e., concentrates, from roughers 42 is frothed off into collecting trough system 82 from which it ultimately passes through line 83 to cleaners designated collectively 84, which are actually additional flotation cells (and not always necessary) and which are very similar to 42 but which are designed to accept the once-frothed off ore as feed which is of much higher CaF_2 content than slurried fresh ore feed. That portion of the slurried concentrates which is not frothed off at cleaners 84 (similarly as from roughers 42) passes out from a point near the bottom of the last cleaner cell through line 85 into line 81 and thence to the tailings pile. The recovered froth from cleaner cells 84 passes into collecting troughs 86 and ultimately into line 87 leading to thickener vessel 88 under slow agitation where a large percent of the water content thereof rises to the top and overflows to waste (or is recycled for reuse with fresh ore) as the concentrates settle toward the bottom and thickens. From thickener 88, as a high viscosity fluid, the CaF_2 is drawn off the bottom of 88 through line 89 into filter system 90 comprising envelopes which are subjected to interior vacuum, alternately being submerged in the thickened slurry which clings thereto to form a cake, and thence being brought out of the slurry into contact with fixed scraper blades that remove the cake (not shown in detail). The rotating envelopes and stationary blades are identified schematically as items 91 and 92, respectively.

The so removed cake (now wet crumbles) is passed via conveyor 94 to dryer 96, which in practice customarily consists of a series of connected drying units, which produces a 97.4 percent or higher anhydrous CaF_2 powder.

Although pneumatically operated controls are shown in the illustration, it should be understood that, other than the pressure impulses received from the density probes by the pressure cells, all signals may be transferred and measured by means of an electric system.

FIG. 2 shows two tubes in combination to define a fixed depth or stratum to obtain a single density value (where the level in the container varies) so that the volume at which density (D_1) is measured remains the same. It is used, for example, when the density is obtained from conditioner 22. Since air must be provided to maintain adequate and substantially dead air in the probes, a metering valve, opening for admission of air without objectionable accompanying air currents, is provided in each of the two tubes comprising the probe.

FIG. 3 shows in some detail the assembly comprising density probes 44 and 50, conduit 46 leading from probe 44 and conduit 52 leading from probe 50 to opposing chambers D'_1 and D'_2 of density-pressure differential instrument 48. The probes, as aforesaid, are elongated hollow cylinders which are open at the bottom and closed at the top to form dead-end systems terminating at the flexible diaphragm which separates 48 into D'_1 and D'_2 chambers. The diaphragm responds to slight changes in pressure differential thereagainst which changes are promptly transferred from instrument 48 via conduit 54 to optimizer 56 and thence via conduit 59 to meter 26. The pneumatic impulses recorded on meter 26 are passed on via conduit 61 to gap controller 64 and valves c and d. Stirring and air supply assemblies are schematically represented and so labeled. Ample air is provided in tube probes 44 and 50 by air entering the cell bottoms for flotation.

FIG. 4 clearly demonstrates the improved control leading to assured improved efficiency and higher percent recovery attained by the practice of the invention.

FIG. 5 shows the percent CaF_2 recovered at increasing slurry pH values to show that recovery is substantially zero at too low or too high slurry EMF, herein referred to as pH values.

FIG. 6 shows that the percent CaF_2 recovered remains high as the pH values are clustered about the optimum value as automatically set by the optimizer as it receives the signals from the pressure-density cell, the signals being in prompt response to the density differential based on densities measured by the probes in accordance with the invention.

The density probe for D'_2 need not be positioned in the cell selected in FIG. 1, although such is preferred. Any succeeding cell after cell C-1 can be used. Since by far the major portion of the flotation has been consumated by the time the slurry has passed from cell C-6, that cell is selected for illustration. The remaining cells, viz. cells C-7 and C-8 of FIG. 1, often called scavenger cells, froth off very little additional CaF_2 and sometimes none. However the D'_2 probe could be satisfactorily placed in cell C-8 rather than cell C-6 to provide for automatic adjustment of the additament required to maintain optimum conditions. C-1 and C-6 are selected for D'_1 and D'_2 density values because a preponderance of the flotation is attained therebetween within a relatively short time and therefore automatic adjustments based thereon are made as promptly as possible.

