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Recent Trends in Flotation of Fine Particles

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Abstract

Fine particles are generated at the mines due to the mechanization and automation in the mining processes. Also, the occurrence of valuable minerals in a finely disseminated form necessitates fine grinding for liberation and subsequent physical separation. Because of the extremely complicated physico-chemico-mechanical conditions existing in the flotation process, the problems associated with the presence of fine particles are most pronounced in flotation. New trends to flotation of fine particles are carrier flotation, column flotation and bio-flotation.

The carrier flotation technique is applied for upgrading of Egyptian kaolin and graphite. The carrier flotation technique has the advantage of reducing the long conditioning time needed for the pulp with the reagents in the conventional technique. But, the main draw backs of carrier flotation process in mineral beneficiation operations, are high reagent consumption and the necessity for subsequent separations of valuables from the carrier particles (when the valuable minerals are being recovered in the froth) .

There is a great potential to recover of fine particles from their gangue using the recent technology such as column flotation or Air Sparged Hydrocyclone (ASH), after its modification to be suitable for flotation of very fine particles to beneficiate many ores such as kaolin, talc, graphite, phosphate and hematite.

Bacteria and enzyme were used in the bio-flotation process to beneficiate the dolomitic phosphate to decrease MgO%.

Keywords

Fine Particles; Column Flotation; Carrier Flotation; Bio-Flotation

Introduction

The Inevitable Production of Fines during Ore Mining and Beneficiation

In recent years remarkable amounts of fine particles are generated at the mines due to the mechanization and automation in the mining processes (Abd El-Rahiem, 1997). Also, the occurrence of valuable minerals in a finely disseminated form necessitates fine grinding for liberation and subsequent physical separation. The fines represent an immense challenge due to the limitation of the conventional methods of beneficiation to recover the valuable minerals in such size with a reasonable efficiency and recovery.

At the same time, the small mass and momentum of fine gangue particles make them either entrained in the liquid of the froth or mechanically entrapped with particles being floated.

For these reasons, a number of new approaches to recover the fine and ultrafine particles have been proposed. Developing any new processing method to treat such fines has to meet, at the same, the present day energy, environmental and economical constraints.

These major developments in the flotation of fine particles can be classified into two categories:

a–processes which are based primarily on increasing the probability of collision between air bubbles and mineral particles and

b-processes which are based on more favorable change in the energetic of bubble – particle contact.

The probability of collision between air bubbles and mineral particles increases when latter is presented as agglomerates (floc-flotation) or is attached to larger (hydrophobic) particles which act as carrier particles (carrier flotation). Such technique was suggested for kaolin ores. Meanwhile, Production of fine bubbles of larger residence time in the column flotation improves the floatability of such fine and ultrafine particles. At the same time, applying the wash water in the column helps in removing the entrained fine gangue particles leading to a product of high grade.

Flotation Processes

Flotation process is the most important process in ore beneficiation in the world. It is used in beneficiation of many minerals, in Table 1, for example, amount of ores are treated by flotation in USA, and in Table 2, recent consumption (in tones) by flotation plants in 1985 (PERC report, 2000).

TABLE 1 AMOUNT OF ORES TREATED BY FLOTATION IN THE USA (PERC REPORT, 2000)

Type of ores	Amount		
	Ore treated, million tones	Concentrated products, million tones	Reagents consumed, million kg
Coal	25.16	17.170	6.000
Copper	176.56	5.300	209.420
Feldspar-Mica- Quart	1.900	1.300	3.200
Glass Sand	2.500	2.900	3.500
Iron	22.00	17.600	47.600
Lead- Zinc	3.300	0.700	1.400
Phosphate	109.500	24.600	226.100
Potash	10.100	1.500	3.200

TABLE 2 RECENT CONSUMPTION (IN TONES) BY U.S. FLOTATION PLANTS IN 1985 (PERC REPORT, 2000)

Types of reagent	Sulfide ores	Nonmetallic ores	Coal
Modifiers	281,893	80,408	353,000
Collectors	10,108	154,043	2,682
Activators	8,090	288,000	
Depresants	13,348	2,130	
Frothers	4,360	522,000	1,700
Flocculalions	540,000	516,000	1,275
Dispersants	161,000	223,000	
Total	318,800	238,130	6,010

Flotation is a method of concentrating finely divided mineral particles in water on the basis of variations in their ability to keep themselves on a phase interface. The particles to be separated float out, together with the phase to which they have attached themselves. The process is subdivided by El-Shall (El-Shall, 1994) into froth, film and oil flotation. Recent flotation processes such as carrier flotation and column flotation have also been adopted. Froth flotation is the usual method of flotation where the selected mineral particles are separated in the form of the froth.

Froth Flotation Processes

1) Flotation Problems of Fine Particles

The flotation process may be conceptualized in terms of a large number of subprocesses, most of which are still rather poorly understood. A complete review of all the sub-processes would be too lengthy. Several review articles have appeared in recent years which look at some of the important aspects of the sub - processes in flotation (Chander, 1978).

The conventional view of the flotation size-recovery curve is shown in Fig. 1. There is a good reason for this view – if you sample almost any flotation plant you will produce a similar curve. The numbers speak for themselves – fine particles float poorly in most plants. Operators carefully avoid "over grinding" and "sliming" of feed (Pease, et al., 2004).

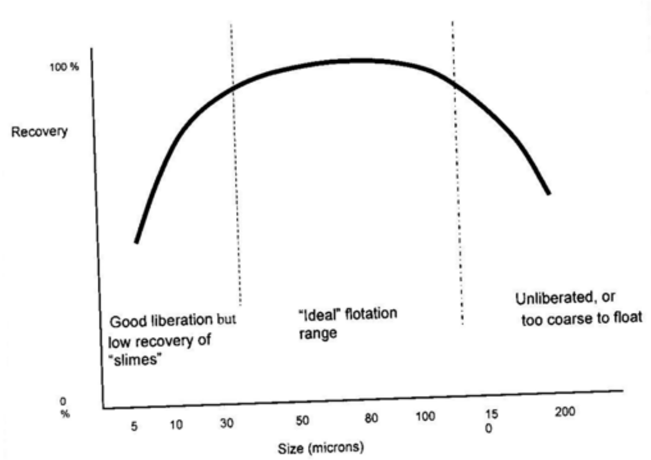

FIG.1 TYPICAL RECOVERY VS SIZE CURVE (PEASE, ET AL., 2004)

Because of the extremely complicated physico-chemico-mechanical conditions existing in the flotation process, the problems associated with the presence of fine particles are most pronounced in flotation. **There is a general agreement that flotation decreases with a decrease in particle size in the fine particle range.**

Two characteristics begin to dominate as the particle size is reduced: the specific surface becomes large and the mass of the particle becomes very small. Fig.2 illustrates the relationship between the physical and chemical properties of fine particles and their behavior in flotation (Chander, 1978).

Because of the small mass and momentum of fine particles, they may be carried into the froth after getting either entrained in the liquid or mechanically entrapped with particles being floated. Some authors (Pease, et al., 2004) have shown that the fine particles are carried into the froth as mechanical in layers of water are attached to air bubbles. When such particles are of gangue minerals, the effect is a reduction in the grade of the concentrate. The large specific surface of fine particles increases the adsorption capacity of reagents when considered on a mass basis. Thus, a significant proportion of the reagent is consumed by small particles. When present in the limited amount, sufficient reagent may not be available for the flotation of larger particles, with a resultant decrease in recovery (Chander, 1978).

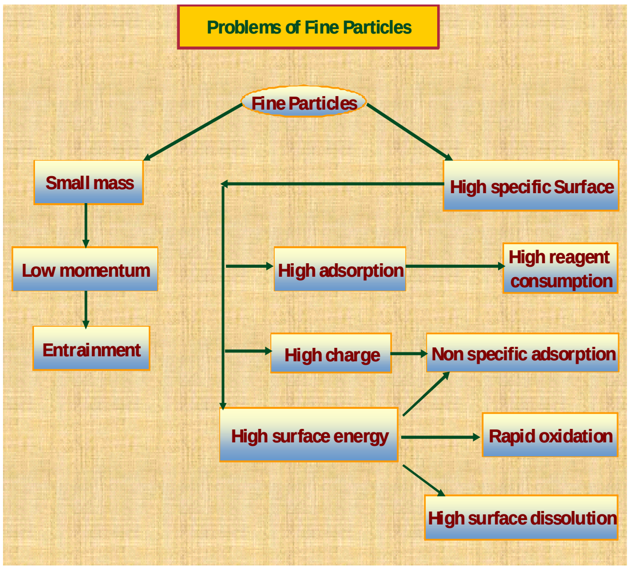

FIG.2 SCHEMATIC DIAGRAM SHOWING THE RELATIONSHIP BETWEEN THE PHYSICAL AND CHEMICAL PROPERTIES OF FINE PARTICLES AND THEIR BEHAVIOR IN FLOTATION (CHANDER, 1978)

The process of slime coatings refers to the attachment of fine particles to larger particles, Fig.3 such slime coatings can be detrimental to flotation in several ways. If the fine particles are the valuable mineral and the coarse particles are the gangue minerals, the grade of the concentrate becomes poor. When the fine particles consist of gangue minerals that coat the coarse particles of the valuable mineral, these particles prevent the attachment of air bubbles and the recovery of valuable mineral may then decreases significantly (Chander, 1978).

