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(71) Applicant: **THE STANDARD OIL COMPANY**
200 Public Square, 36-F-3454
Cleveland Ohio 44114-2375(US)

(72) Inventor: **Szentiaszloi, Alex**
RD 1, Box 353
Hockessin Delaware 19707(US)
Inventor: **McDonnell, Francis J.**
2743 Harmil Road
Broomall Pennsylvania 19008(US)
Inventor: **Duttera, James V.**
1006 Polk Drive
Springfield Pennsylvania 19064(US)

(74) Representative: **Hoffmann, Klaus, Dr. rer. nat. et al**
Hoffmann . Eitle & Partner Patentanwälte
Arabellastrasse 4
D-8000 München 81(DE)

(54) **Apparatus and method for froth flotation.**

(57) Apparatus for froth flotation comprising a flotation tank having a series of cells separated by partitions but having a communicating common bottom sloped towards the feed end of the tank under all the cells. A method for froth flotation employing the novel apparatus is also disclosed.

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APPARATUS AND METHOD FOR FROTH FLOTATION

This invention relates to a method and apparatus for flotation separation and more particularly to a method and apparatus for beneficiating carbonaceous matter by flotation separation.

Coal is an extremely valuable natural resource in the United States because of its relative abundant supplies in this nation. It has been estimated that the United States has more energy available in the form of coal than in the combined natural resources of petroleum, natural gas, oil shale, and tar sands. Recent energy shortages, together with the availability of abundant coal reserves and the continuing uncertainties regarding the availability of crude oil, have made it imperative that methods for converting coal into a more useful energy source be developed.

Some known prior art processes for froth flotation separation of a slurry of particulate matter are based on constructions wherein air is introduced into the liquid slurry of the particulate matter as, e.g., through a porous cell bottom or a hollow impeller shaft, thereby producing a surface froth. These prior art methods are relatively inefficient approaches especially when large concentrations of particulate matter are being processed. Generally, these techniques are inefficient in providing sufficient contact area between the particulate matter and frothing air. As a result, large amounts of energy can be expended in frothing. In addition, froth flotation techniques which permit bubbles to rise in the slurry can tend to trap and carry impurities, such as ash in the froth slurry, and accordingly the resultant beneficiated particulate product can have more impurities therein than necessary.

With more particularity to the prior art, U.S. Patent No. 3,351,199 discloses an apparatus for froth flotation comprising a flotation cell divided in its upper part into compartments by partition walls. The flotation cell is described as being a rectangular or trapeziform elongated trough the bottom of which slopes away from the point at which the feed is introduced. The froth is removed by rotating paddles located at the top of the flotation cell.

U.S. Patent No. 2,350,943 discloses a countercurrent froth flow flotation system where the froth is caused to flow from the tailing end of the flotation apparatus towards the feed end. Concomitantly, the tailings are caused to flow counter to the flow of the froth and are discharged at the opposite end of the pulp body. The apparatus is comprised of a plurality of individual flotation cells arranged together in series to form a multiple cell unit in which free communication among the constituent cells, as well as a common pulp level are maintained, while at the same time the cells are operatively distinct one from another.

U.S. Patent No. 2,184,115 discloses an apparatus for flotation concentration of ores comprising a plurality of cells interconnected to permit the flow of concentrates from one cell to another and the counterflow of middlings and tailings from one cell to another. The middlings and tailings pass through pipes connecting the various cells.

Other patents which disclose froth flotation apparatus comprising pluralities of cells include U.S. Patent Nos. 4,399,028, 953,746, 2,073,148, 4,045,243, 3,491,880, 2,423,456, 2,765,081, 4,184,967, 2,983,377, U.S. 52,687,213 and 2,416,066.

Other methods have been suggested and are being explored in the beneficiation of coal, i.e., the cleaning of coal of impurities such as ash and sulfur, either prior to burning the coal or after its combustion. In one recently developed technique for beneficiation disclosed in U.S. Patent No. 4,304,573 and U.S. Patent No. 4,412,843, raw coal is pulverized to a fine mesh size and is then chemically treated. According to this technique the chemically treated coal is then separated from ash and sulfur, and a beneficiated or cleaned coal product is recovered therefrom.