The principal use of D_1 density, i.e., the density of the unfrothed slurry, is for the purpose of controlling the total solids, (i.e., amount of water added to the ore) in the ball mill. D_2 is the density of the tailings. Both values are used for the calculation: $D_1–D_2/D_1$ to give the overall percent CaF_2 recovery.

EXAMPLES

To illustrate the practice of the invention in comparison with conventional practice employing as nearly as possible the same mill lay-out, ore, and processing techniques except that, in the practice of the invention, the hereinafter claimed density-pressure probes and optimizer control of soda ash were employed whereas control was exercised in the conventional or comparative example in accordance with the most efficient techniques known prior to the instant invention.

The most significant operating conditions and results obtained for illustrative and comparative examples are shown in Table I.

Comparative

This example was conducted to illustrate the recovery of CaF_2 from fluorspar ore in accordance with conventional practice. Complete daily records were maintained for a prolonged period of continuous operation. The procedure followed consisted of feeding crushed fluorspar ore by way of conveyor 2 into ball mill 12 as shown in FIG. 1 into which were also fed 10 percent by weight aqueous solutions of quebracho and soda ash and sufficient water to provide the desired solids. The

ore was thereby converted to a conditioned slurry of fine particle ore. From **12** the slurry was passed into a cyclone separator of the type designated **14** in FIG. **1.** Therein particles coarser than 200 mesh size were returned to the ball mill and the finer particles were pumped to a highly agitated conditioning tank (e.g., conditioner **22**) into which concurrently were fed oleic acid and additional aqueous soda ash solution controlled as needed.

From the conditioner the substantially uniformly mixed treated ore slurry was caused to flow to the series of flotation (rougher) cells as represented by **42** of the drawing.

Air was released into each cell near the bottom center by way of an annular opening about the shaft of a rotating stirrer-centrifugal pump assembly (illustrated in FIG. **3**) vertically positioned in each cell to produce froth. The CaF_2 being attracted to the froth in the cells, rose to the top thereof, was caused to overflow, and was collected as a slurry in troughs positioned along the outer edges, where, aided by limited additional water flow, it was drained away, and thereafter subjected to a second flotation treatment in similar series of cells known as cleaners, e.g., **84** of FIG. **1** of the drawing. The uncollected portion of the slurry in rougher cells **42** was drained away to a tailings pond as also was the uncollected portion of cleaner cells **84.** The recovered froth from the cleaners **84,** usually aided by more additional water for satisfactory flow, was pumped to a relatively large moderately heated tank **88,** called a thickener, provided with very slow agitation wherein an appreciable amount of the water present continued to rise and was separated by its overflowing. From **88** the thickened paste-like slurry was flowed at a controlled rate from the bottom thereof to filter (dewatering) system **90** comprising exhausted envelopes, i.e., envelopes **91** having a vacuum applied to the interior causing the thickened slurry to cling to the exterior, whereby moisture was drawn inwardly from the slurry by the vacuum leaving a cake-like layer on the envelope exteriors. This layer was removed by causing the envelopes to rotate against fixed scraper knives or blades **92** (or if more convenient the knives may be moved across the envelopes) causing the wet recovered mineral to fall in crumbles on a conveyor, e.g., **94,** and be taken into the first of a series of dryers represented by **96.** The dryer produced an anhydrous CaF_2 product.

The only process control practiced in the above conventional operation, other than observation and "hand feel" consisted essentially of ore analyses, periodic sampling for manual determinations of both pH and density, and laboratory analyses of the periodic samples of the CaF_2 product.

The conditions and results of the conventional examples are shown in Table I.

Example of the Invention

The following example is illustrative of the practice of the invention. As aforesaid, the rate of feed of ore, the additives, and flotation principles applied and the general flow pattern were substantially the same as in the above comparative example except that the techniques applied to the control of the process were those of the invention.