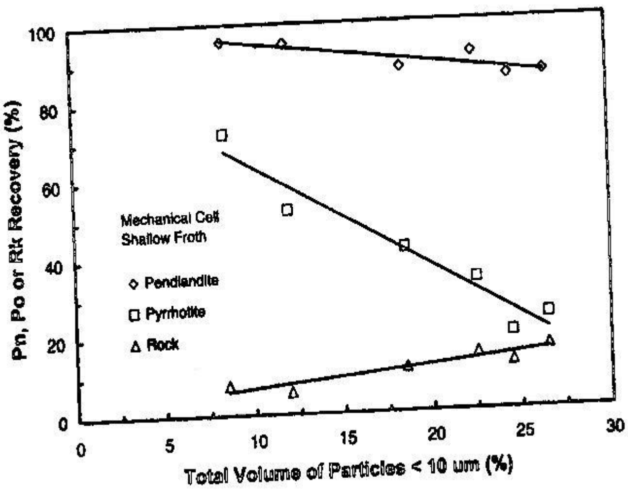

FIG. 3 RECOVERIES AS A FUNCTION OF TOTAL VOLUME OF PARTICLES<10 (CHANDER, 1978)

The possibility to improve the floatability of fine particles is to increase the probability of collision between these fines and the air bubbles (Xu and Wells, 2004). Such attempt has been made through column flotation.

Carrier Flotation of Fine Particles

Carrier flotation can be achieved via the enhanced aggregation between fine (carried) and coarse (carrier) particles under intense agitation and follow by froth flotation. The common and critical requirements for carrier flotation are:

1. presence of coarse particles
2. use of higher energy agitation , and
3. hydrophobicity of the carrier (coarse) and carried (fine) particles (Xu and Wells, 2004).

The process of ultraflotation is schematically illustrated in Fig.4. Fine particles to be floated from slime coatings on the auxiliary or carrier material, and the coated particles are then floated (Waksmundzki et al., 1971). The first commercial use of this process was in the purification of kaolin at Minerals and Chemicals Phillipp's plant at Mc Intyre, Georgia (Hummadi, et al., 1994). The process was originally developed to upgrade kaolin clay. Titaniferous impurities were removed with 60 micron limestone particles as the carrier mineral.

Jenkins et al. have reviewed the use of carrier flotation technique for removal of colloidal impurities as bacteria, silica, clays, metal oxides and humic acid from natural waste waters. The general conditions necessary for successful removal of these colloidal particles include coagulation or attachment of the particles onto the surface of the large size particles (carrier mineral), finding a suitable collector, frother, and floating the agglomerates in a flotation cell. In this application, the process objective is complete removal of all the colloidal particles, rather than selective separation as desired in mineral beneficiation. In the latter case, conditions are sought where only mineral particles are attached to the carrier mineral floated (Chander, 1978).

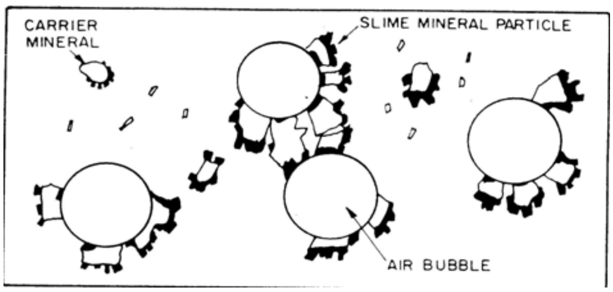

FIG.4 SCHEMATIC REPRESENTATION OF THE UTRAFLOTATION OR CARRIER FLOTATION PROCESS (WAKSMUNDZKI ET AL., 1971)

It is not always necessary to externally add particles as coarser particles originally presented may act as the carrier. Accidental ultraflotation in such a case is detrimental to the grade of the concentrate if the coarse particles comprised are of gangue minerals. When coarse particles are inherently presented which may act as carrier particles the addition of carrier mineral may or may not improve the process.

The main draw backs of this process in mineral beneficiation operations are high reagent consumption and the necessity for subsequent separations of valuables from the carrier particles (when the valuable minerals are being recovered in the froth) (Wang et al. 1988**).**

Flotation of Fine Particles

The technique of column flotation has been developed to utilize the principle of the counter current flow to improve separations in the flotation of fine particles. The column flotation offers a solution for the removal of entrained fine gangue particles by using a counter - current flow of wash water (Fuerstenau, D. W., 1979).

The column differs dramatically from conventional mechanical flotation machines, both in design and operation philosophy, which has been a principal reason for its slow acceptance by the mineral industry. The concept was developed in the 1960's in Canada and since then the plant and laboratory column have been marketed commercially by the column Flotation Company of Canada Ltd (Dobby, et al., 1985).

Principles of Column Flotation

The flotation column is a long tube, either of a square or circular cross section with dimensions of 300 mm to 3 m (side length or diameter) and a length -to-diameter ratio of 10 to 100 (Al-Maghrabi, 2004) Laboratory columns are 20-60 mm in diameter and 3-10 m in height. A reagentized pulp enters the column at about $1/4^{th}$ to $1/3^{rd}$ of the distance from the top of the column. Inside the column it meets a downward flowing stream of water and an upward flowing mass of air bubbles (Al-Maghrabi, 2004). Flotation takes place in this counter current system. The hydrophobic particles are collected by the air bubbles and carried upward to the top of the column, producing a mineral - rich froth and a tailing of the hydrophilic particles, which leave with the slurry at the bottom of the column Fig. 5.

The principle operating features of column flotation are as follows:

a) <u>No moving parts</u>. Solids are kept in a suspension not by an agitating action of a propeller but by the rising air bubbles.

b) <u>Wash water</u>. Spray pipes are installed below the froth surface and they deliver the required volume of water.

The purpose of this water is of twofold:

I) it washes the raising froth in the lower flotation section thereby displacing entrained hydrophilic (gangue) particles that have been reported to the froth phase. As a result, the concentrate produced is of higher purity than in the conventional flotation. The column is characterized by a very high up grading.

ii) it keeps in balance the flow of material through the column .

c) Flow balance. For the correct operating conditions the volume of the underflow (tail) is larger than that of the feed. The wash water makes up this difference. This difference is called bias.

In the column flotation, there exist two distinct regions: the flotation region, which extends from the point of the feed inlet to the point of aeration and the cleaning region, which covers the region between the feed addition and the froth overflow.

A typical flotation column is shown in Fig.6. This figure suggests four distinct zones. These zones have been defined as:

<u>Beneficiation Zone 1:</u> The froth phase cleaning zone. This zone extends from the top of the column to slightly above the pulp-froth interface.

<u>Beneficiation Zone 2:</u> The pulp-froth interfacial zone. The boundaries of this zone are at slightly above the pulp-froth interface and slightly below the pulp-froth interface. The primary upgrading is a function of this zone. Hydrophilic minerals are rapidly rejected in this zone as a result of their preference for the liquid phase.

<u>Beneficiation zone 3:</u> The pulp phase cleaning zone. This zone begins slightly below the pulp-froth interface and extends down to the feed slurry injection - inlet.

<u>Beneficiation Zone 4</u>: The collection zone. This zone includes the length of the column from the feed slurry

injection part to the air sparger at the base of the column. In this zone, an initial contact between the settling feed slurry and rising bubbles occurs.

These zones are characterized according to the normalized percent mineral upgrading per height of each zone. The boundaries of zones 1,2,3 and 4 are set by physical limits, however, those of the pulp-froth interfacial zone are arbitrary .