In further detail, in the heretofore mentioned chemical surface treating technique, coal is first cleaned of rock and the like, and is then pulverized to a fine size of about 48 to 300 mesh. The extended surfaces of the ground coal particles are then rendered hydrophobic and oleophilic by a polymerization reaction. The sulfur and mineral ash impurities present in the coal remain hydrophilic and are separated from the treated coal product in a water washing step. This step utilizes oil and water separation techniques, and the coal particles made hydrophobic can float in recovery on a water phase which contains hydrophilic impurities.

In the multi-stage cleaning mode of operation, such as disclosed in U.S. Patent Nos. 4,304,573 and 4,412,843 several independent flotation tanks are used in a series for the beneficiation circuit. For a three stage beneficiation, as disclosed in these patents, three flotation tanks are used, and one scavenger tank. The floating fraction of the slurry containing the coal particles is reintroduced into successive flotation tanks for stage cleaning. The tailing fraction of the slurry, containing some ash laden coal is withdrawn from the bottom of the tanks into a scavenger for the recovery of coal from the counterflow stream. The rate of withdrawal

of tailings is regulated by pumps, controlled from level sensors of the tanks to prevent settlement of solids in the piping between each individual tank unit.

An improved apparatus for carrying out the aforedescribed chemical beneficiation technique is disclosed in U.S. Patent No. 4,347,127. This patent discloses a flotation apparatus wherein a primary spray nozzle is positioned above the flotation tank for spraying input slurry and a recycle spray nozzle is positioned above the tank for respraying particulate matter collected in a collecting trough positioned in the tank for collecting sinking material.

While the aforedescribed chemical surface treating beneficiation flotation systems have provided excellent end product results, improved systems are desirable which will provide for a simpler, less expensive arrangement and reduce the complexity of the overall control required to operate the system.

Accordingly, it is a primary object of the present invention to provide an improved apparatus and method for froth flotation separation of a slurry of particulate matter.

Another object of this invention is to provide an improved method and apparatus for beneficiating coal by a froth flotation separation of particulate coal from impurities associated therewith such as ash and sulfur.

Still another object of the present invention is to provide a method and apparatus for froth flotation separation of a slurry of particulate matter which is simpler, less expensive, more efficient and moreover provides improved yields of clean product.

The foregoing objects and advantages of the present invention for an apparatus and method for froth flotation separation may be more readily understood by one skilled in the art with reference to the following detailed description of several embodiments thereof, taken in conjunction with the accompanying drawings wherein like elements are designated by identical reference numerals throughout the several drawings and in which:

Fig. 1 is a flow diagram of the method of the present invention and also illustrates a schematic view of the novel apparatus of the present invention.

Fig. 2 illustrates a section of the method and apparatus of Fig. 1 taken along the lines indicated A-A.

Fig. 3 is a perspective view of the froth flotation apparatus of the present invention.

The apparatus and method of the present invention are adapted to the separation of a wide variety of solid-fluid streams by the creation of a solids containing froth phase and is suitable for the separation of many types of particulate matter. U.S. Patent Nos. 4,304,573 and 4,412,843, incorporated herein by reference may be referred to for further details on the chemical treating processes which are particularly useful in conjunction with the present invention.

In accordance with the present invention, the flotation tanks, called cells herein, are not independent from each other but combined into one large tank having a hydraulically commuting inclined common bottom for the slurry at each cell. In this arrangement, as shown in Figs. 1-3, the collection and transportation of coal laden tailings in the counterflow stream into the scavenger tank is more efficient than in previous methods. Instead of using discrete piping and pumps between each tank, a common sloped bottom extends under all of the beneficiation compartments or cells, as shown in Figs. 1 and 3. The common bottom which extends under all the beneficiation cells is sloped downwardly towards the point at which the input slurry enters the tank. Water input at the upper end of the sloped bottom provides a counterflow stream of tailings. This method of collection of tailings, including some coal laden particles for recycling into the scavenger tank, as shown in Fig. 1, results in both improved yield and reduction of ash in the final clean coal product. Further, this arrangement results in a simpler, less expensive construction of the beneficiation tank in that only one liquid level sensor is used for all cells in the tank.