Fluorspar ore, quebracho, soda ash, oleic acid, and water were fed into the system similarly as in the example of conventional practice hereinabove. However, meter **19** was positioned in line **16** so that, as the ore slurry moved therethrough, the total ore mass thereof was measured and a correlated signal transmitted by wire **20** to recording instrument **21.** Complete daily records were maintained for the same period of time as in the above example of conventional practice.

By the term positive-negative electrical potential as used herein is meant any variation in electrode potential in a liquid.

In accordance with the invention the pair of density probe tubes **28** in conditioner **22** were positioned so that the vertical distance between their lower open ends was 25 inches, thus giving a fixed stratum or layer of slurry for measurement of density. Likewise, by inserting single density probe tubes **44** and **50,** respectively, in rougher cells C-**1** and C-**6,** so that their open ends were 15 inches above the bottom of the cells, a fixed stratum of slurry was defined since the cells are maintained full of liquid at all times during the flotation operation. The top of tubes **44** and **50** led into smaller flexible tubing lines **46** and **52,** respectively, which dead-ended on opposite sides of the diaphragm in D'_1–D'_2 meter **48** which converted the density values of the contents of cells C-**1** and C-**6** to a pressure differential which was transmitted via conduit **54** to optimizer **56** which translated the pressure differential to the desired EMF potential (which may be considered pH value) corresponding to maximum pressure differential. Conduit **59** carried the pneumatic impulse to **26** where it was indicated as the optimizer-guided desired pH value. Conduit **61** further relayed the pneumatic impulses from optimizer **56** via conduit **62** and **63** to motor valves *c* and *d* whereby adjustments were automatically made in soda ash feed, by means of gap controller **64,** which tended continuously to maintain an optimum feed composition. The cells **42,** cleaners **80,** thickener **88,** filter assembly **90,** and dryers **96,** were employed as in the conventional examples.

By means of the peak-seeking optimizer **56,** that pH was maintained which caused the Δ density, and hence percent CaF_2 recovered, to remain at the top of the curve shown in FIG. **6.** The optimizer attains this objective by continuously adjusting the rate of aqueous soda ash solution flow toward maximum density, i.e., whenever increments in soda ash continue to increase the Δ density, such increments continue to be made but when such increments result in a decrease in Δ density, the optimizer immediately calls for a reduction in soda ash and continues to make such reductions until the Δ density again is not improved by such decreases.

TABLE I

Ore Feed Kgm/ Min.	% CaF_2 in Ore	Kgm/ min. of CaF_2 available in Ore	10% aq. sol. of quebracho ml/ min.	10% aq. soda ash sol'n. ml/ min.	Oleic acid ml/ min.	Conditioner * % T.S.	Conditioner Temp.°C.	CaF_2 product Kgm/ min.	% CaF_2 Product based on CaF_2 ore Content	% CaF_2 in CaF_2 Product
Comparative (conventional) Examples										
140.28	58.0	81.4	500–900	1200–4300	3–5	32–33	110–130	50.00	61.5	97.4
130.50	67.3	87.7	500–1000	1100–4500	3–5	32–33	110–130	55.50	63.3	97.4
Example 1 of the Invention										
148.50	69.5	103.2	500	1400–2000	0.3	32	120	68.00	65.8	97.4
151.40	69.2	104.8	500	1500–1800	0.3	32	120	68.00	64.9	97.5

* % Total solids

Reference to Table I clearly shows a number of significant advantages due to the practice of the invention. Although exactly the same mill was employed for all examples, except for the use of the instrumentation of the invention, the following benefits of the invention are clearly realized:

1. the amount of ore, i.e., the rate of feed, that can be put through the mill is far greater;
2. the amount of quebracho (suppressant) required was steady;
3. the amount of soda ash was controlled within narrower limits;
4. the amount of oleic acid (collector agent) required was less;
5. the temperature in the conditioner was held more steady;
6. the percent of CaF_2 product (of the same purity) recovered, based upon the CaF_2 available in the ore, was considerably higher. (It is estimated that 1 percent greater recovery has a money value of about $500 per 100 tons of ore processed).