Industrial columns have a height of 9-14 m, and a diameter of not more than 2 m, without baffling. Usually they are operated with sufficient over head wash water to provide a net down ward flow of water, a condition known as a positive bias (Abdel-Khalek 1989).

Positive bias has been norm in column operation because the wash water stabilizes the froth layer in a column. The greater flow of water down the column, the greater the selectivity and the chicaner froth layer. The depth froth in stable is somewhat over a meter. A negative bias will eliminate the froth altogether, very deleterious for a process where the concentrate is a desired product, but in case of coal cleaning, when the reagent selection results in the lower volume produce (ash) going to the tails (Abdel-Khalek, 1989).

A major factor that must be kept in mind in the design of dressing experiments with columns is that the rate controlling flotation mechanism is always bubble captures, and usually with mineral that has been precoated with collectors in a prior flotation.

It is customary to describe the operating conditions of flotation columns in terms of superficial velocities (J) of the fluids, to normalize the information for different size columns. Typical values are as follows:

J_g = gas velocity -0.5 to 3.0 cm/second

J_P = pulp feed velocity - 0.7 to 2.0 cm/ second

J_w = wash water velocity - 0.1 to 0.8 cm/ second

J_b = bias water velocity - 0.07 to 0.3 cm / second

In addition, in scale – up equations it is also customary to normalize the gas velocity for different height columns by the pressure correction:

$$Jg = \frac{(Pc)(Jg^*)(\ln(Pt/Pc)}{Pt - Pc}$$

Where Jg*= gas velocity is at standard conditions at the top of the column, Pc = absolute pressure at the top of the column and Pt= absolute pressure at the sparger.

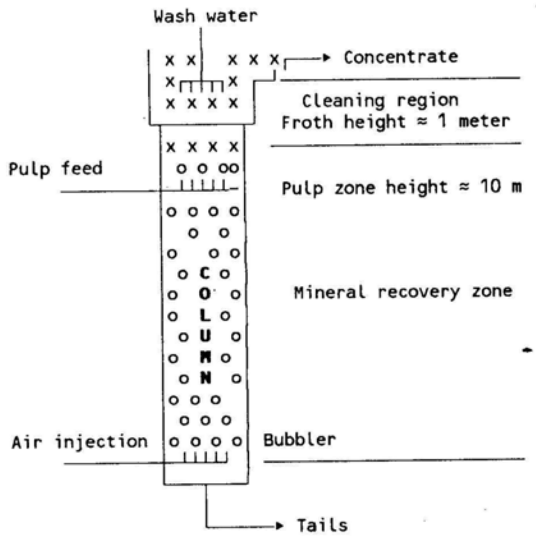

FIG.5 SCHEMATIC REPRESENTATION OF A FLOTATION COLUMN

For a 10 m Pt is approximately twice Pc, so that Jg ~ 0.69 cm/second. The effect of gas velocity on recovery and grade is dominated by bubble size, which is affected by both the absolute amount of gas fed to the column as well as the pore size of the sparger. In practice, bubble sizes can range from 0.2 to 0.3 mm; industrially, a target range for normal pulp mesh sizes is 0.4 – 0.8 mm. Because bubble size is a function of the porosity of the sparger, the type and quantity of frother present, and the gas rate, it is not possible to generalize on the effect of the gas rate or recovery, although for a specific system there is usually a reduction in mineral carrying capacity with an increase in gas rate.

An increase in wash water rate will increase the height of the froth layer, increase the concentrate grade, and reduce recovery. The optimum water rate is an important variable to determine experimentally. Other variables, such as column height, have a logical effect on flotation; i.e., the higher the column, the greater the selectivity.

In the laboratory, where glass columns are prevalent, this level can be controlled on the feed and the tails, and to vary the wash water as a function of the interface height, which is approximated by a differential pressure measurement at the bottom of the column. As this control method is inherently unstable because there is a relation between the froth height and the wash water rate, this is not the ideal operating (Abdel-Khalek, 1989, Mckay, et al.1988).

In the mineral processing area, all employed flotation devices do not generate microbubbles but coarser bubbles, usually between 600 and 2500 μm. According to most researchers, the lack of "mid-sized" bubbles in the cells is the main reason why the capture of the very fine particles is inefficient leading to considerable losses, an old problem in mineral processing , especially for the fine (>13 μm) mineral particles. The losses are due to the intrinsic properties of these particles (mainly small mass and low inertia) and main flotation drawbacks are related to the low probability of bubble–particle capture phenomena. Many authors have also found high efficiencies of bubble–particle detachment in fine particles–bubbles (coarse) interactions. Many different processes to reduce this problem have been proposed but most of them have not found practical applications yet. But, this is not the situation in effluents treatment whereby most particles are fine (even within the colloidal range) and are readily removed by flotation because of the use of fines bubbles. Accordingly, it may be concluded that for the recovery of fine minerals particles in ore flotation, the cell machine should provide a wide bubbles size distribution, which must include micro or mid-sized bubbles (100–600 μm) plus the coarser bubbles generated in conventional flotation cells. Column flotation cells generate, with their various commercial spargers, finer bubbles than conventional "rougher" cells machines, improving somewhat the recovery of the F–UF mineral particles. However, determination and report of bubble size distribution, in this kind of flotation cells are scarce and more; recoveries of the coarser particles, in columns, are usually very low and this is another reason to explain why they are used mostly in cleaner flotation circuits.

The column flotation has become increasingly popular over the past few years in mineral industry, primarily in Canada and USA. The column flotation holds several distinct advantages over conventional froth flotation such as the following:

- More quiescent separation conditions due to the lack of tubulence caused by mechanical impellers.

- Capability to produce high grade concentrates by employing:

i- Wash water additions to the froth.

ii- Increased froth depth.

iii- Current flow of bubbles and pulp

iv- often replacing 2-3 stages of mechanical cleaning with one stage.

v- Increased energy efficiency

vi- Decreased floor space requirement.

vii- Natural adaptability to the computer control because the control is based on flows into and out of the column.

Column Flotation Design

1) The Novel Design for flotation Column *(Yosry, et al.1994)*

<u>Theory:</u>

The theory of Novel designed column flotation which is used in flotation of fine coal is based on creation of a flow pattern which has the following characteristics:

1- Efficient mixing between the mineral particles and air bubbles;
2- Fluid flow reversal to enhance the separation of pyrite and other ash minerals by gravity.
3- Creation of quiescent zone for pyrite and ash minerals separation; and
4- Gentle flow, which ensures high recovery of clean coal in froth.

The fulfillment of these principles should ensure efficient treatment of fine cleaning and produce high Btu recovery with satisfactory ash and sulfur removal.

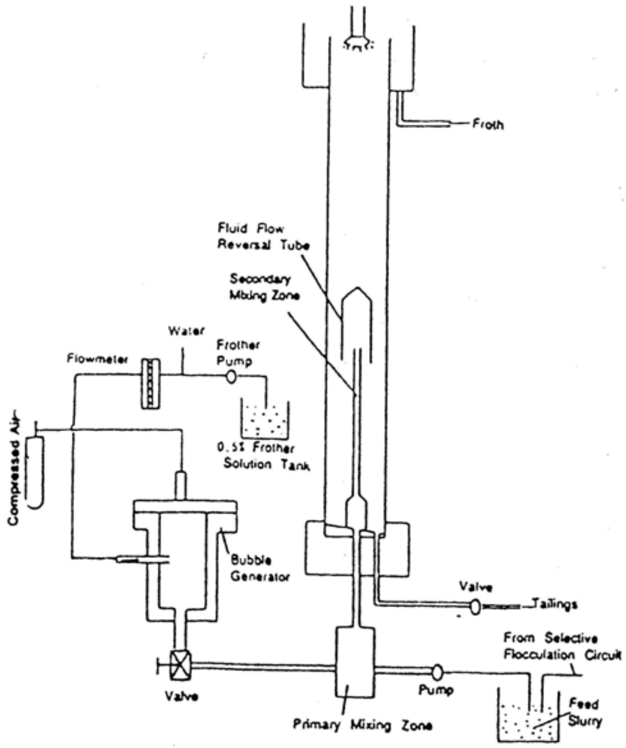

FIG.6 LAYOUT OF THE AGGLOMERATE COLUMN FLOTATION SYSTEM

As shown in Fig.6, the column flotation system consists of two main parts namely, the column and the bubble generator.

The Air- Sparged Hydrocyclone (ASH) flotation technology is particularly well suited to handle high volumes of pulp at a specific capacity 50-100 times greater than that offered by other flotation machines. The specific capacities of various flotation machines are compared in Table 3.

TABLE 3 COMPARISON OF SPECIFIC CAPACITIES OF VARIOUS FLOTATION MACHINES

Flotation	Capacity tpd / ft^3 (20% solids, s.g. 2.5)
Mechanical Flotation Cell	1 -5
Flotation Column	1 – 5
Air – Sparged Hydrocyclone	200 - 400

Fig.7 is a schematic drawing of the Air-Sparged Hydrocyclone (ASH) which consists of a right vertical tube having a jacket porous wall, a conventional cyclone header with a vortex finder, and a froth pedestal / under flow structure which is centered on the cyclone axis at the bottom of the porous tube. The suspension is fed tangentially through the cyclone header to develop a swirl flow inside the porous tube. Air passed through the jacket porous tube wall and is sheared into numerous small bubbles by the high – velocity swirl flow of the suspension. The fine hydrophobic mineral particles in the suspension collide with the bubbles, and after bubbles/particle attachment, are transported radially into a froth phase, which forms on the cyclindrical axis. The froth phase is supported and constrained by the froth pedestal and thus moves towards the vortex finder of the cyclone header, being discharged as an overflow froth product containing hydrophobic particles. The hydrophilic particles, generally unwanted gangue particles, are discharged as an underflow stream through the annulus created between the porous tube wall and the froth pedestal (Miller, et al.1999, Miller et al., 1996).

Air–Sparged Hydrocyclone (ASH) flotation technology has been evaluated for phosphate recovery from the Central Florida phosphate deposits in pilot-plant experiments (Miller, et al.1999). It was demonstrated that the 2–inch ASH system has a high specific capacity of about 435- 550 gpm/ft^3 in both rougher flotation and amine flotation system (50–100 times higher than that of a traditional flotation cell). In case of fatty acid flotation, single–stage ASH flotation produced a recovery of 75–77 % in a rougher concentrate containing 24% P_2O_5. In reverse, ASH system produced a phosphate recovery of 98 % in a cleaner concentrate containing 31% P_2O_5. Table 4, shows the recommended conditions for single–stage rougher and amine flotation with the 2- inch ASH system. The results, as shown in table 4, are comparable with those obtained at plant operations in the Florida phosphate industry (Miller, et al. 1999).

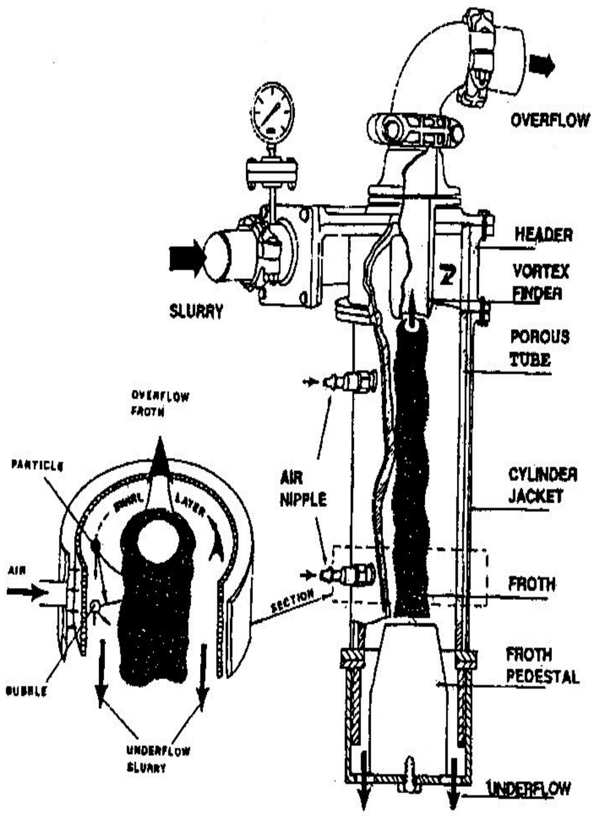

FIG.7 A SCHEMATIC DRAWING OF THE AIR – SPARGED HYDROCYCLONE

TABLE 4 RECOMMENDED CONDITIONS FOR SINGLE ROUGHER AND AMINE FLOTATION WITH 2–INCH ASH SYSTEM

Items	Specification of Rougher Flotation	Specification of Amine Flotation
Conditioning pH		
Conditioning pulp density	9.2	6.5 – 7.0
by Wt%	75	20
Conditioning , minute	5.0	2
Collector dosage *, Ib/t	3.0	1.6 – 2.0
Frother *, Ib/t	2.0	-
A*	3.3	2.87
Q*	3.67	4.5
Flotation pulp density by	20	20
Wt%	1.17	1.17
Vortex finder diameter, inch	3.0	3.0
Vortex finder depth, inch		

- Collector dosage : Fatty acid: fuel oil at 7:3 in rougher flotation and amine in reverse

- flotation
- Frother: lion Surf 777.
- A: Ratio of overflow opening area to underflow opening area.
- Q: Ratio of airflow rate to slurry under flow rate.

2) Packed Column Jig (PCJ)

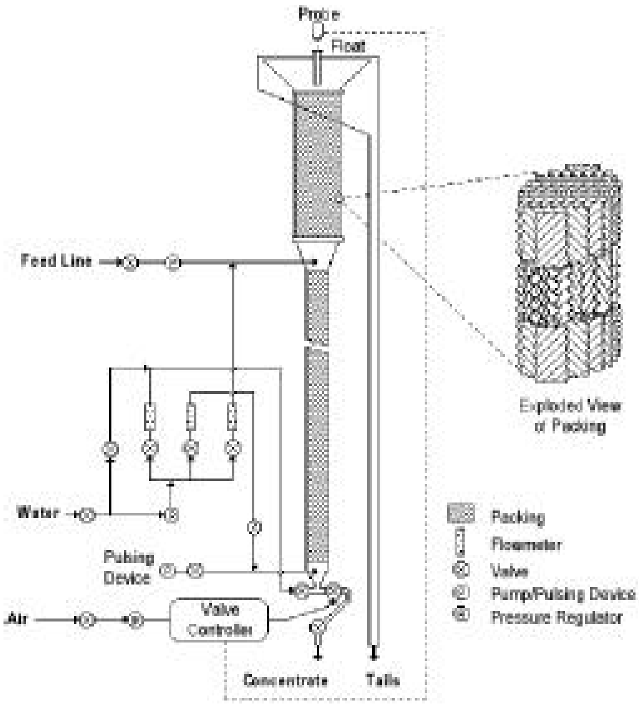

FIG. 8 SCHEMATIC REPRESENTATION OF PACKED COLUMN JIG

PCJ is a column filled with packing plates which are corrugated diagonally and set in an alternating configuration. The packing plates create a myriad of small cells in the column, Fig. 8. A stream of mixed particles is fed through an inlet located near the top of the column. The feed point depends on the feed characteristics and concentrate grade target. A steady state water flow enters the bottom of the column and a pulsating flow is also superimposed to create a jigging action that maintains all particles in suspension limiting stagnation problems. Initially, light and fine particles move to the top while heavy and coarse particles move downward based on settling velocities. A density gradient is formed inside the column, high density at the bottom and low density at the top, and each of the product streams is discharged from the designated outlet. By changing operational conditions, light-coarse and heavy-fine particles are separated either on a size or density basis. A stronger density gradient means that particles tend to separate on density criteria. Jigging frequency is set based on particle size: finer particles require higher frequency. Two jigging frequencies can be superimposed to assure an effective particle separation while keeping particle dispersion (Yang et al., 2003).

Applications of Column Flotation

1) Upgrading Fine Particles of phosphate

In 1998, Ityokumbul, continuous experiments were carried out in a column flotation system to determine the feasibility of recovering the phosphate values in phosphatic clays. The contact column is an improvement over the conventional flotation column with significantly increased throughput. The heart of this new separation process is in the turbulent contact chamber where particle-bubble contact is affected. As a result of the turbulent conditions in the contact chamber, particle collection is complete in about a second. Thus the flotation column is mainly used to effect the separation of the bubble- particle aggregates. The contact column has two major advantages: fast collection that translates to high throughput; and quitter froth, which is beneficial to higher recovery from fine feed materials. However, flotation of a bulk phosphatic clay sample with fatty acid collector showed no selection of phosphate from gangue materials (mainly clay minerals and sand).

In 1999, El-Shall et al., applied column flotation for upgrading Florida phosphate. Depending on the experimental conditions, it is possible to achieve a concentrate of high grade (61.23% BPL) and recovery (84.13 %) from a fine feed sample (35x 150mesh) containing about 17.13 % BPL and 78.45% A.I.

Application of factorial design to column flotation of the fine feed has shed some light on effect of column parameters on metallurgical performance. The results of the central composite design showed that % BPL recovery is progressively improved with increasing the collectors dosage from ~ 0.4 to 1.4 IB/t (El-Shall, at el., 1999). The BPL recovery is gradually improved with increasing the concentration of froth from 5 ppm up to 15 ppm, at which the highest grade is obtained. This is accompanied by a gradual decrease in the estimated bubble diameter. Above such concentration, both recovery and bubble size are almost constant. The selectivity of separation process improved by using the polyglycol frother at high pH levels. For Instance, the results indicate that F- 507, as a non-ionic frother, gave better results at alkaline pH (9.5 to 9.8). Response surface contours are generated for %

BPL grade and recovery as a function of the studied variables, i.e. collector dosage, frother concentration and pH are within the range of high recovery but slightly more collector(>1.4 Ib/t) needed to get the maximum recovery. A concentration of 15ppm of frother is enough to maximize the recovery. Meanwhile, a pH of 9.5 closes to optimum for using such non- ionic frother.

In another study (El-Shall, et al., 2000), to select the best combination of sparger and frother phosphate flotation, 28 commercially available frothers were investigated by measuring air holdup under various operational conditions in an air/ water system. An edutor sparger and two- phase ejector have strong air dispersion ability, simple operation, less clogging potential and less energy consumption, compared with other external spargers. However, the addition of such more water to the eductor is required to aspirate atmospheric air into the sparger and to disperse into fine bubbles. For phosphate flotation, the water added by eductor meets the requirement for dilution of the rougher dewatered reagentized feed. In applications where the feed is not dewatered, the eductor water may cause excess water addition to the flotation system. This problem can be overcome by properly selecting the eductor size to minimize the addition water amount. An economic performance measure was developed, which includes recovery, grade, and the reagent prices. A parametric study was conducted on both unsized and sized feed to optimize column flotation.

In phosphate concentrate by using column flotation, it is desirables to achieve an MgO of less than 1.0 % at an acceptable P_2O_5 grade and at an acceptable P_2O_5 recovery. In processing dolomitic phosphates, the flotation separation of dolomite from the phosphate minerals is difficult to achieve (El-Shall, et al., 2002).The results of the flotation of a primary desliming hydrosizer over flow material containing high concentrations of dolomite are studied. The phosphate minerals were collophone and francolite. Microscopic examination of the material indicated that all the P_2O_5 is in the – 150 + 400 mesh (-106+ 38 µm) fraction while most of the MgO is in the 270 mesh (-53 µm) fraction. The material has not been treated with flotation reagents. The particular sample studied contains 14.6 wt% P_2O_5 and 3.6 wt% MgO.

In 2002- El-Shall et al., various collectors (two different long chain alkyl sulfonates, a tall oil plus fuel oil, and the disodium salt of 1-hydroxyoctylidene1, 1–diphosphonic acid) were evaluated for their effectiveness for phosphate flotation and the performance of three different flotation devices were compared. Finaly, a two- stage flotation scheme was proposed using column flotation of dolomite in the first stage and Denver cell flotation of phosphate in the second.

In 2013, a flotation column has been designed and applied in the beneficiation of Al-Jalamid Saudi phosphate ores of the calcareous type by reverse scheme (Tariq et al, 2013).The significant parameters like superficial gas velocity, slurry feed rate, particle size of processed ore, wash water consumption and collector dosage of flotation process were investigated to achieve the best recovery and quality of the beneficiated ores. The results of this study revealed that column flotation technology is a promising tool for beneficiation of calcareous phosphate ores. A high purity ore of 35% P_2O_5 can be easily achieved at a high recovery value of 95% starting from a rock contains 25% P_2O_5, high calcite content (52.7% CaO) and CaO: P_2O_5 ratio equals 2.1.

2) Upgrading Fine Particles of Hematite

In 2003 - Yang et al. applied Pack Jig Column flotation technique to beneficiate hematite. Extensive testing has been carried out using a magnetite concentrate from Mine A and a magnetic taconite crude ore from Mine B, which contains 32.8% total Fe, but only 24.8% is magnetic Fe. In this example, the packed column jig can recover both magnetic and non-magnetic iron including magnetite and hematite while rejecting light undesired particles, including those interlocked with iron or other minerals. A crude hematite ore was also tested to verify PCJ performance on coarser non-magnetic particles. The flow sheet of the process is shown in Fig .9.

Yang and co- authors, found that , in finely ground iron ores, the packed column jig yields significantly higher grades and recoveries than do conventional flotation or magnetic separations do; silica levels less than 2% are economically achievable. A two-stage packed column jig circuit with reground to reduce concentrate size can produce higher quality concentrate at much higher iron recovery than present practices. This is due to its capability to recover non-magnetic iron and its unique design, which prevents misplacement of particles during separation. Because no chemicals are used in the process, the column jig is environmentally friendly. Due to the simplicity of the equipment and the circuit, per ton costs are substantially lower than conventional treatments.

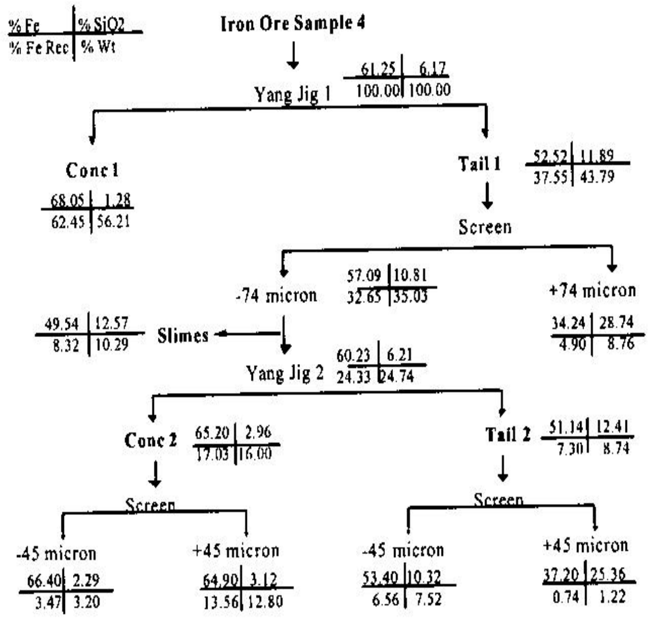

FIG. 9 THE FLOWSHEET OF THE BENEFICIATION OF HEMATITE BY PACK JIG COLUMN FLOTATION

3) Applications of Prototype Column Flotation high grade fluorite

In 2007, Aliaga et al were used prototype column cell to beneficiate the high grade fluorite samples from Nossa Senhora do Carmo (NSC)Mining, Criciu´ma city, Santa Catarina state, Brazil without wash water addition. Concentrate flow was obtained by making tailing flows smaller than feed flows. Hence, part of the feed water was carried up within bubble wakes. No pulp/froth interface was established.

A high recovery was obtained in a 2 m collection zone column. The recovery reached >80% with a grade of~ 90%. It was found that the recovery depended on the value of the difference between the feed flow and tailing flow. In addition, a straight line between the surface velocity of mineral and the recovery was found. It appears that a maximum capacity of solid is ~10 g min^{-1} cm^{-2}.

Industrial and laboratory-scale column cells are used for flotation silica sand for iron and heavy mineral rejection, limestone for brightness improvement and reduction of insoluble, such as kaolin clay and talc for brightness improvement. Column flotation has also been examined in pilot and commercial plants for flotation of phosphate ores, lithium cleaning and gold flotation.

Agglomeration Flotation / Floc- Flotation

Fine particles aggregation and flotation are very important in the minerals industry .Aggregation of fine was developed as a shear flocculation process, where the hydrophobic particles were aggregated in a shear field. One possibility for effective agglomeration can be obtained through the interaction of classical ionic surfactants (flotation collectors) pre-adsorbed on the oxide fine particles with oppositely charged polymers (flocculants). Sadowski and Polwczk, 2004, studied the interaction between surfactant and polymer and the effect of those interactions on aggregation and flotation of fine particles. Such interaction may lead to an agglomeration that combines electrostatic and hydrophobic interactions.

Hydrophobic flocculation arises as a result of hydrophobic interaction between hydrophobic particles and oppositely charged or non- ionic flocculant. The separation of hydrophobic flocs can then be achieved using froth flotation (Song and Lu, 2000). The agglomeration flotation process is schematically illustrated in Fig. 10. Agglomeration is formed first, which is then attached to air bubbles and float.

Moses and Petersen 2000, studied gold recovery using coal/ gold agglomeration (CGA) process, whereby hydrophobic gold particles are recovered from ore slurries into coal – oil hydrophobic agglomeration. The coal oil agglomeration is separated by settling or flotation technique.

Bio-Flotation

Introduction

The large amounts of valuable minerals are discarded as fines and ultrafines due to inadequate of today's technology to process them economically. Treatment of fine particles presents a difficult problem in the mineral industry, and its solution is required. These fines can be of substational impact in production, even at low concentrations and additionally can cause potential environmental problems, if released to the environment (Neidhardt, et al., 1990).

The biological processes are becoming more attractive in mineral processing due to their low operating costs and their possible applications to treat difficulty to beneficiate low grade complex ores. Introducing the biological processes involving microbes for mineral processing was first reported by Solojenken et al. Biological processes are attractive since microbes or microbial fat and secreted metabolites can have specific interactions with minerals. Such interactions of microbes and their agents with minerals can be indirect, with biological products acting as surface-active agents, or direct due to microbial adhesion or attachment to particles bringing out surface modification. Both types of interactions can lead to alteration of mineral hydrophobicity, and in some cases cause flocculation or dispersion of mineral suspension. Microbes can also remove toxic metal ions from ground and surface-waste-water by biosorption or bioaccumulation processes.

Application of Microorganisms in Mineral Processing

Solid – solid interactions are dependent on biochemical properties and the interfacial properties of the interfaces existing in the system. Microorganisms can be used instead of conventional chemicals for the following purposes (Smith and Miettinen, 2006):

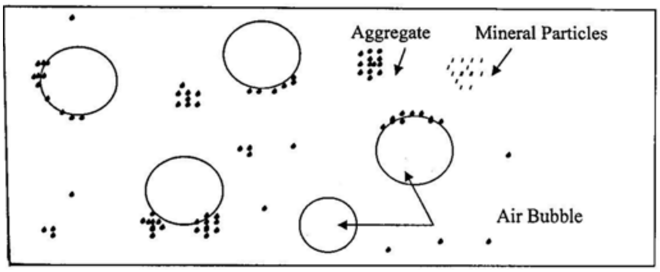

FIG.10 SCHEMATIC REPRESENTATION OF FROTH FLOTATION OF AGGLOMERATED SPECIES

- To act as leaching agents either directly attaching to the mineral surface or by producing acids which aid in leaching.
- To act as surface modifier to enhance the separation of one mineral from another either by flotation or flocculation.
- Hydrophobicity.
- Electrostatic Interactions.
- Biosorption of Metal ions.
- Biofloccualtion process.
- Bioflotation process which includes:
  - ✓ Bioflotation of sulphide minerals.
  - ✓ Desulphurization of Coal.
  - ✓ Bioflotation of some oxide minerals.
  - ✓ Bioflotation of salt type minerals.

In both flotation and flocculation, the attachment or adsorption of microorganism to the mineral surface is an important process (Attia and Elzeky 1985). The attachment is dependent on both the solution conditions such as pH and ionic strength and the surface properties of the minerals and the microorganisms such as zeta-potential and hydrophobicity.

Microbe-mineral interactions yield results that are of relevance to various applications:

- Adhesion of microorganisms to mineral substrate resulting in bio-film formation.
- Biocatalysed oxidation, reduction, complexation and precipitation reactions.
- Reactions of bacterial cells and metabolic products with different mineral constituents in an ore matrix.

The end result of such biological processes is formation and conversion of various minerals, surface modification, selective dissolution of mineral constituents and bio-accumulation of dissolved metal ions. Mineral surface hydrophobicity itself can be brought about by controlled microbe-mineral interactions as shown in Fig.11, indicating that water drops are not spreading on the apatite surface treating with the microorganism. Metabolic products as well as the bacterial cell components including the cell wall and membrane can take part in these microbiological reactions.

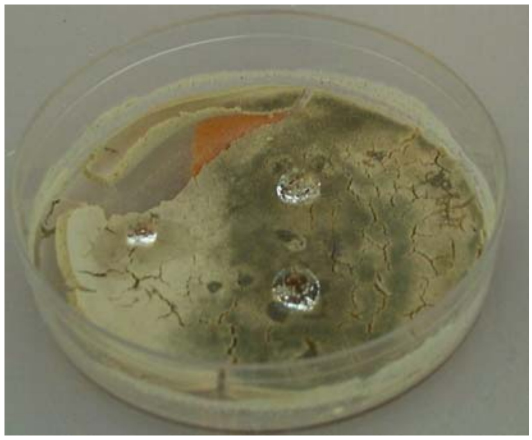

FIG. 11 HYDROPHOBICITY OF APATITE SURFACE TREATED WITH MO WITH BACILLUS POLYMYXA AS ESTABLISHED BY FROTH FLOTATION

1) Bio-flotation of Oxide Minerals

The difference in surface properties between two minerals, i.e. hydrophobicity and surface charge were utilized for selective attachment of the microorganism, which in turn led to selective flotation or flocculation. In recent years, the microorganism Bacillus polymyxa has been used for bio-processing of various minerals. In this case, the microbe was adapted to the particular mineral, i.e. it was grown in the presence of the mineral. This approach of adaptation made the organism secrete different bio-surfactants in the presence of different minerals thereby making the attachment selective. For example, either paenibacillus polymyxa or its metabolite renders the hematite and corundum surface hydrophilic, Fig. 12 (Shashikala and Raichur, 2002) .

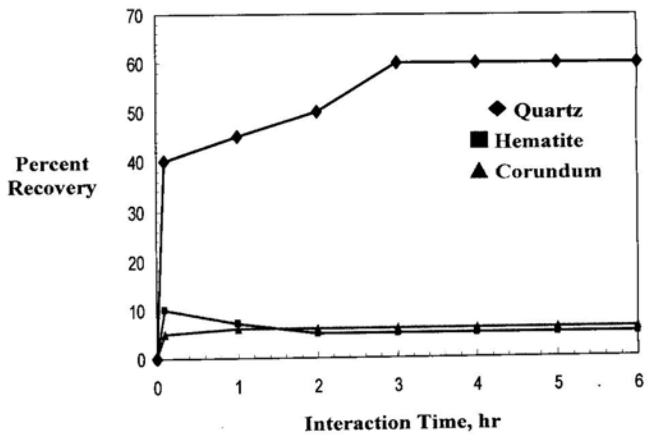

FIG.12 HYDROPHOBICITY / HYDROPHILICITY OF DIFFERENT MINERALS AFTER INTERACTION

However, similar interactions make quartz surface hydrophobic. The above difference in surface properties has been utilized to efficiently separate quartz from hematite and alumina. The mechanisms responsible for bio-mineral beneficiation are not fully known. Further, it will be helpful to identify various physicochemical and biochemical parameters that can influence microbially induced beneficiation processes. The interactions of P. polymyxa with hematite, corundum and quartz were investigated in order to understand the mechanisms behind its contrasting behaviour with three minerals (Mesquita et al., 2001).

In 2001, Mesquita et al, used a non-pathogenic hydrophobic bacterium (RRO 1879) as a flotation reagent in investigation of hematite-quartz system. They found that a strong interaction between cells and mineral particles, mainly for hematite. The scanning electron photomicrograph was showed the presence of RRO 1879 cells adhered on mineral surfaces.

For a constant ionic strength (0.1 m M NaCl), the change on the surface properties showed a high influence of pH on the adhesion process, and both physical and chemical mechanisms would be involved in particles and cells interaction.

The selectivity for hematite flotation against quartz was observed in the tests, by using a synthetic minerals mix, showing the potentiality for using RRO 1879 cells as a collector, in a neutral pH, in flotation systems where iron grade is low, or in materials where hematite is a contaminant.

2) Bio-flotation of Black Shale

TABLE 5 COMPARISON OF FLOTATION PRODUCTS OF BLACK SHALE

	Product	Mass	Ni	Ni - recovery
		Wt %	%	%
Flotation	Rougher	65.7	0.436	91.8
	CC1	20.8	0.217	47.4
	CC2	25.8	0.229	60.2
	CC3	34.5	0.672	74.3
Bio- flotation I	Rougher	72.6	0.39	93.6
	CC1	52.2	0.484	83.4
	CC2	29.1	0.648	62.1
	CC3	16.8	0.782	43.3
Bio- flotation II	Rougher	64.6	0.451	85.4
	CC1	49.10	0.506	72.7
	CC2	42.00	0.539	66.2
	CC3	25.10	0.756	55.5

In 2007, the bio-beneficiation of multimetal black shale ore was studied (Jörg and Reijo), within the framework of the EU co-funded Bioshale project. This project aims to define innovative biotechnological processes for ''eco-efficient'' exploitation of black shale ores. The ore sample was from the Talvivaara deposit in Finland. In the black shale ore sample, the total amount of sulphides was 31.5% of which the Ni-minerals pentlandite and altered pentlandite is 0.52%. Nickel is distributed into pyrrhotite and oxidized pyrrhotite, 32.5%, and pentlandite and altered pentlandite, 66.0%. Other sulphides are chalcopyrite (Cu), sphalerite (Zn), pyrite (Co) and alabandite (Mn). The ore sample contanied 12.3% graphite as a fine mixture with other minerals. In standard flotation for a feed of 78 μm, a low grade sulphide concentrate with 0.67 % Ni and nickel recovery of 74 % was obtained from the studied black shale ore, Table 5. The mass of concentrate was then 34.5% of the ore feed. The recoveries of copper and zinc were 91%, of cobalt 89% and of manganese 53%. The content of carbon in the concentrate was 11.3% as graphite represents a naturally floating harmful mineral in the ore. The bioflotation tests showed that collector chemicals, i.e xanthates, had to be supplied to achieve reasonable flotation results. Out of the three tested bacterial strains, *Staphylococcus carnosus*, *Bacillus firmus* and *Bacillus subtilis*, the minor hydrophobic strain *S. carnosus* yielded the best test results.

Contribution of CMRDI in Flotation of Fine Particles

The author applied (Abd El-Rahiem,1997) the carrier flotation technique, as an alternative to conventional flotation, can be successively applied for separation on anatase impurities from the Egyptian kaolin preconcentrate, of El-Tih locality at Sinai, see Table 6. In this technique the amount and grain size of the carrier play a very important role in determining the performance of the flotation process. The best results are obtained while adding 133.33 kg/ t of limestone, as a carrier. The presence of such carrier particles increases the aggregation rate of carrier–anatase aggregates thereby facilitating their rate of collision with air bubbles and consequently improves the efficiency of the flotation process. Moreover, the long conditioning time which requires froth flotation can be significantly reduced from 35 to 20 min. in carrier flotation technique. Such reduction in conditioning time will decrease the power consumption needed for the process.

Application of carrier flotation technique for upgrading of Egyptian kaolin preconcentrate , using 83.33 kg/t of limestone with grain size of -25 + 10 µm , and the aforementioned optimum conditions of froth flotation, gave a concentrate of 0.61 % TiO_2 only with degree of whiteness (~ 90), from a feed assaying 1.52 % TiO_2 with degree of whiteness 56.

TABLE 6 EGYPTIAN KAOLIN CONCENTRATION PRODUCE BY DIFFERENT FLOTATION TECHNIQUES

Flotation Process	Whiteness
Conventional	78
Carrier	90
Column	91.5
Feed	56

The author (Abd El-Rahiem, 2003) used carrier flotation technique for decreasing sulfur content and ash from fine particles (- 25 µm) of El-Maghara coal from Egypt. A highly floatable coarse coal is capable of carrying fine and difficult-to-float coal through some kind of heterocoagulation process. The best size for the present system is -0.3+ 0.1mm. The higher the amount of fine carried coal for the same size of carrier; the lower is the flotation performance. The ratio of 0.02 for carrier by weight is found to be suitable to achieve good flotation performance. The mechanism of the carrier flotation process is ascribed to the electrostatic forces between the positively charged carrier particles (+20 mV) and negatively charged particles (-20 mV) of fine coal. The attraction is governed by the hydrophobic/hydrophilic balance at the carrier carried surface. As the carrier size approaches that of the carried size, it is adversely affected. As the size of carrier increases above a certain value, the hydrophilic exceeds the ability of bubbles to levitate such a large and relatively hydrophilic aggregate, leading to a significant decrease in flotation efficiency.

It is well known that during the beneficiation of phosphate ore, 25 – 35 % by weight of the ore is discarded as slimes (-45µm). For example, in Florida phosphate industry, about 1/3 of the feed is lost as phosphatic clay slimes. In Sebaiya West , Egypt, such slimes represent about 25-30 % of the feed. For this reason, the author tried to recover such fine phosphate column flotation.

During the beneficiation of Sebaiya West phosphate, Egypt, application of column flotation for recovery of fine particles (- 45 µ m), Table 7, indicated that the optimum conditions are : superficial gas velocity 0.84 cm/sec., frother concentration 0.1 kg/ton, column height 230.5 cm and superficial wash water velocity 2.2 cm/sec. At such condition ,a concentrate assaying about 25.30 % P_2O_5 and 14.64 % I.R. from the original feed, which contains 18.26 % $P_2O_5$and 24.68 % I.R. with on operational P_2O_5 recovery of about 76.50 %, was obtained. Such grade and recovery are not obtained by the conventional froth flotation process for upgrading such fines even after a stage of cleaning. The grade of the concentrates obtained by column flotation can be improved by altering the amount of wash water used, which help in minimizing the feed water recovery by washing the entrained , non-floated particles from the floatable bubble- particle aggregates(Abd El-Rahiem,1997) .

Also, applying column flotation technique on Sebaiya West phosphate sample (100% - 75 µ m), Egypt, table 7, gave a concentrate assaying 30.4 % P_2O_5 and only 8.64% IR. With total recovery of about 70.24%. Such grade and recovery have never been obtained before, through the conventional froth flotation technique, at the flotation plant at Sebaiya West, Egypt, even after two cleaning stages. Such superior results obtained by column flotation technique may suggest its application at Sebaiya West, as a new technique, may have many advantages: first, reducing the operating costs of phosphate production by saving the cleaning stages which are actually performed at Sebaiya West, second maximizing the values of Egyptian phosphate by producing high grade concentrates suitable for exportation and for manufacturing of high quality complex phosphatic fertilizers.

TABLE 7 RESULTS OF COLUMN FLOTATION ON SEBAIYA WEST PHOSPHATE SAMPLE

Grinding Size, mm	P_2O_5 %	I.R. %	P_2O_5 % recovery
- 0.045	25.30	14.64	76.50
- 0.075	30.40	8.64	70.24
Feed	18.26	24.68	------

The author applied (Abd El-Rahiem, 2004) column flotation technique to separate graphite from Um Qureia ore, taken from Eastern desert of Egypt. The flotation of fine particles (-45μm) using conventional cell, a rougher concentrate about 34 % C with recovery 38 % was obtained from a feed assaying 15.58 % carbon content, Table 8. However, applying flotation at its optimum conditions, a rougher concentrate at 36 % C with recovery 93 % was obtained. In cleaning of rougher concentrate 4 stages are needed by conventional cell to get a concentrate of about 71 % C with recovery 87 %. In cleaning of rougher concentrate by column flotation, needed 2 stages to get better grade about 79 % C and about 98 %. Thus the column flotation is better than conventional flotation in fine particles of graphite.

TABLE 8 COMPARISON OF RESULTS OF CONVENTIONAL CELL AND COLUMN

Details	- 45 μm		+ 45 μm	
	Cell	Column	Cell	Column
Weight % Carbon content % Carbon recovery % No. stage of cleaning	41.07 70.59 86.60 4	45.30 78.55 98.30 2	44.70 45.17 89.17 4	47.90 46.14 96.05 2
Feed	33.99 % Carbon		22.86 % Carbon	

The flotation of coarse particles + 45μm, almost similar results were obtained either by cleaning in 4 stages by conventional cell or 2 stages by column flotation. Thus the performance of column is better compared to cell by reducing the number of stages required for flotation of coarse particles of graphite, and also improving the recovery.

Also, The author applied (Abd El-Rahiem, 2005), used column flotation technique to beneficiate preconcentrate talc sample of Shalatin locality in the Eastern Desert at the following conditions feed (- 75 μm), the flow sheet in Fig. 13., at Column height 225 cm, with 30 % pulp density at pH 6.5, while superficial air flow rate was 4 cm/sec. The collector used was Aero 825 with consumption of 300 g/t. Also, Na_2SiO_3 was used as carbonate depressant with the consumption of 100 g/t. The frother was employed Aerofroth 71 of Cyanamide with 100g/t of consumption. Finally, the superficial flow rate of wash water was 1.5 cm/sec. At such conditions, a concentrate assaying 1.48 % CaO and 5.40 % L.O.I. with a recovery 95 % was obtained from a feed containing 6.32 % CaO and 11.53 % L.O.I., Table 9.

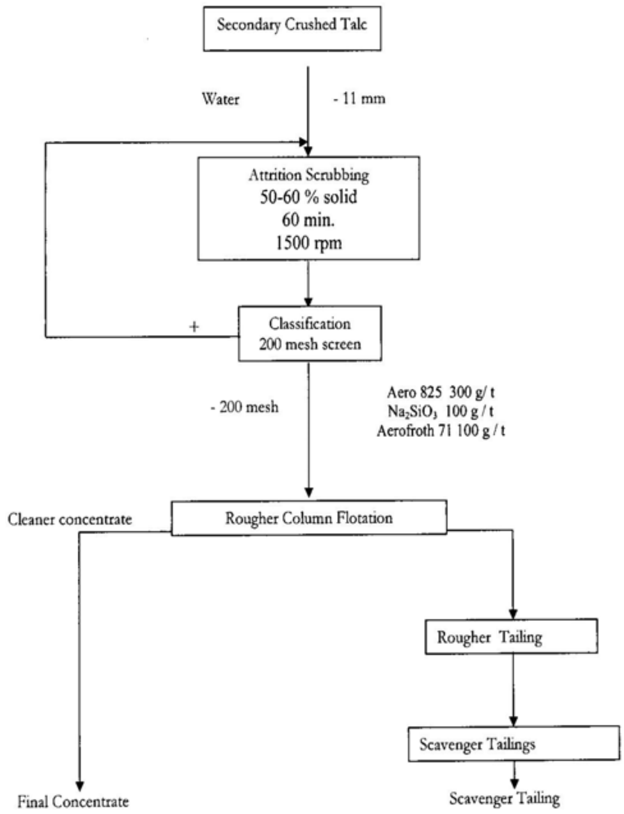

FIG .13 FLOWSHEET OF THE BENEFICIATION OF TALC BY COLUMN FLOTATION TECHNIQUE

These results indicate clearly the supremely of the column flotation in floating such fine particles of talc where the selectivity in separation carbonate (as CaO and L.O.I.) is significantly need in the concentrate.

TABLE 9 COMPLETE CHEMICAL ANALYSIS OF THE ORIGINAL AND FINAL CONCENTRATE OF TALC

Constituent %	**Original**	**concentrate**
MgO	28.41	30.05
SiO_2	49.71	57.04
CaO	6.32	1.48
Fe_2O_3	1.15	0.76
L.O.I.	11.53	5.40
Na_2O	2.11	0.13
Al_2O_3	0.13	3.63
TiO_2	0.02	0.02
MnO	0.04	0.04

In 2008, Abdel-Khalek and co- author used bio-flotation technique to beneficiate a low grade sample of phosphate ore (Abu-Tartur area, New Valley, Egypt). Microorganisms were used mainly as surface modifiers for either apatite or dolomite surface, leading to better selectivity for adsorption of collector on the mineral surface. In most of phosphate flotation plants, fatty acids (e.g. oleic acid or oleate) are used as collector for direct flotation of phosphate minerals from their associated gangue (mainly silica). Since oleic acid was a conventional collector, the bio-flotation experiments aim at comparing its efficiency to a second collector known as amphoteric. The latter shows better selectivity towards carbonate flotation (Yassin, 2004). Preliminary flotation experiments were conducted, as control tests, using both collectors without addition of microorganisms, the results of which are shown in Table 10.

TABLE 10: CONTROL TESTS FOR FLOTATION OF PHOSPHATE SAMPLE WITH BOTH COLLECTORS

Collector type	P_2O_5%	MgO %	P_2O_5 recovery %
Amphoteric (4.0 kg/t)	29.15	1.12	75.43
Oleate (0.25 kg/t)	30.19	0.84	55.52
Oleate (> 0.25 kg/t)	Bulk flotation with 100 wt % floated		
Flotation Feed	27.07	2.24	----------

Two types of bacteria were used in the bio-flotation process. These bacteria were isolated from the surface of Abu-Tartur phosphate ore at the Microbiology Department, University of Florida, USA. Two of them were selected for the bio-flotation experiments. The bacteria were grown in a liquid medium containing 30% mycological agar, 10.0 g L^{-1} sucrose,1.0 g L^{-1} ammonium nitrate and 700 mL double distilled water. The bacteria were incubated at 25℃ for two weeks (Yassin, 2004).

Control tests, without addition of bacteria, were conducted using 0.25 kg t^{-1} sodium oleate at pH 5.5.The results showed that starting from feed containing 27.07%P_2O_5 and 2.24%MgO, a concentrate contains 30.2%P_2O_5 and 0.85%MgO can be obtained but at a low recovery (55.5%). Using a higher sodium oleate concentration (>0.5 kg t^{-1}) resulted in bulk flotation (100 wt-% floated) of the flotation feed with no selectivity.

Other flotation tests were conducted to clarify the effect of pH and bacteria concentration in terms of collector concentration. The results of these tests were shown in Fig. 14.

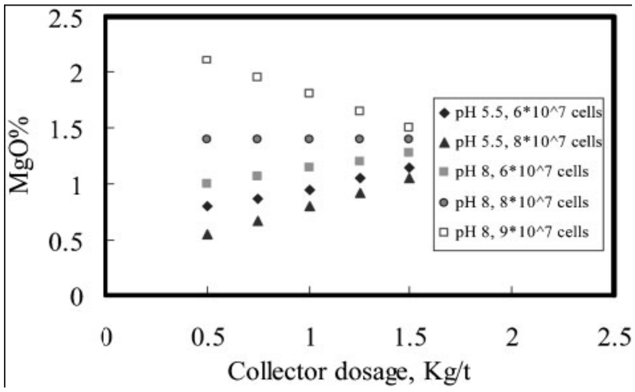

FIG. 14 EFFECT OF COLLECTOR DOSAGE ON MGO REMOVAL AT DIFFERENT PHS AND BACTERIA CONCENTRATIONS

The best grade (0.78%MgO and 30.2%P_2O_5) with a high recovery (92.6%) was obtained at pH~5.5, 2.0 kg t^{-1} sodium oleate and a concentration of bacterium # 1 of 1.0 x10^8 cells. In the absence of bacteria, such grade and recovery could not be obtained. Also, it was found that strong interaction between sodium oleate and the bacteria enhances the selectivity of the flotation process. Both microorganisms (coded #1 & #2) have minor electro-negativity especially in the acidic medium. Their zeta potential slightly increased (by not more than 12 mv) with raising the pH from the very acidic medium (pH 2) to the strongly alkaline medium of pH 12. These results illustrate the hydrophobicity of these microorganisms.

In 2004, enzyme, obtained from Aspergillus's Niger F–909 cultures, was used as a surface modifying agent during phosphate fatty acid flotation to beneficiate a low grade sample of phosphate ore (Abu-Tartur area, New Valley, Egypt). The results revealed more efficient separation of carbonate from phosphate rock. The Concentrate at 0.70 % MgO with recovery 86.41% was obtained from a feed containing 2.88 % MgO.

Conclusions

- The problems associated with the presence of fine particles are most pronounced in flotation. There is a general agreement that flotation decreases with a decrease in particle size in the fine particle range. The flotation of fine particles need the long conditioning time and need long flotation time.
- The carrier flotation technique has the advantage of reducing the long conditioning time needed for the pulp with the reagents in the conventional technique.

- The main draw backs of carrier flotation process in mineral beneficiation operations, are high reagent consumption and the necessity for subsequent separations of valuables from the carrier particles (when the valuable minerals are being recovered in the froth).
- There is a great potential to recover fine particles from their gangue using the recent technology such as column flotation or ASH after its modification to be suitable for flotation of very fine particles.
- The biological processes are becoming more attractive in mineral processing due to their lower operating costs and their possible applicatios to treat difficult to beneficiate low grade complex ores.

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