In order to better understand the method and apparatus disclosed herein, the present invention is described with reference to the coal beneficiating process as disclosed for example in said U.S. Patent Nos. 4,304,573 and 4,412,843. Thus, referring to the drawings herein in greater detail, Fig. 1 - schematically illustrates a preferred embodiment of the present invention having a flotation tank 5 comprised of three cells filled with water to a level 6. Flotation tank 5 is generally trapezoidal in shape having a bottom which slopes toward the end of the tank where the input slurry is fed. In operation, a slurry of finely ground coal particles, associated impurities, and additives and reagents, if desired, such as monomeric compounds, chemical initiators, catalysts and fluid hydrocarbon carriers, are initially fed, e.g., from a ball mill, to a coal slurry feed tank 7 and then sprayed into flotation tank 5 through at least one primary spray nozzle 8 positioned at a spaced apart distance above the water level 6 in tank 5. In alternative embodiments, two or more primary nozzles can be used to spray slurry and/or any other desired ingredients into the cells of flotation tank 5. Preferred types of spray nozzles utilized herein are, for example, the spiral or helix open flow spray nozzles disclosed in U.S. Patent

No. 4,5I4,29I incorporated by reference herein or the full jet spray nozzles for example as disclosed in U.S. Patent No. 4,347,I26, or U.S. Patent No. 4,347,I27 also incorporated by reference herein.

The stream of treated coal is pumped under pressure to the primary spray nozzle 8 wherein the resultant shearing forces spray the coal flocculent slurry as fine droplets such that they are forcefully jetted into the mass of continuous water bath in cell No. I creating a froth 2 on the liquid surface having a substantial quantity of particulate matter floating therein, while other components of the slurry and a minor quantity of particulate matter sink in the liquid bath.

The froth produced in cell No. I is discharged by skimmer paddle I6 into collection tank I7, as illustrated in Fig. 2 which is a section of the apparatus of Fig. I taken along lines A-A. While Fig. 2 is a sectional view taken through cell No. I, Fig. 2 is also representative of the same sectional view taken through cell No. 2 and cell No. 3. As shown in Fig. 2, an upwardly inclined and curved surface I8 extends from the water surface at skimmer I6 to collection chute 2I in the cell for the draining of excess (and laden) water from the froth before it is discharged into froth collect tank I7. The froth which is discharged from the first cell into froth collect tank I7 is generally diluted and mixed with water from spray nozzle 40 before being pumped and sprayed through primary nozzle I9 into the liquid surface of cell No. 2 for additional cleaning. Cell No. 2 (as well as cell No. 3) is like cell No. I and the operation in cell No. 2 (as well as cell No. 3) is similar to that which occurs in cell No. I. After treatment in Cell No. 2, the froth from cell No. 2, collected in a froth collect tank like tank I7, is then pumped and sprayed through primary nozzle 20 into the liquid surface of cell No. 3 after which the clean coal froth produced is removed from a further froth collect tank like tank I7 for drying and final fuel blending. As is evident from the drawings, the tailings from each cell are removed in a counterflow stream I0 at the hydraulically communicating sloped common bottom II of the flotation tank 5 as shown in Figs. I-3. Water is introduced at inlet 25, shown in Fig. I, to sloped common bottom II to maintain a controlled hydraulic flow therein.

Flotation tank 5 is divided in its upper part into the various cells by partitions 30 and 3I. The partitions 30 and 3I extend vertically into the tank but as shown do not extend completely to the bottom thereby providing the common communicating bottom II.

In order to illustrate further details of one embodiment of the present invention, a typical beneficiation cell in accordance with the present invention is shown in Fig. 2. As stated before, Fig. 2 is a section taken from Fig. I along the line A-A through cell No. I, as indicated. In this embodiment, the primary spray nozzle 8, positioned above the liquid bath in the cell, sprays an input slurry of particulate matter through an aeration zone into the liquid surface. The spraying operation creates a froth 2 on the liquid surface having a substantial quantity of particulate matter floating therein, while other components of the slurry and a minor quantity of particulate matter sink in the liquid bath. A collector trough 33 is positioned in the cell.below the primary spray nozzle 8 for collecting the sinking materials. The collected materials are then recycled to at least one recycle spray nozzle 4 positioned in proximity to the primary spray nozzle(s) 8 of the cell. A verticle baffle I5 is positioned between the primary and recycle nozzles to provide separation for materials sinking from the sprays of the respective nozzles. The froth 2, produced in the cell, is discharged by skimmer paddle I6 through chute 2I and into the froth collection tank I7. The primary and recycle spray nozzles, 8 and 4, are preferably inclined from a vertical in the direction in which the skimmer paddle I6 operates to direct the flow of froth in that direction along the liquid surface.

The froth which is discharged from the first cell into tank I7, is diluted and mixed with water before being pumped and sprayed into the liquid surface of the second cell for additional cleaning. In the same manner, the final (third) stage cleaning of the froth is accomplished in the cell No. 3, after which the clean coal froth product is transferred for drying and fuel blending. The tailings are removed in a counterflow stream I0, flowing in opposite direction of the froth, at the hydraulically communicating common bottom II of the tank as shown in Figs. I-3.

Referring to Fig. 2, materials which tend to settle from the recycle spray in the pulp are withdrawn along the sloped bottom of the cell I2, by counterflow stream I0, flowing through common bottom II. Similarly, settling materials in the pulp from the primary spray, which are not collected in trough 33, are withdrawn along cell bottom I4 by the counterflow stream I0, as also shown in Fig. 2. The angle of the slope used for the cell bottoms I2 and I4 is about forty-five degrees, in one embodiment. The angle of the slope of common bottom II, as shown in Figs. I and 3 is about fifteen degrees in the same embodiment. This geometry of the tank bottom is given herein only as an example, and is not intended to be as a restriction of using different slopes for other size tanks.

The use of one level sensor control with communication between cells, as shown in Fig. I, results in a simpler and less expensive system than the system with individual level control for each tank as in prior art arrangements. The rate of flow of water added to the system at location 25 as

shown in Fig. I must be controlled so as to prevent any back-flow of the pulp from cell No. I to cell No. 2, and from cell No. 2 to cell No. 3, that is, to exchange liquid in the direction of the counterflow stream as shown, so that the greater ash content of pulp in cell No. I does not contaminate the pulp in cell No. 2, and the pulp in cell No. 2 does not contaminate the pulp in cell No. 3. Further, the velocity of the counterflow at the bottom of the tank must be sufficient to prevent settling of the tailings in conduit II.

Thus, in accordance with the present invention, a froth flotation apparatus utilizing at least two and preferably three beneficiation cells are used side by side with a hydraulically communicating common bottom of liquid under all the cells. The arrangement permits the use of one tank level control, which is common for all of the cells. Further, controlled flow of water is introduced to the system to produce a counterflow stream pattern under the cells by which the greater ash content of pulp in the first cell cannot contaminate the pulp in the second cell. In the same manner, the higher ash content of pulp in the second cell cannot contaminate the same in the third cell. The counterflow stream is sufficient to prevent any settling of the tailings at the tank bottom. With this improved method of collection, transportation of the tailings for recycling from a scavenger tank as shown in Fig. I is more efficient than in previous methods.

While several embodiments and variations of a method and apparatus for froth flotation separation of the components of a slurry have been described in detail herein, it should be apparent that the teachings and disclosure of the present invention will suggest many other embodiments and variations to those skilled in the art. For example, while the drawings illustrate the use of three beneficiation cells, fewer or more cells can be employed depending upon specific requirements.

Claims

I. Apparatus for froth flotation separation of the components of a slurry having particulate matter therein which is to be separated, said apparatus comprising:

(i) a flotation tank comprised of at least two independent flotation cells separated by a partition and having a commuting common sloped bottom for withdrawing tailings from each of said flotation cells, wherein said sloped bottom is sloped downwardly towards the feed input end of said flotation tank; and

(ii) primary means for feeding slurry into said flotation cells, said means for feeding slurry positioned above said flotation cells.

2. The apparatus of claim I further comprising means for withdrawing a floating fraction from said individual flotation cells.

3. The apparatus of claim I wherein at least one of said flotation cells contains a collector means positioned in said cell below said slurry feeding means for collecting sinking material.

4. The apparatus of claim I wherein at least one recycle feeding means for re-feeding sinking material is positioned above at least one of said flotation cells and in proximity to said primary means for feeding slurry.

5. The apparatus of claim 2 wherein said means for withdrawing said floating fraction includes at least one skimmer paddle.

6. The apparatus of claim I wherein said flotation tank is comprised of at least three independent flotation cells separated from each other by a partition and having a commuting common sloped bottom for withdrawing tailings from each of said flotation cells.

7. Apparatus for froth flotation separation of the components of a slurry having particulate matter therein which is to be separated, said apparatus comprising:

(i) a flotation tank comprised of at least three independent flotation cells separated from each other by a partition and having a commuting common sloped bottom for withdrawing tailings from each of said flotation cells, wherein said sloped bottom is sloped downwardly towards the feed input of said flotation tank and wherein said sloped bottom is provided with an inlet means for introducing liquid at the upper end of said sloped bottom;

(ii) primary means for feeding slurry into said flotation cells, said primary means for feeding slurry positioned above said flotation cells;

(iii) recycle feeding means for re-feeding sinking material, said recycle feeding means positioned above said flotation cells and in proximity to said primary means for feeding slurry; and

(iv) means for withdrawing a floating fraction from said flotation cells.

8. A method for froth flotation separation of the components of a slurry having particulate matter therein which is to be separated, said method comprising the steps of:

(i) feeding an input slurry of particulate matter to a liquid bath in a first flotation cell to create a froth on the surface of said liquid having a substantial quantity of particulate matter floating therein, while other components of the slurry and a minor quantity of particulate matter sink in the liquid;

(ii) feeding the froth created on the liquid surface in said first flotation cell to a liquid bath in a second flotation cell to create a froth on the surface of said liquid in said second flotation cell having a substantial quantity of particulate matter

floating therein, while other components of the slurry and a minor quantity of particulate matter sink in the liquid; and

(iii) withdrawing a tailings fraction from said first flotation cell and a tailings fraction from said l0second flotation cell in a counterflow stream in a common communicating bottom beneath said first and second flotation cells, said common communicating bottom sloped downwardly in the direction wherein said input slurry of step (i) is being fed.

9. The method of claim 8 wherein at least a portion of the sinking materials in said first flotation cell are collected in a collector means and recycled to the liquid bath in said first flotation cell whereby at least a portion of the recycled materials floats as froth on the liquid surface.

l0. The method of claim 8 wherein the sinking materials in said second flotation cell are collected in a collector means and recycled to the liquid bath in said second flotation cell whereby a portion of the recycled materials floats as froth on the liquid surface.

ll. The method of claim 8 wherein froth created on the liquid surface in said second flotation cell is fed to a third flotation cell containing a liquid bath to create a froth on the surface of said liquid bath having a substantial quantity of particulate matter floating therein.

l2. The method of claim ll further comprising the step of withdrawing a tailings fraction from said third flotation cell in a counterflow stream in a common communicating bottom beneath said first, second and third flotation cells, said common communicating bottom sloped downwardly in the direction wherein said input slurry of step (i) is being fed.

l3. The method of claim l2 wherein a fluid is fed into the upper end of the common communicating sloped bottom to provide a controlled counterflow stream of tailings.

l4. The method of claim ll wherein the froth on the surface of said liquid in said third flotation cell is collected.

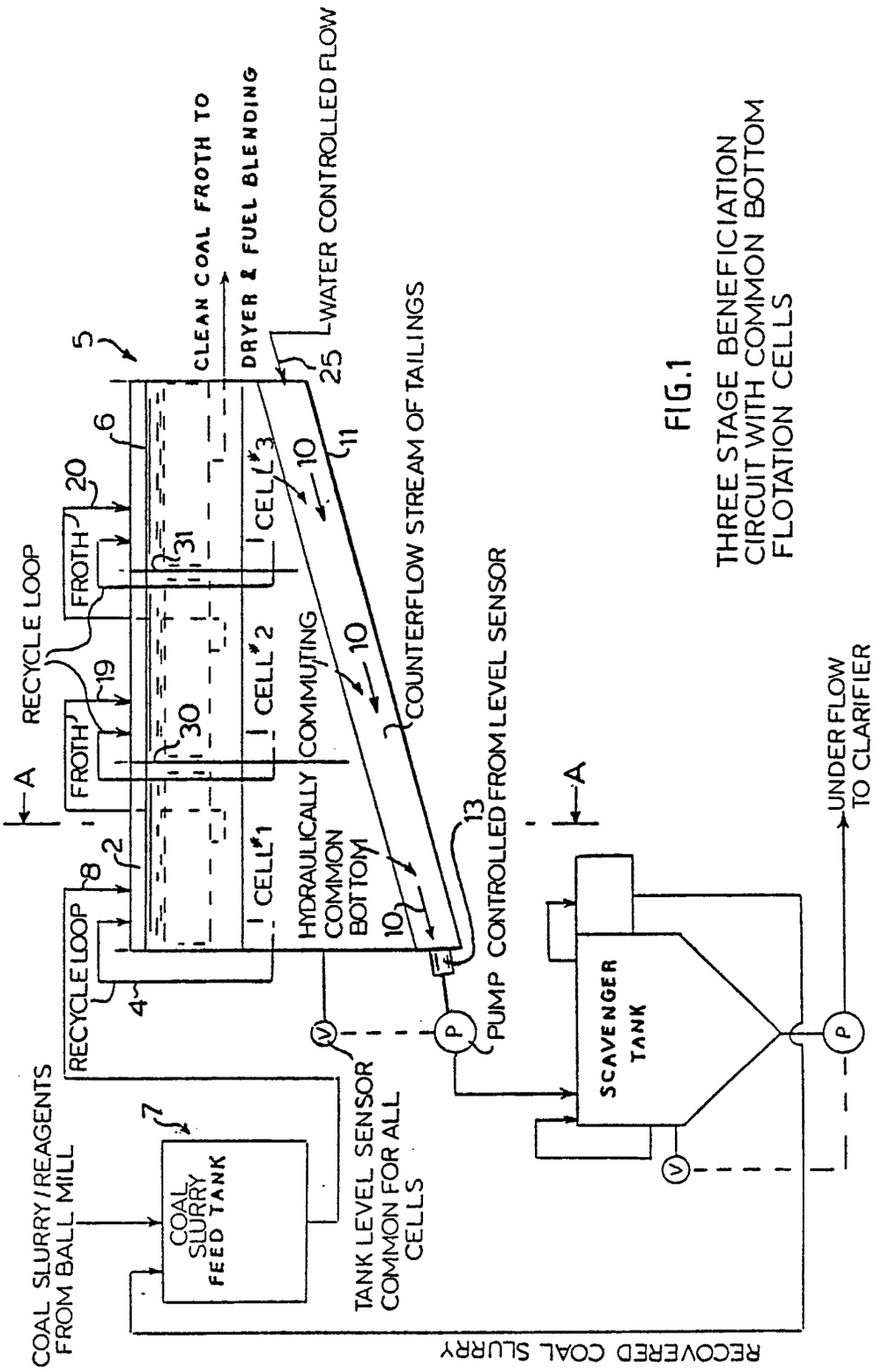

FIG.1

THREE STAGE BENEFICIATION CIRCUIT WITH COMMON BOTTOM FLOTATION CELLS

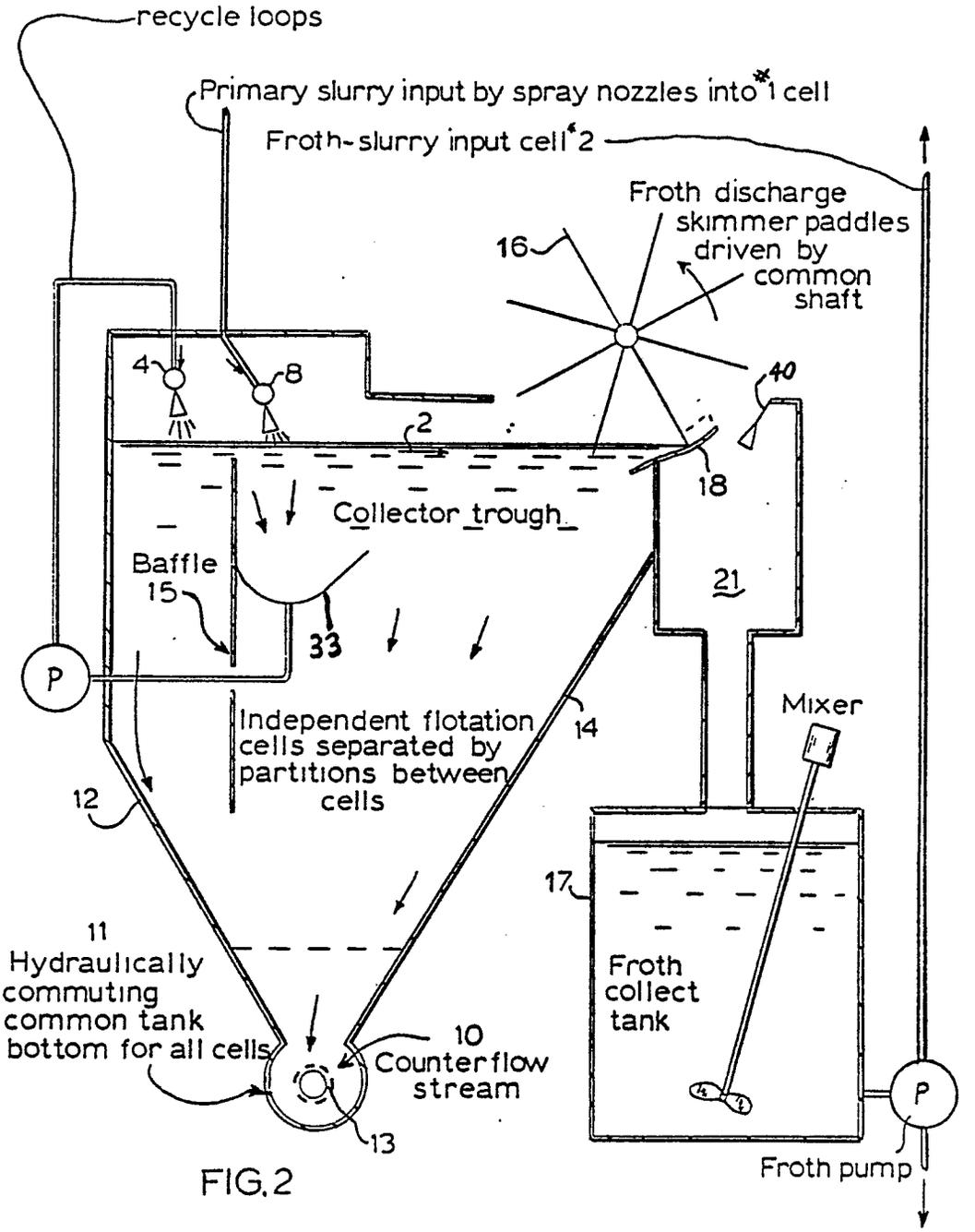
recycle loops
Primary slurry input by spray nozzles into cell 1
Froth-slurry input cell 2
Froth discharge skimmer paddles driven by common shaft
16
4
8
40
2
18
Collector trough
Baffle 15
33
21
P
Independent flotation cells separated by partitions between cells
14
Mixer
12
17
11
Hydraulically commuting common tank bottom for all cells
10
Counterflow stream
13
Froth collect tank
P
Froth pump

FIG.2

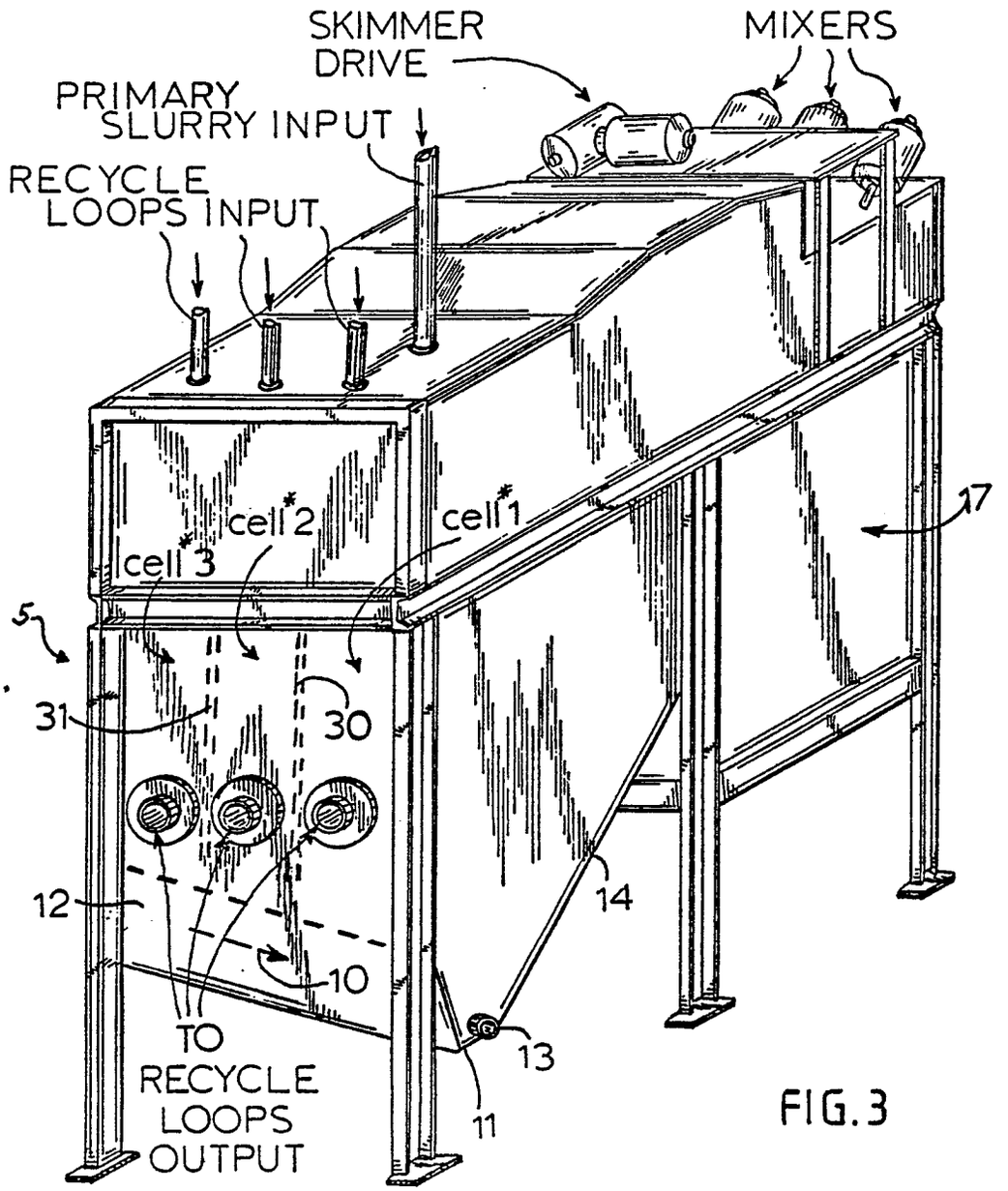
SKIMMER DRIVE
MIXERS
PRIMARY SLURRY INPUT
RECYCLE LOOPS INPUT
cell 2
cell 1
cell 3
17
5
31
30
12
14
10
13
TO RECYCLE LOOPS OUTPUT
11

FIG.3