Although not specifically shown on the table, operation according to the invention was much more steady: the pH reading fluctuated over a much narrower range; the rate of ore feed and the periodic analyses of the recovered product showed less variation. The elimination of the man hours required for sampling the slurry and taking the pH and density by conventional methods released operators for other duties.

The percent of SiO_2 and $CaCO_3$ in the CaF_2 product were less than in that produced conventionally.

EXAMPLE 2

Shortly after the optimizer-density probe assembly of the invention had been installed, calibrated, and conditions stabilized, it was employed to guide and control a production size operation for 24 hours. The analysis of the ore being processed showed 76.80 percent CaF_2, 12.0 percent $CaCO_3$, 7.68 percent SiO_2 and about 1,000 ppm Be. Simultaneously with the practice of the invention, the slurry in process was sampled, the pH value and D_1 and D_2 density values obtained according to conventional procedures, and indicated changes that normally would have been made (but in fact were not) recorded every hour. The pH values, D'_1, D'_2 and hence D'_1 less D'_2 were automatically regulated in accordance with the invention. (Note that D_1 is taken in conditioner 22 and D_2 in cell C-8; D'_1 is taken in cell C-1 and D'_2 in cell C-8).

The optimizer through its peak-seeking principle continued to change the rate of addition of the soda ash solution at pre-selected intervals of siz minutes, increasing the rate of flow thereof so long as the density differential increased, but when such increase in flow of soda ash ceased to increase the density differential, reversing direction and decreasing the rate of flow of soda ash so long as the density differential was not decreased by such decreased flow.

The percent CaF_2 recovery, based on the CaF_2 content of the ore, is directly related to the D_1 less D_2 value and is calculated by $D_1–D_2/D_1$.

The production unit was started at 8 a.m. and continued until 8 a.m. of the following morning, following the method of the invention. Manual tests were taken regularly and calculations made based thereon but such tests were not used to control the operation.

TABLE II

Density Time	pH Values Manually Taken	pH Values From Optimizer-Density Probe Control	Percent CaF_2 Product Recovered Based on CaF_2 Content of Ore: Calculated Recovery if Operation Had been Guided by Manual Tests	Percent CaF_2 Product Recovered Based on CaF_2 Content of Ore: Actual Recovery Based on Optimizer Probe Control
A.M.				
8	9.7	9.35	52.2	59.6
9	9.4	9.35	64.2	72.6
10	9.5	9.35	60.8	68.5
11	9.3	9.30	64.2	70.3
12	9.2	9.30	74.0	71.6
P.M.				
1	9.3	9.25	63.6	67.4
2	9.5	9.30	79.6	69.6
3	9.4	9.25	61.6	69.2
4	9.2	9.20	55.6	66.6
5	9.2	9.25	47.2	52.8
6	9.3	9.30	59.4	70.4
7	9.3	9.35	66.6	72.8
8	9.3	9.35	65.3	69.2
9	9.3	9.35	65.3	67.0
10	9.4	9.35	65.3	69.2
11	9.1	9.40	66.0	64.0
12	9.5	9.40	66.0	70.0
A.M.				
1	9.3	9.40	64.0	70.0
2	9.5	9.40	65.0	65.8
3	9.5	9.40	55.6	65.0
4	9.3	9.40	63.2	69.8
5	9.3	9.40	63.0	70.4
6	9.4	9.40	60.6	69.6
7	9.5	9.40	60.0	78.0

Reference to Table II evinces convincingly the more reliable control promptly and effectively made by the practice of the invention.

Below is a summary showing the real recovery according to the invention and the recovery that would have been made had conventional practices been followed, i.e., had the manual sampling and the pH and density values which were thereby obtained been used to adjust the rate of flow of ore, water, and soda ash solution. The summary shows the superior performance of the method of the invention employing the required apparatus of the invention.

Shifts	Average Per Cent Recovery: Manual Operation	Average Per Cent Recovery: Optimizer-Density Cell Control
8 a.m. to 4 p.m.	65.0%	68.6%
D P)M) TO AB P)M)	61.3%	66.5%
12 p.m. to 8 a.m.	63.5%	69.8%

This increased recovery was achieved at a much higher ore through-put than conventional control would have permitted.

The above figures show that the more accurate density readings and the prompt changes in soda ash solution flow according to the invention make possible a more efficient operation. Of particular significance were the erratic density values obtained when the samples were manually tested. Had changes been made based thereon, compared to the relatively steady consistent density values obtained according to the invention, the lower percent recovery would have followed.

Having described my invention, what I claim and desire to protect by Letters Patent is:

1. In the recovery of mineral values from an ore slurry employing flotation principles wherein conditioning agents are admixed with water and pulverulent ore to make a treated slurry and said slurry is subjected to flotation by passing air upwardly through the agitated slurry in successive connected cells whereby the mineral sought to be recovered is collected in a froth which is overflowed and recovered from the thus provided overflow, the improvement comprising:

continuously measuring the density values of at least two of said cells, continuously converting the density values to a pressure differential which is proportional to the differential of density values;

causing a pneumatic impulse in accordance with variations in the pressure differential to be relayed to a continuous registering instrument to provide a continuous pressure differential record which is calibrated to show density differential;

adjusting at least one additive of the flotation process in accordance with the recorded density differential to tend to maintain said differential at a maximum.

2. The method according to claim **1** wherein the electrical potential (EMF) value of the slurry prior to its being subjected to flotation is continuously recorded so that, for purposes of process control, said electrical potential can be adjusted in accordance with changes in said density differential.

3. The method according to claim **2** wherein the electrical potential (EMF) is calibrated into pH values.

4. The method according to claim **1** wherein a pneumatic impulse in accordance with said pressure differential, as controlled and determined by said density differential, is continuously sent to an optimizer which automatically seeks the maximum density differential which is continuously recorded.

5. The method according to claim **4** wherein said maximum density differential is continuously converted to pH values and such values used to guide the amount of an ingredient which, when admixed with the slurry, modifies the electrical potential (EMF) thereof.

6. The method according to claim **4** wherein a series of pneumatic impulses provided by said optimizer are sent to the feed control of an ingredient which modifies the electrical potential (EMF) in the slurry and increases or decreases the rate of said feed to cause the potential to trend at predetermined time intervals in the direction of maximum density differential in the slurry bath in the two cells being measured.

7. The method according to claim **6** wherein the optimum positive-negative potential differential in the slurry bath is recorded as well as automatic adjustment made of the rate of feed of a positive-negative modifying ingredient to continue to modify that rate to one which gives maximum density differential between the density of the slurry at or near the beginning and that at or near the end of the flotation operation.

8. An apparatus for continuously measuring, recording and controlling an ore flotation process which comprises in combination:

1. at least two independently operating vertically positioned elongated hollow probes, open at the lower end, each immersed to substantially the same depth in a body of ore slurry, each probe being located at one of selected successive flotation stages and filled with a non-turbulent gas, substantially chemically unreactive with the slurry;
2. a tube extending from the upper end of each of said probes leading to opposite sides of a closed bichambered pressure-sensitive instrument, the chambers being formed by a dividing flexible membrane, thereby providing entrapped substantially dead gas in each probe-tube chamber combination, the pressure of which increases or decreases directly in response to the density of the liquid at the level of the lower end of each of said probes and deflects said membrane in accordance with the pressure differential and therefore in accordance with the density differential;
3. means for continuously measuring the electrical potential (EMF) of the ore slurry at a location prior to the first flotation stage and means for recording and adjusting said electrical potential; and
4. a peak-seeking optimizer responsive to the pressure differential provided by said pressure-sensitive instrument and which adjusts the said electrical potential (EMF) of the slurry at said location prior to the first flotation stage at the optimum necessary to maintain the pressure differential (and thus the ore recovery) at a maximum.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,834,529

DATED : September 10, 1974

INVENTOR(S) : Porter Hart

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 13, line 19, "DP)M) TO ABP)M)" should be changed to 4 p.m. to 12 p.m.

Signed and Sealed this

second Day of *September 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks