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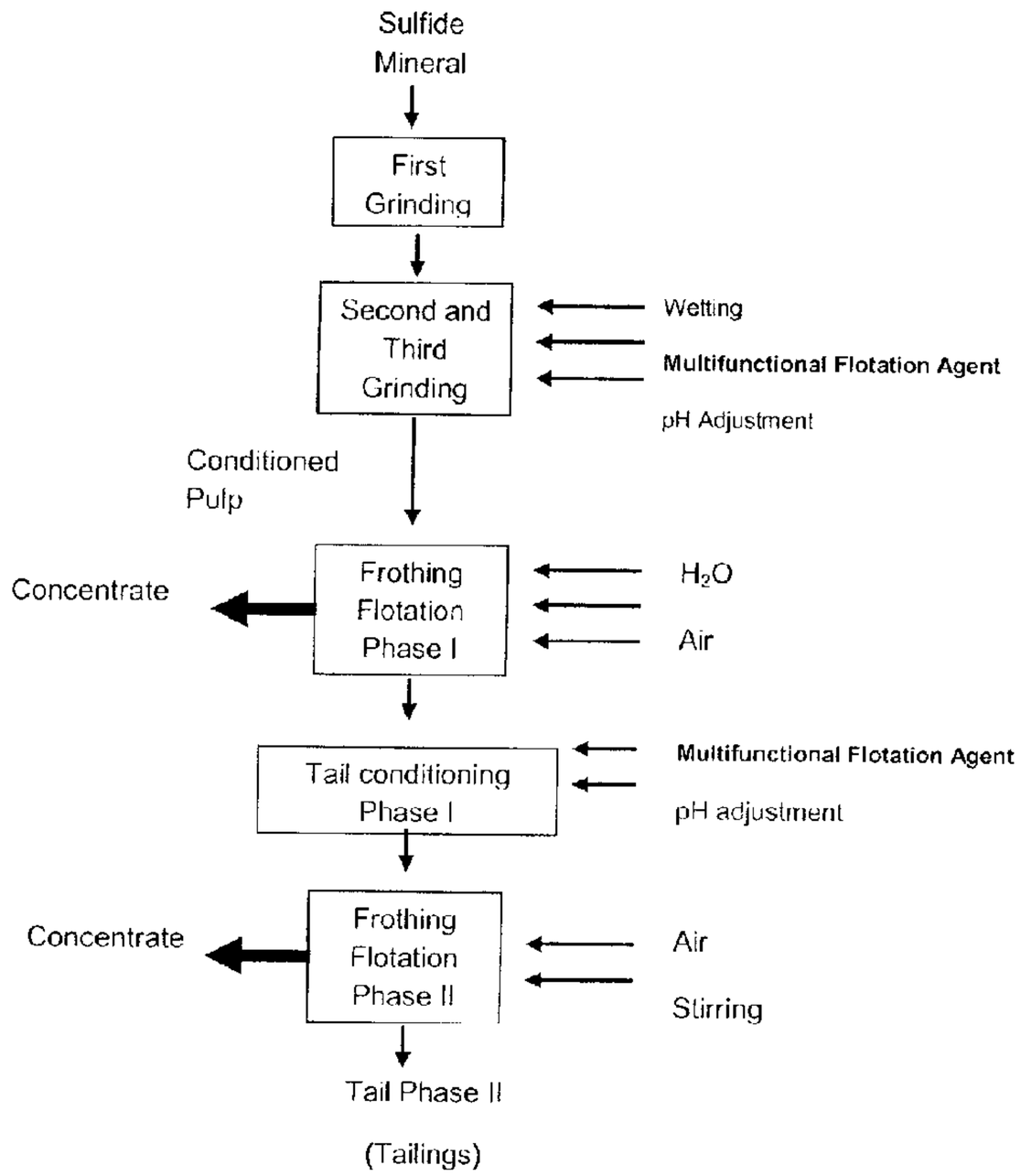
(72) **Inventeurs/Inventors:**
SAEZ NAVARRETE, CESAR ANTONIO, CL;
REYES BOZO, LORENZO, CL;
GINOCCHIO CEA, ROSANNA, CL;
HERRERA MARCHANT, MIGUEL NICOLAS, CL

(73) **Propriétaires/Owners:**
CENTRO DE INVESTIGACION MINERA Y METALURGICA, CL;
PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE, CL;
GINOCCHIO CEA, ROSANNA, CL;
HERRERA MARCHANT, MIGUEL NICOLAS, CL

(74) **Agent:** SIM & MCBURNEY

(54) **Titre : AGENT COLLECTEUR ET MOUSSANT POUR LA FLOTTATION A BASE DE RESIDUS ORGANIQUES POUR LA RECUPERATION DE METAUX A PARTIR DE MINERAIS PAR FLOTTATION PAR MOUSSE, PROCEDE D'OBTENTION DE L'AGENT COLLECTEUR ET MOUSSANT DE FLOTTATION ET PROCEDE DE FLOTTATION PAR MOUSSE QUI UTILISE CET AGENT COLLECTEUR ET MOUSSANT**

(54) **Title: COLLECTOR AND FROTHING AGENT FOR FLOTATION BASED ON ORGANIC RESIDUES FOR THE RECOVERY OF METALS FROM MINERALS BY FROTH FLOTATION, COLLECTOR AND FROTHING AGENT RECOVERY PROCESS ANDFOAMING FLOTATION PROCESS THAT USES THE COLLECTOR AND FROTHING AGENT**



(57) **Abrégé/Abstract:**
The invention relates to a multifunctional flotation agent having collection and frothing functions, for a froth flotation method for the recovery of commercially valuable metals from minerals, said agent consisting of organic residues selected from the group

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(57) **Abrégé(suite)/Abstract(continued):**
consisting of biosolids from wastewater treatment plants, organic mud from biogas production systems, hydrosoluble organic matter from compost or other similar organic residues that are biologically treated or stabilised in aerobic and/or anaerobic conditions, industrial mud from the treatment of industrial organic liquid residues, and hydrosoluble organic matter from peat, guano, manure, or a combination of at least two of any of same, or a fraction thereof, said biosolids containing between 35% and 98% of organic matter, with a bulk density of between 0.2 and 0.8 g/mL, a pH of between 6.0 and 8.5, and an electrical conductivity of between 4.0 and 15 mS/cm. The invention also relates to the method for producing said multifunctional flotation agent (collection and frothing agent) and to the froth flotation method using the disclosed multifunctional agent.

ABSTRACT

The present invention involves a multifunctional frothing agent with collector and frothing functions for frothing flotation processes to recover valuable metals from minerals, based on organic residues selected from biosolids from wastewater treatment plants, organic sludge from biogas production systems, compost hydrosoluble organic matter or other similar biologically treated or stabilized organic in aerobic or anaerobic conditions, industrial sludge from industrial organic liquid waste treatments, hydrosoluble organic matter from vegetal peat, manure, dung or a combination of two or more of these, or a fraction of them, representing between 35% and 98% organic matter, apparent density between 0.2 and 0.8 g/mL, a pH between 6.0 and 8.5, an electrical conductivity between 4.0 and 15 mS/cm. It also involves the process of the multifunctional collector and frothing agent recovery (collector and frothing agent) and the frothing flotation process that uses the multifunctional agent disclosed in this investigation.

COLLECTOR AND FROTHING AGENT FOR FLOTATION BASED ON ORGANIC RESIDUES FOR THE RECOVERY OF METALS FROM MINERALS BY FROTH FLOTATION, COLLECTOR AND FROTHING AGENT RECOVERY PROCESS AND FOAMING FLOTATION PROCESS THAT USES THE COLLECTOR AND FROTHING AGENT

WORK SPECIFICATIONS

Field of the Invention

The present invention relates to collector and foaming agents based on organic waste, useful in froth flotation processes to recover commercially valuable metals from either sulfide minerals (copper, zinc, lead, iron, molybdenum, etc.) or non-sulfide ores (gold, etc.). It consists of multifunctional flotation agents used as collector and foaming agents based on organic waste that are derived from aerobic or anaerobic treatment or decomposition processes, or from just a fraction of them (extract). It also involves the production process and use of such collector and foaming agents in a froth flotation process to recover metals of commercial value from minerals. These processes result in the creation of tailings whose composition is suitable for an environmental remediation treatment.

Background

The current scenario has imposed resource, operation and exogenous challenges on the mining industry, particularly on associated metallurgical processes. In the case of resources, there has been not only a continuous decrease of mineral grades, and therefore a sustained increase in liabilities and environmental waste, but also the creation of new mineralogical associations. From an operational standpoint, the most important, the urgent need to reduce energy costs and water consumption. In the case of exogenous challenges, increasingly demanding and rigorous environmental policies have been imposed. Also, new standards of product quality requirements have been implemented, and in recent years, there has been a strong impact on production costs associated with supplies used in both mining and metallurgical operations.

It becomes more urgent than ever the need to address these challenges efficiently and effectively. This invention aims to address some of these challenges, particularly with regard to improving the mineral concentration stage through the development of unique, bifunctional, effective, inexpensive and very competitive flotation reagents. It also improves the efficiency of flotation and generates tailings that favor a positive environmental management to implement technologies such as phytoremediation.

The froth flotation process is the most use in the beneficiation of either sulfide minerals (copper, zinc, lead, iron, molybdenum, etc.) or non-sulfide ores (gold, etc.) containing metals of value. The process makes it possible to separate commercially valuable metals from the gangue and /or to separate valuable metals from each other, from minerals previously subjected to crushing and grinding stages.

In the case of sulfide mineral subjected to froth flotation, different chemical compounds of specific action, such as frothers, collectors and modifiers are used. Collectors are organic compounds of relatively short carbonic chain and without foaming capacity. After the injection of air into the mineral pulp under stirring, a foam composed of an aqueous solution of the finely ground mineral containing a foaming agent (e.g., pine oil, cresylic acid, ROH alcohols as methyl isobutyl , carbonyl, polyglycols and 2 ethyl hexanol) is formed. An important advantage of the separation by froth flotation is its substantially lower cost than other beneficiation processes, such as gravitational and centrifugal concentrations, among others.

During flotation, one or more reagents called collectors or promoters are added, which make the selective transformation of a lyophilic surface (hydrophilic in the case of the use of water) into a lyophobic surface (hydrophobic in the case of the use of water) possible in minerals containing the valuable metal to be obtained as final product. From a scientific standpoint, it was found that the separation of a mineral species from another by flotation depends on the wettability of its surfaces in water, which is determined by the net balance of the interfacial energies, i.e. the variation of free energy per unit area among different phases: solid, liquid and gas. Various reagents as collectors in froth flotation processes for recovery of commercial valuable metals have been suggested and used, the most common are xanthates (xanthates, xanthate esters), carbamates (dithiocarbamates, thiocarbamates), mercaptans , mercaptobenzo-thiazole and the organic derivatives of phosphoric or phosphorus acid (dithiophosphates, thiophosphates, dialkyldithiophosphate acid).

One of the problems associated with these collectors is that lower pyrite and pyrrhotine depressions are obtained at a pH lower than 11. Also, experience has shown that as the pH decreases, the collector ability of these reagents also decreases, reducing significantly the feasibility of using them in slightly alkaline, neutral or acidic pulps. During manufacturing operations, the pH adjustment is performed by adding lime, alkali and hydroxide metal oxides, among others. The inclusion of an inorganic base is widely used to achieve desired pH values. After controlling the pH of the pulp at levels of 8.0 and higher, frequently around 11, the collector performance improves.

Other relevant aspects related to collectors on the market is their high cost, their specificity is very sensitive and interfered by other species present in the pulp and not very efficient in pyrite/pyrrhotite depression. Also, foaming agents must be added, which are costly, making the costs of the whole process to increase due to the large amount of mineral that is processed in the mining sector.

In operational terms, the application of flotation aims to obtain a range of copper concentrate of 25% - 30% (w/w, dry basis), from low grade minerals (0.5 - 2% Cu). Currently, the concentration operation by flotation in the copper industry reaches a copper recovery range between 80% and 85%, and in some cases, optimal values close to 90%. However, the above is obtained at very high operational costs.

Currently, flotation reagents used are formed by recalcitrant chemicals, which have a negative environmental impact.

In that sense, having flotation reagents of lower cost and less environmental impact, like organic waste either from treatment processes or aerobic or anaerobic decomposition, or just a fraction of them, such as those generated from household wastewater purification processes (biosolids) and/or livestock production systems (slurry, manure) would have a significant economic impact on the mining industry, and would simultaneously solve environmental and social problems related to its current operational management. The treatment of household wastewater, using activated sludge, generates a significant amount of organic waste or biosolids on landfills and monorrellenos, with a significant cost not only for water companies but also for users of the system. It is important then to identify alternatives for recovery of organic soils, which due to their massive nature should relate to other big industrial processes, such as large-scale mining industry.

In the state-of-art there is a proposal to use treatment plant wastewater effluents as process water for froth flotation of minerals without altering their effectiveness, as disclosed in U.S. Patent 4,028,235 in 1976. The document mentions that the effluent must be conditioned with polyglycerol or with a physical treatment of clarification, sedimentation and/or aeration to obtain water of adequate quality and to not adversely affect the froth flotation. It is also mentioned that the conditioning of the effluent with polyglycerol is essential, critical and cheaper in the process than other suggested alternatives. The direct use of the effluent without polyglycerol has negative effects on the froth flotation process, as the gangue floats instead of being depressed, producing a concentrate of lesser quality. Although the mechanism of action of polyglycerol in the effluent is unknown, an effluent addition between 3 and 10 parts per million (ppm) is suggested. Larger amounts of polyglycerol do not benefit the effluent. Additionally, the document mentions that the froth flotation process, based on the use of polyglycerol-conditioned effluents, requires the addition of foaming and collectors conventionally used in the rougher stage of flotation. As shown, the solution proposed in this document is the use of effluents of treatment wastewater plants conditioned with polyglycerol. It is not intended to replace all or part of the foams conventionally used in froth flotation processes, but it is intended to be used as an alternative source of water in mining process in places where the chances of access to natural water sources are limited.

Definitions

In the present specification, the term "multifunctional flotation agent" means an agent that can have both, collector and foaming functions. Also, the term "foaming and collector agent" refers to a single multifunctional agent that includes both collector and foaming functions.

In the context of the present invention, the term "organic matter" refers to biosolids from wastewater treatment plants, sewage organic sludge from biogas production systems, water-soluble organic matter from compost or other biologically similar organic waste treated or stabilized under aerobic and/or anaerobic conditions, industrial sludge from treatments of industrial organic liquid waste, organic matter from vegetable peat, manure or a combination of two or more of any of them, or just a fraction of them.

The term "fulvic acids" refers to organic compounds present in the organic material (i.e. biosolids, manure) which are obtained by basic extraction and do not precipitate at low pH.

The term "humic acids" refers to organic compounds present in the organic material (i.e. biosolids, manure) which are obtained by basic extraction and precipitate at low pH.

The term "liquid extract from multifunctional flotation agent" is understood as a liquid agent that may have collector and foaming function. It is a liquid extract obtained from the processing of organic waste derived from treatment processes or aerobic decomposition, such as biosolids and/or manure.

Technical Problem

There is a need to generate frothing and collector agents for flotation of either sulfide minerals (copper, zinc, lead, iron, molybdenum, etc.) or non-sulfide (gold, among others.) with low environmental impact, low cost, multifunctional agents (simultaneous collector and foaming functions) and efficient concentration and separation of multiple valued metals from minerals subjected to flotation, operating at wide ranges of pH in the recovery processes of commercially valuable metals by froth flotation.

Technical Solution

The present invention provides multifunctional flotation agents, with both, collector and foaming functions based on organic waste derived from treatment processes or aerobic or anaerobic decomposition, or from just a fraction of them, available for foaming flotation processes for the recovery of valued metals from minerals. Also, it provides a manufacturing process of these agents and how to use them in mineral flotation processes.

Advantageous Effects

The main advantage of the present invention over the current state of technology is the lower cost and lower environmental impact of this foaming and collector agent versus the current chemical collector and foaming reagents. Also, it has a better selectivity for the recovery of commercially valuable metals from minerals and a wider range of applications.

These collector and foaming agents have the advantage of having a much more competitive cost than collectors and foaming agents on the market. Additionally, due to their organic origin, they are harmless to human health, environment and subsequent metallurgical processes, as they are biodegradable. The latter attribute is particularly important in terms of job stress and health, as collector and foaming chemical agents in the market are toxic and flammable organic compounds and are stored in tailings deposits after their use.

Also, this invention increases the value to organic waste derived from treatment processes or from aerobic or anaerobic decomposition, or just a fraction of them. For example, water companies could increase the value of biosolids generated by their plants of household wastewater treatment, and the livestock industry could increase the value of its organic waste (manure, slurry).

This invention provides an environmentally safe and valued view for massive waste, which has traditionally had a very negative social perception. Simultaneously, the total or partial replacement of existing reagents from organic waste flotation or just a fraction of them would eliminate the environmental hazards associated with the existing chemical flotation reagents.

In accordance with an aspect of the present invention, there is provided a collector and foaming agent for froth flotation processes in the recovery of commercially valuable metals from sulfide minerals or non-sulfide ores, the collector and foaming agent comprising organic waste derived from treatment processes, aerobic decomposition, anaerobic decomposition, or a fraction thereof.

In accordance with another aspect of the present invention, there is provided a collector and foaming agent for froth flotation processes in the recovery of commercially valuable metals from sulfide minerals or non-sulfide ores, the collector and foaming agent comprising organic waste derived from treatment processes, aerobic decomposition, anaerobic decomposition, or a fraction thereof, wherein the organic waste is derived from treatment processes or selected aerobic or anaerobic decomposition of biosolids and/or manure and/or humic substances and wherein the biosolids comprise between 35% and 98% organic matter on a dry basis.

In accordance with another aspect of the present invention, there is provided a production process for the foaming and collector agent as described above, the process comprising:

(a) collecting organic waste from generating sources of organic matter from treatment processes, aerobic decomposition, anaerobic decomposition, or a fraction thereof and determining properties selected from the group consisting of organic matter content and humic substances content;

(b) conditioning of the collected material from (a) by the following steps:

(i) dehydrating the collected material to a moisture content less than or equal to 75%; and

(ii) reduction of size and separation of the dried material by milling and sieving to obtain material with a size less than or equal to 10 millimeters (mm); and

(c) compacting the obtained material from (ii) to form pellets or briquettes.

In accordance with another aspect of the present invention, there is provided a froth flotation process for the recovery of commercially valuable metals from sulfide minerals or non-sulfide ores, the process comprising the steps of:

- reducing the size of sulfide minerals or non-sulfide ores to a particle size below 400 microns by first, second and third crushing, and afterwards, semi-autogenous or conventional grinding;
- conditioning of the mineral ground into a pulp by mixing the ground mineral, water to obtain a mineral pulp with a range from 5% to 20% of solids weight, pH modifiers, strong bases, and the collector and foaming agent as described above;
- receiving the conditioned pulp in a flotation device and adding water to obtain a pulp with a range of 20% to 50% of solids weight;
- stirring to keep the material in suspension, aerating such pulp with a stream between 5 and 200 cubic meters per minute for a period of time 2 to 20 minutes, and concentrating the commercially valued metal in a foam and depressing a flotation tail; and
- collecting the foam rich in the commercially valued metal as a metal concentrate.

In accordance with another aspect of the present invention, there is provided a use of the collector and foaming agent as described above, in froth flotation of sulfide ores or non-sulfide.

Brief Description of the Figures

Figure 1: It shows the stages of froth flotation process for the recovery of commercially valuable metals.

Figure 2: It illustrates the variation of surface tension at pH 7 and 10, at different concentrations of humic substances (HS), biosolids (BS) and methyl isobutyl carbinol (MIBC): (A) shows the results obtained for a total concentration of foaming agent (HS, BS, MIBC), (B) illustrates the results obtained for a concentration of foaming agent corrected by the fraction of seditnented material. Both graphs show the average values ($n \geq 4$); the error bars are within the symbols.

Figure 3: It shows the quantification of the hydrophobic fractions of the copper sulfide mineral (M), chalcopyrite (CPY) and pyrite (Py) for a dose of HS, BS, goat manure and RQCI obtained for the experimental condition of 100% water (surface tension of 72.1 mN m^{-1}). Average values ($n \geq 4$) and the error bars are shown.

Figure 4: It illustrates the kinetics of froth flotation obtained from industrial chemical reagent dosage (collector + frother), biosolids (BS) and humic substances (HS), (A) illustrates the results obtained with respect to the copper grade and (B) shows the results obtained with respect to iron grade.

Detailed Description of the Invention

The present invention consists of a multifunctional flotation agent with collector and foaming functions used in froth flotation processes for the recovery of commercially valuable metals either from sulfide ores (copper, zinc, lead, iron, molybdenum, etc.) or non-sulfide minerals

(gold, etc.), which are organic waste derived from treatment processes or aerobic or anaerobic decomposition, or from just a fraction of them (extract).

The multifunctional flotation agent, or "collector and foaming agent" is organic waste derived from treatment processes or aerobic or anaerobic decomposition, such as biosolids and/or manure. Results of physical and chemical analysis obtained from literature for biosolids and manures are shown in Table 1. The percentages are given on a dry basis.

Table 1: Ranges for the chemical composition and physical characteristics of biosolids and manures obtained from literature.

Parameter	Range
Organic matter (%)	35 – 98
Total N (%)	1.2 – 8.0
Total P (%)	0.2 – 3.0
Total C (%)	20.0 – 70.0
Humic and fulvic acids (%)	1.0 – 25.0
Proteins (%)	5.0 -25.0
Sugars (%)	0.1 – 5.0
Ethereal extract (%)	0.2 – 0.5
Apparent Density (g/mL)	0.2 – 0.8
pH	6.0 – 8.5
Electrical conductivity (mS/cm)	4 – 15

The production process of the multifunctional flotation agent of this invention consists of the following stages:

1. To collect the organic matter of biosolids and/or manure from the generating sources and select according to the physical and chemical properties listed in Table 1.

2. To condition some of the following operations, depending on their origin and mode of application:

a. To dehydrate until reaching a moisture content less than or equal to 75% and more generally to a moisture content less than or equal to 20%.

b. To reduce size and separate, for example through grinding and sieving to values less than or equal to 10 millimeters (mm).

c. To compact in the form of pellets or briquettes, among other options.

3. Packaging of the product.

The product obtained in number 2 can be subjected to a liquid aqueous extraction process using acids and/or strong bases to maintain the same characteristics mentioned for the multifunctional flotation agent (foaming and collector agent) of this invention.

The liquid extraction process of the multifunctional flotation agent (foaming and collector agent) consists of the following steps:

1. Take the product at the end of step 2 as described above.

2. Perform an extraction that considers some of the following alternative methods, depending on its origin and mode of application:

a. Extract using an acid-base process that considers a pH reduction between 1 and 2 with a strong acid such as HCl, H_2SO_4, H_3PO_4, at room temperature. Adjust the volume of the solution with acid until obtaining a ratio between 1:5 and 1:10 organic waste: acidic solution (mass: volume), dry basis. Stir the suspension for a period of time less than or equal to 10 hours. Separate and reserve the supernatant of the solid fraction. Adjust the pH of the solid fraction to neutrality using a strong base such as KOH, NaOH, etc, at room temperature. Adjust the volume of the solution with a base to obtain a ratio between 1:5 and 1:10, solid fraction: basic solution (mass:volume). Stir the suspension for a period of time less than or equal to 10 hours. Separate and reserve the second supernatant from the second solid fraction. Mix the supernatants of the first and second stages as described above to obtain the extract.

b. Extract using water as aqueous extractant considering to adjust the volume of the solution with water in a range between 1:5 and 1:10, organic residue: water (volume:volume) in dry basis, at ambient conditions. Stir the suspension for a period of time less than or equal to 10 hours. Separate and reserve the supernatant (extract) of the solid fraction.

3. Bottle the extract.

Description of a froth flotation method in mining

There is a competitive and alternative process of froth flotation for the recovery of commercially valuable metals from either sulfide or non-sulfide minerals, which uses the multifunctional flotation agent (foaming and collector agent) of the invention as an alternative and highly competitive element compared to collector and foaming agents used until this invention (Figure 1).

The froth flotation process for the recovery of commercially valuable metals from sulfide or non-sulfide minerals according to the present invention consists of the following steps:

1. Reducing the size of sulfide or non-sulfide minerals to a particle size below 400 microns. This includes the first, second and third grinding stages, and the subsequent semi-autogenous and conventional grinding;

2. Conditioning of the mineral ground into a pulp by mixing:

a. the ground mineral;

b. water to obtain a mineral pulp with a range from 5% to 20% of solid weight;

c. PH modifiers such as lime, strong bases such as KOH, NaOH, etc.

d. collector and foaming agent, it is generally added in amounts less than or equal to 30% of the mineral weight and preferably between 5% and 20%;

3. Placing the conditioned pulp in a flotation device, then water is added to obtain a pulp with a range of 20% to 50% solid weight, preferably between 30% and 40%;

4. Stirring to keep the material in suspension, preferably at a speed in a range of 40 to 500 rpm, ideally from 70 to 90 rpm, airing then with a stream of 5 to 200 cubic meters per minute for a period of 2 to 20 minutes, concentrating the valued metal in the foam and comprising a flotation tail.

5. Collecting such foam rich in metal as a concentrate of the metal.

In addition, the froth flotation process for the recovery of commercially valued metals according to the present invention consists of the additional steps:

6. Transferring such flotation tail to a second flotation equipment to collect a second commercially valued metal;

7. Conditioning the flotation tail using:

a. liquid extract from the multifunctional flotation agent (foaming and collector agent). Generally, a foaming and collector agent amount less than or equal to 45% of the mineral weight are added, more preferably between 2% and 30%;

b. PH modifiers such as lime, strong bases such as KOH, NaOH, etc.;

8. Subjecting the conditioned tail to a second froth flotation while stirring to keep the material in suspension, at a speed range of 70 to 90 rpm and aeration at 15 - 200 cubic meters per minute for a period of 2 to 20 minutes, concentrating the second metal as a foam and depressing the gangue;

9. Collecting the foam rich in the second metal.

10. Clearing the tail (tailings) for final destination. The tailings are discarded in tailings deposits built specifically for this purpose, following the procedures and methods used for each plant tailings.

The froth flotation process, according to the present invention, is suitable to benefit sulfide minerals (copper, zinc, lead, iron, molybdenum, etc.) or non-sulfide ones (gold, etc.), and also commercially valuable metals present in tails of the first processing phase, out of two, of flotation froth. For example, copper can be benefited from minerals such as chalcopyrite ($CuFeS_2$) and mixtures of minerals (chalcocite, Cu_2S, covellite, CuS, bornite, Cu_5FeS_4, etc.). Normally, copper sulfide ores contain pyrite (FeS_2) and other metal sulfides that are also benefited.

From this point forward, the description will be applied to benefit and recover copper from sulfide ores, as an example. To not limit the invention, however, this description also applies to other sulfide and non- sulfide ores of commercially valuable metals, such as galena (PbS) and spheralite (ZnS), among others. The process of the present invention has proven to be suited to benefit copper sulfide ores, minerals such as copper sulfide type associated with pyrite, like the typical association $CuFeS_2$/ FeS_2.

In step 2 and optionally in step 6, the multifunctional flotation agent is added. It has collector and foaming functions, and the amount will depend on various factors such as the physical and chemical properties, speciation, particle size distribution, mineral grade and release rate, among others.

In a first stage of froth flotation, most commercially valuable iron content can be recovered in the foam as iron concentrate and commercially valued copper minerals can be depressed (e.g. chalcopyrite) as well as other commercially valuable metal sulfides in the pulp (molybdenum, silver, etc..).

In the first stage of flotation, between 5% and 25% of the mineral weight collector and foaming agent is added. The pulp is agitated and aerated for a period of time that maximizes the recovery of iron. The specific period of time will depend on the physical, chemical speciation, particle size distribution, rate of liberation and grade properties among others; the time needed to float a certain mineral can be estimated according to the efficiency and production plans of the concentrator plant. Typically, the flotation is conducted for a period between 2 and 20 minutes and more preferably for a period between 5 and 15 minutes.

Once the first phase of flotation is over, the iron concentrate is collected and the tail is subjected to the second phase of froth flotation. The tail then undergoes a second phase of froth flotation to recover most of the commercially valuable copper content in the foam (copper concentrate) and depress minerals without commercial value and the gangue that remains in the lower phase (tailings).

In the second stage of flotation, between 2% and 30% of the liquid extract mineral weight of the collector and foaming agent is added. The tail is agitated and aerated for a period of time that maximizes the recovery of copper. The specific period of time depends on the physical, chemical speciation, particle size distribution, rate release and grade properties, among others; the time needed to float a certain mineral can be estimated according to the production goals and efficiency of the concentrator. Typically, the flotation is conducted for a period between 2 and 20 minutes, and preferably, for a period between 5 and 15 minutes.

Once the second flotation stage for the desired time period has been completed, the copper concentrate is collected and the tailing or new tail is removed and discarded. The tailings are discarded in tailings deposits built for this purpose, according to the procedures established in each tailings plant. A fraction of organic waste used as foaming and collector agents in the froth flotation process of this invention is retained in the generated tailings, leaving them in a better condition for subsequent environmental remediation processes.

Both the first and second flotation stages (stages I and II), the multifunctional flotation agent (foaming and collector agent) of the present invention can be supplemented with one or more of the traditionally used frothers and/or collectors in a specific operation of froth flotation of sulfide or non-sulfide minerals; the amount of frother and/or collector added will depend on the desired characteristics and the critical variables of the process, which are determined by the specificities and peculiarities of each mineral concentration process.

The use of such auxiliary and traditional collector and/or foaming agents in combination with the multifunctional flotation agent (foaming and collector agent) of this invention often results in higher recoveries and consequently a better efficiency in the stage of mineral iron and/or copper concentration. In the case of collectors, any of the market collectors, such as compounds containing anionic and cationic polar groups (e.g. fatty acids, xanthates, xanthate esters, dithiocarbamates, mercaptans, thioureas and tionocarbamatos), can be used with new collectors shown in phases I and II of this invention (Figure 1). Also, a wide variety of foaming agents have been successfully used in the flotation of minerals from sulfide ores, such as alcohols dihydrocarbonated of low molecular weight (for example methyl isobutyl carbinol, MIBC, polyglycol, pine oils, polyglycol monoesters and alcohol ethoxylates, etc.). Any of them can be used in a complementary and synergistic way in the process of this invention.

While this invention may use a single flotation equipment, both in froth flotation Phase I and Phase II (Figure 1), it is preferred to use a multiple system of flotation devices in both phases, as this allows a better recovery of commercially valuable metals due to higher-contacting time of the flotation reagents with minerals and the possibility of adding additional amounts of collectors or auxiliary chemicals when they are required.

The froth flotation process of the present invention provides a better quality copper concentrate due to the lowest content of iron minerals, increasing its commercial value for sale in either the domestic or international market. However, the copper concentrate obtained by the present invention maintains an adequate iron content to the requirements of the smelting stage, in the case of those processes using Teniente converter furnaces.

APPLICATION EXAMPLE

These application examples used a multifunctional flotation agent, with collector and foaming functions based on sanitary sludge (biosolids) and a foaming and collector agent based on humic substances whose characteristics are given in the following Tables:

Table 2: General physical and chemical characteristics of biosolids

Parameters	Value

Total Solids (%)	76.9
Organic matter (%)*	55.0
pH in water	7.5
Electrical conductivity (mS cm^{-1})	7.80
Density (g mL^{-1})	0.71
Total Ca (mg kg^{-1})*	20,313
Total Cu (mg kg^{-1})*	407
Total Zn (mg kg^{-1})*	1,222
Total Fe (mg kg^{-1})*	17,382
Total N (g kg^{-1})*	41.3
Total P (mg kg^{-1})*	21,210
Total SO_4^{-2} (mg kg^{-1})*	1,000
Total C (%)	31.7
Total N (%)	4.4
Fulvic Acids (%)	3.0
Humic Acids (%)	7.8

* Dry basis

Table 3: General chemical characteristics of Humic Substances

Parameter	Value
C (%)	44.67
H (%)	5.87
N (%)	4.88

O (%)	43.9
S (%)	ND
P (%)	ND
Total Acidity (mol/Kg)	12.3
COOH (mol/Kg)	4.1
Phenolic OH (mol/Kg)	8.2
Ash (%)	0.58

ND: Not determined

Unless otherwise indicated, all parts and percentages are based on dry weight. The copper ore used in this example consists primarily of chalcopyrite-pyrite, with an average content of 0.74% copper and 4.50% iron and a particle size less than or equal to 400 microns.

Example 1: Foaming power: Measurement of surface tension

The surface tension measurements were performed on a Krüss K8 tensiometer using the Du Nouy method at a room temperature of 18 ° C. Solutions of biosolids (BS), humic substances (HS) and methyl isobutyl carbinol (MIBC) were prepared with deionized ultrafiltered water, with a resistivity of 18 MΩ-cm (equivalent to 5.55×10^{-2} μS cm^{-1} electrical conductivity), and a surface tension of 72.1 mN m^{-1}. The concentrations tested for BS were 0, 1, 10, 25, 50 and 100 g L^{-1}; for HS, 0, 0.1, 1, 5, 10 and 25 g L^{-1} and for MIBC, 0, 0.1; 0.5, 1, 2.5, 5 and 7.5 g L^{-1}. The tested concentrations expressed in grams per liter of humic substances are equivalent to BS and HS. A pH adjustment for each BS, HS and MIBC solution, at pH 7 and 10 was subsequently carried out, adding small aliquots of NaOH and 0.1 M HCl solution. The samples were measured at least four times for the various concentrations tested. The results obtained are shown in Figure 2.

Results showed that HS, BS and MIBC have a surfactant activity in the whole concentration range measured. The surface tension of the HS is pH dependent; showing that at pH 10 is more surfactant than at pH 7. A similar behavior showed BS and MIBC. Figure 2A shows that BS and MIBC are able to change the surface tension, determining that a concentration of 100 g L^{-1} of BS, the surface tension is 40 mN m^{-1}, while MIBC obtains a similar surface tension with a concentration of 7.5 g L^{-1}.

Figure 2B shows that when correcting HS and BS concentrations for the sedimented fraction of these substances, biosolids have a behavior similar to MIBC. BS dosages lower than 4 g L^{-1} are shown to be more surfactant at both pH tested, compared to MIBC, and therefore, they have better foaming properties.

Example 2: Foamability Measurement and foam stability.

Foaming tests were performed using the Bikerman method. This method determines the dynamic generation of foam, ε and the static stability, τ. In each trial, 20 mL of solution according to the following foaming concentrations of methyl isobutyl carbinol (MIBC), humic substances (HS) and biosolids (BS): 0.1, 1, 5 and 10 g L^{-1} were used. The samples were prepared with double distilled water, adjusting the initial pH of the solutions with small solution aliquots of NaOH and 0.1 M HCl to reach pH 7 and 10, agitating and homogenizing the samples for 10 minutes at 200 rpm. All trials were performed in duplicate and at room temperature.

The dynamic foam generation is produced continuously by injection of atmospheric air. To do so, a dry air compressor was used with four air flows 1, 2, 3 and 4 L min^{-1}. The injected air passed through an air flow meter (Gilmont Instruments, Inc., USA) and then through Pyrex glass filter of porosity grade 2, with an average diameter between 40 and 100 μm. The test sample (20 mL of solution) was inside the filter. The air passed through the liquid in a column, and for each flow of air injected, the height of the foam at steady state was determined. The inaccuracy in measuring the foam height at steady state was ± 1 cm, depending on the type and concentration of foaming and air flow used. Also, the static stability of the foam was quantified τ, which corresponds to the total time until total decrease of the foam produced, once the gas flow is turned off. The results are shown in Table 4.

Tabla 4: Bikerman parameters for Humic Substances (SH), Biosolids (BS) and Metil-Isobutil-Carbinol (MIBC).

		ε (s)		τ_1 (s) ± DS		τ_2 (s) ± DS		τ_3 (s) ± DS		τ_4 (s) ± DS	
		pH		pH		pH		pH		pH	
Conc. (g/L)*	Reagent	7	10	7	10	7	10	7	10	7	10
0.1	HS	0.9	0.8	0.4 ± 0.1	0.4 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.1	0.6 ± 0.1	0.8 ± 0.1	0.8 ± 0.1
	MIBC	2.1	1.7	4.4 ± 0.1	3.6 ± 0.1	4.1 ± 0.2	4.3 ± 0,2	5.1 ± 0,2	4.7 ± 0.1	4.6 ± 0,2	6.9 ± 0.7
	BS	0.5	0.9	4.8 ± 0.3	2.0 ± 0.3	7.8 ± 0.3	1.8 ± 0.3	13.5 ± 0.8	2.7 ± 0.5	15.4 ± 0.9	2.1 ± 0.1
1.0	HS	1	1.2	11.6 ± 0.9	4.1 ± 0.6	7.9 ± 1.0	2.1 ± 0.3	10.7 ± 0.8	2.1 ± 0.2	16.2 ± 2.1	1.9 ± 0.8
	MIBC	2.1	1.6	5.6 ± 0.4	8.2 ± 0.2	7.2 ± 0.2	9.6 ± 0.3	6.1 ± 0.1	8.1 ± 0.3	4.8 ± 0.1	5.6 ± 0.3
	BS	2.2	1.5	5.6 ± 0.6	3.2 ± 0.2	6.9 ± 0.6	3.5 ± 0.5	12.0 ± 1.3	3.9 ± 0.5	18.3 ± 1.9	3.3 ± 0.4

5.0	HS	2.1	2.3	16.9 ± 1.3	37.9 ± 3.8	7.2 ± 0.3	27.2 ± 1.4	7.3 ± 1.0	24.1 ± 1.3	5.5 ± 0.6	17.7 ± 1.0
	MIBC	1.9	3.1	9.9 ± 0.4	9.7 ± 0.3	6.6 ± 0.1	9.1 ± 0.3	5.9 ± 0.1	7.4 ± 0.2	6.3 ± 0.3	9.2 ± 0.1
	BS	2.3	1.3	13.4 ± 0.5	24.4 ± 4.1	18.6 ± 1.8	10.3 ± 2.3	19.9 ± 2.1	11.1 ± 2.1	31.7 ± 3.4	12.6 ± 3.6
10.0	SH	1.1	1.8	99.9 ± 5.4	120.0 ± 4.0	81.8 ± 8.5	80.0 ± 2.0	65.4 ± 3.1	40.3 ± 5.0	32.0 ± 1.6	20.5 ± 2.7
	MIBC	4.2	3.9	7.5 ± 0.2	6.4 ± 0.1	8.3 ± 0.2	7.7 ± 0.2	9.4 ± 0.1	8.9 ± 0.2	11.4 ± 0.5	9.3 ± 0.2
	BS	3.8	3.2	44.4 ± 3.1	24.2 ± 1.2	53.0 ± 3.6	10.1 ± 0.3	49.7 ± 2.9	11.3 ± 0.3	54.4 ± 3.7	18.6 ± 1.1

* The Humic substance (HS) and Biosolids (BS) concentration are expressed in HS grams per liter of solution.

Table 4 above shows that for all concentrations and pH tested, HS, MIBC and BS can generate foam. For HS and BS, the pH has an effect on the volume of foam generated. In all cases, the foam volume presents a linear dependence on the gas flow.

HS, BS and MIBC show a positive relationship between concentration and the generation and static stability of the foam. Concentrations of 0.1 and 1 g L^{-1} of HS, BS and MIBK have τ values that increase depending on the air flow, but at concentrations of 5 and 10 g L^{-1} of HS and BS, the relationship is opposite, showing that for a specific concentration, when increasing the air flow, τ decreases drastically. By increasing the air flow, the foam is more unstable, promoting coalescence of the bubbles produced. Also, BS show Bikerman parameters (ε and τ) of similar magnitude to those obtained for MIBC, for both, the concentrations and airflows tested.

Example 3: Collector Power: Film flotation Tests

The "film flotation" technique determines the hydrophilic and hydrophobic fractions of a mineral and/or mineral species exposed to different mixtures of water: alcohol. Humic substances (HS), biosolids (BS) and goat manure (GM) were added in a dosage of 1.5% of humic substances (w/w, dry basis), while the industrial chemical collector reagents (ICCR) were used in the following dosages: dialkyl dithiophosphate potassium (Lib-K), 16 g ton^{-1}; isobutyl xanthate, sodium 5 g ton^{-1}; mercaptan (P-3), 11 g ton^{-1}. Mineral samples (copper sulfide mineral, chalcopyrite, and pyrite) were conditioned by the addition of collector reagents (SH, BS, GM and ICCR) for a period between 10 and 20 minutes. Afterwards, the pH was adjusted with HCl and/or NaOH, and each experimental condition was agitated on a shaker for 3 hours at 25 ° C. In each trial, a particle size between 75 and 106 microns was

used. Depending on the wettability characteristics of the solid in each sample and at a given surface tension of the mixture water:alcohol, the hydrophilic fraction was recovered, dried and weighed, and using mass difference, the hydrophobic fraction was quantified. The results for the experimental condition of 100% water are seen in Figure 3.

Figure 3 shows that the natural buoyancy, without addition of reagents, of the copper sulfide mineral and mineralogical species, such as chalcopyrite and pyrite, is low (around 10%). The use of ICCR changes the natural buoyancy of the copper sulfide mineral and mineralogical species, making chalcopyrite and pyrite float 40%. ICCR make such mineralogical species to float in a non-selectively way, increasing the natural hydrophobicity of both mineralogical species. The HS increased the natural buoyancy of copper sulfide ore and/or mineralogical species in 15%. BS and GM show a better affinity with pyrite compared to chalcopyrite. BS makes pyrite to float in a 42%, while GM results in 37.5% of this mineral species to float. Now regarding chalcopyrite, BS reaches 21% and GM 25%. Therefore, BS and GM behaved similarly regarding the sulfide mineral, chalcopyrite and pyrite tested, showing more selectiveness for pyrite. At the same time, BS and GM change the natural buoyancy of copper sulfide mineral, making it possible to float 36% and 26% of the mineral, respectively.

Example 4: Denver Cell Froth Flotation Test

In the Denver cell tests, a copper sulfide mineral with a particle size between 30 and 300 microns (greater at 400 mesh and lower at 50 mesh) was used. A solid concentration of 30% was used; the pulp was stirred at 1100 rpm while maintaining a pH between 10 and 11, at room temperature. PH adjustment was made with lime and/or NaOH. Tests with industrial chemical reagents were used in the following dosage: 300 g ton^{-1} lime; 250 2.5 g ton^{-1} DowFroth; 25 g ton^{-1} methyl isobutyl carbinol; 16 g ton-1 dialkyl dithiophosphate potassium (Lib-K); 5 g ton^{-1} isobutyl xanthate, sodium; 11 g ton^{-1} mercaptan (P-3). Biosolids (BS) and humic substances (HS) were used as frothing and collector agents in a dosage of 1.5% of humic substances (w/w dry basis). For all experimental conditions tested a conditioning time of 10 minutes was used. The experimental procedure considers the opening of the air injection valve of the cell to form a froth phase in the pulp, which is extracted from the surface of the froth using the rotating paddle and the following times: 1 -3 minutes, 3-6 minutes 6-10 minutes 10-14 minutes 14-18 minutes. At such times, concentrate samples are collected, filtered, dried and chemically analyzed via atomic absorption method.

The experimental conditions tested in Denver cell are described in the following table:

Nº	**Experimental Condition**		
	Mineral	**Collector and Frothing Agents**	**pH Adjustment**
1	Copper Sulfide Mineral	ICCR + ICFR	Cal
2	Copper Sulfide Mineral	ICCR+ ICFR	NaOH
3	Copper Sulfide Mineral	Biosolids (BS 1, type1)	NaOH
4	Copper Sulfide Mineral	Biosolids (BS 2, type 2)	NaOH
5	Copper sulfide Mineral	Humic Substances (HS 1, type 1)	NaOH
6	Copper Sulfide Mineral	Humic Substances (HS 2, type 2)	NaOH

Type 1 and type 2 biosolids (BS 1 and BS 2) refer to biosolids samples from the same household wastewater treatment plant; BS 1 was generated at least 2 years before BS 2.

Type 1 and type 2 Humic substances (HS 1 and HS 2) refer to the same material tested in two different runs (repetitions).

ICCR= Industrial chemical collector reagent (dialkyl dithiophosphate potassium, sodium isobutyl xanthate, mercaptan)

ICFR = Industrial chemical froth reagent (DowFroth, methyl isobutyl carbinol)

Concentrated copper and iron grade results are shown in Figure 4. The results prove that BS can recover a concentrate with a copper grade lower than that obtained with HS and ICCR + ICFR. However, BS produces a concentrate with an iron grade similar to that obtained with HS and ICCR + ICFR. Figure 4B shows that BS can recover a concentrate with a high iron grade. Also, the extract of the collector and foaming reagent, i.e., humic substances shows in Figure 4A that such reagent recovers a copper concentrate with a higher grade during the first 10 minutes of flotation, compared to the copper concentrate grade copper using ICCR + ICFR. As it seems evident from the examples, biosolids are effective frothers and collectors of iron in froth flotation systems, while humic substances are effective copper collectors in the froth flotation systems at levels comparable with standard flotation reagents used.

The present invention has been explained (pictured) in relation to some of its possibilities, but it must be understood that these examples and specific information given are not intended to limit the spirit or field of the claimed invention.

What is claimed is:

1. A collector and foaming agent for froth flotation processes in the recovery of commercially valuable metals from sulfide minerals or non-sulfide ores, the collector and foaming agent comprising organic waste derived from treatment processes, aerobic decomposition, anaerobic decomposition, or a fraction thereof, wherein the organic waste is derived from treatment processes or selected aerobic or anaerobic decomposition of biosolids and/or manure and/or humic substances and wherein the biosolids comprise between 35% and 98% organic matter on a dry basis.

2. The collector and foaming agent of claim 1, wherein the fraction is an extract.

3. The collector and foaming agent of claim 1 or 2, wherein the sulfide minerals are selected from the group consisting of copper, zinc, lead, iron and molybdenum and the non-sulfide ores are gold.

4. The collector and foaming agent of claim 1, wherein the biosolids comprise between 40% and 60% organic matter on a dry basis.

5. The collector and foaming agent of claim 1, wherein the biosolids comprise between 1 and 25% humic substances.

6. The collector and foaming agent of claim 5, wherein the humic substances comprise between 1% and 25% fulvic acids.

7. The collector and foaming agent of claim 6, wherein the humic substances comprise between 5% and 15% humic acids.

8. The collector and foaming agent of claim 1, wherein the humic substances comprise between 20% and 70% carbon.

9. The collector and foaming agent of claim 6 or 7, wherein the humic substances comprise between 40% and 60% carbon.

10. A production process for the collector and foaming agent of claim 1, the process comprising:

(a) collecting organic waste from generating sources of organic matter from treatment processes, aerobic decomposition, anaerobic decomposition, or a fraction thereof and determining properties selected from the group consisting of organic matter content and humic substances content;

(b) conditioning of the collected material from (a) by the following steps:

(i) dehydrating the collected material to a moisture content less than or equal to 75%; and

(ii) reduction of size and separation of the dried material by milling and sieving to obtain material with a size less than or equal to 10 millimeters; and

(c) compacting the obtained material from (ii) to form pellets or briquettes.

11. The process of claim 10, wherein the collected material is dehydrated to a moisture content less than or equal to 20%.

12. The process of claim 10, further comprising the additional step of packaging the compacted material.

13. The process of claim 10, wherein the conditioning step comprises subjecting the collected material to liquid extraction.

14. The process of claim 13, wherein the liquid extraction is carried out using acid-base extraction, which performs a pH reduction between 1 and 2 with a strong acid at room temperature and comprises:

(A) adjusting the solution volume with acid until obtaining a ratio between 1:5 and 1:10 organic residue:acid solution (weight:volume) on a dry basis;

(B) stirring the suspension for a period of time less than or equal to 10 hours, and separating and reserving the supernatant fraction solid for a subsequent pH adjustment of the solid fraction to neutrality with a strong base at room temperature;

(C) adjusting the volume of the solution with a base to obtain a ratio between 1:5 and 1:10 solid fraction:basic solution (mass:volume);

(D) stirring the suspension for a period of time less than or equal to 10 hours, separating and reserving the second supernatant from the second solid fraction;

(E) mixing the supernatant of the first and second stages to obtain the extract by extracting with water as aqueous extractant, adjusting the volume of the solution with water in a range between 1:5 and 1:10 organic residue:water (volume:volume) on a dry basis, at room conditions; and

(F) stirring the suspension for a period of time less than or equal to 10 hours, and removing and reserving the supernatant or extract of the solid fraction.

15. The process of claim 14, further comprising packaging the extract obtained.

16. The process of claim 14, wherein the strong acid is selected from the group consisting of HCl, H_2SO_4 and H_3PO_4.

17. The process of claim 14, wherein the strong base is selected from the group consisting of KOH and NaOH.

18. A froth flotation process for the recovery of commercially valuable metals from sulfide minerals or non-sulfide ores, the process comprising the steps of:

- reducing the size of sulfide minerals or non-sulfide ores to a particle size below 400 microns by first, second and third crushing, and afterwards, semi-autogenous or conventional grinding;

- conditioning of the mineral ground into a pulp by mixing the ground mineral, water to obtain a mineral pulp with a range from 5% to 20% of solids weight, pH modifiers, strong bases, and the collector and foaming agent according to any one of the claims 1 to 11;

- receiving the conditioned pulp in a flotation device and adding water to obtain a pulp with a range of 20% to 50% of solids weight;

- stirring to keep the material in suspension, aerating such pulp with a stream between 5 and 200 cubic meters per minute for a period of time 2 to 20 minutes, and concentrating the commercially valued metal in a foam and depressing a flotation tail; and

- collecting the foam rich in the valued metal commercially as a metal concentrate.

19. The process of claim 18, wherein the pH modifiers are lime and the strong bases are selected form the group consisting of KOH and NaoH.

20. The process of claim 18 or 19, wherein the stirring is at a speed in a range selected from the group consisting between 40 rpm and 500 rpm and between 70 rpm and 90 rpm.

21. The process of any one of claims 18 to 20, wherein the collector and foaming agent is added in amounts smaller than or equal to 30% of the mineral weight.

22. The process of claim 21, wherein the collector and foaming agent is added in amounts between 5% and 20% of the mineral weight.

23. The process of any one of claims 18 to 22, wherein water is added in an amount between 30% and 40%.

24. The process of any one of claims 18 to 23, comprising the following:

- placing the tail in a second flotation equipment to collect a second metal of commercial value;

- conditioning the tail using collector and foaming agent liquid extract of any one of claims 1 to 11, pH modifiers and strong bases; and

- subjecting the conditioned tail to a second froth flotation, stirring to keep the material in suspension, aerating with a stream of 5 to 200 cubic meters per minute for a period of time of 2 to 20 minutes, concentrating the second metal in a foam and depressing the gangue;

- collecting the foam rich in the second metal of commercial value as metal concentrate of commercial value; and

- leaving the tail for final destination.

25. The process of claim 24, wherein the collector and foaming agent is added in amounts smaller than or equal to 30% of the mineral weight.

26. The process of claim 25, wherein the collector and foaming agent is added in amounts between 5% and 20% of the mineral weight.

27. Use of the collector and foaming agent of any one of claims 1 to 9, in froth flotation of sulfide minerals or non-sulfide ores.

28. The use of claim 27, wherein the sulfide minerals are selected from the group consisting of copper, zinc, lead, iron and molybdenum and the non-sulfide ores are gold.

29. The use of claim 27 or 28, in froth flotation of chalcopyrite ($CuFeS_2$) and mixtures of minerals.

30. The use of claim 29, wherein the minerals are selected from chalcocite, Cu_2S, covellite, CuS, bornite and Cu_5FeS_4.

31. The use of claim 27 or 28, in froth flotation of copper sulfide minerals that contain pyrite (FeS_2).

32. The use of claim 27 or 28, in the flotation of the minerals $CuFeS_2/FeS_2$.

33. The process of claim 24, wherein traditional auxiliary collectors and/or foaming agents are added in combination with the collector and foaming agent of any one of claims 1 to 11.

34. The process of claim 33, wherein the traditional auxiliary collector is hydrocarbon compounds containing anionic and cationic polar groups.

35. The process of claim 33, wherein the traditional auxiliary foaming agent is dihydrocarbonated alcohols of low molecular weight.

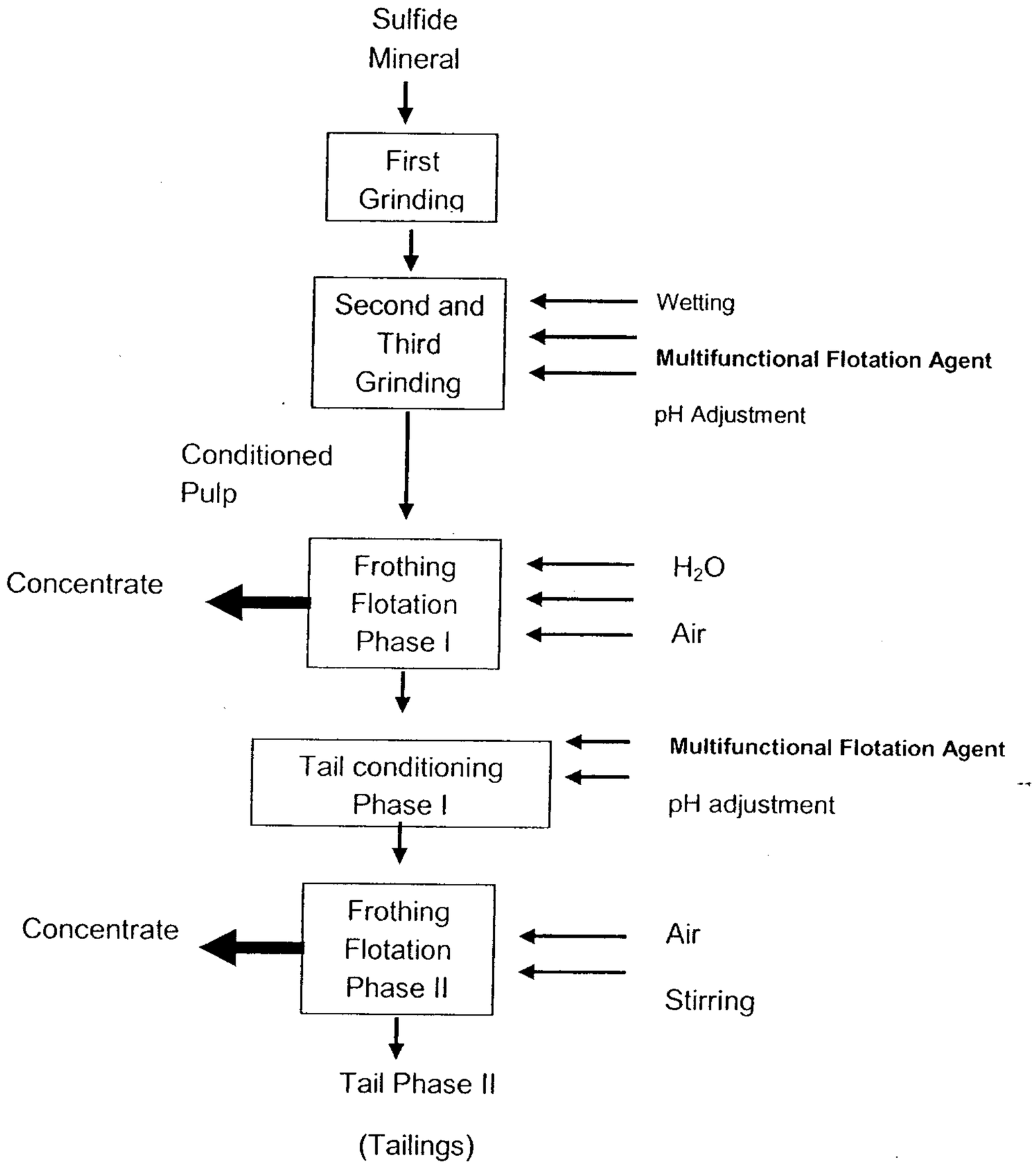
36. The process of claim 34, wherein the hydrocarbonate compound is selected from the group consisting of fatty acids, xanthates, xanthate esters, dithiocarbamates, mercaptans, tiureas and tionocarbamatos.

37. The process of claim 35, wherein the dihydrocarbonated alcohol is selected from the group consisting of methyl isobutyl carbinol, MIBC, polyglycol pine oils, polyglycol monoesters and alcohol ethoxylates.

38. The process of claim 10, comprising collecting organic waste from treatment or decomposition processes of sanitary sludge or biosolid.

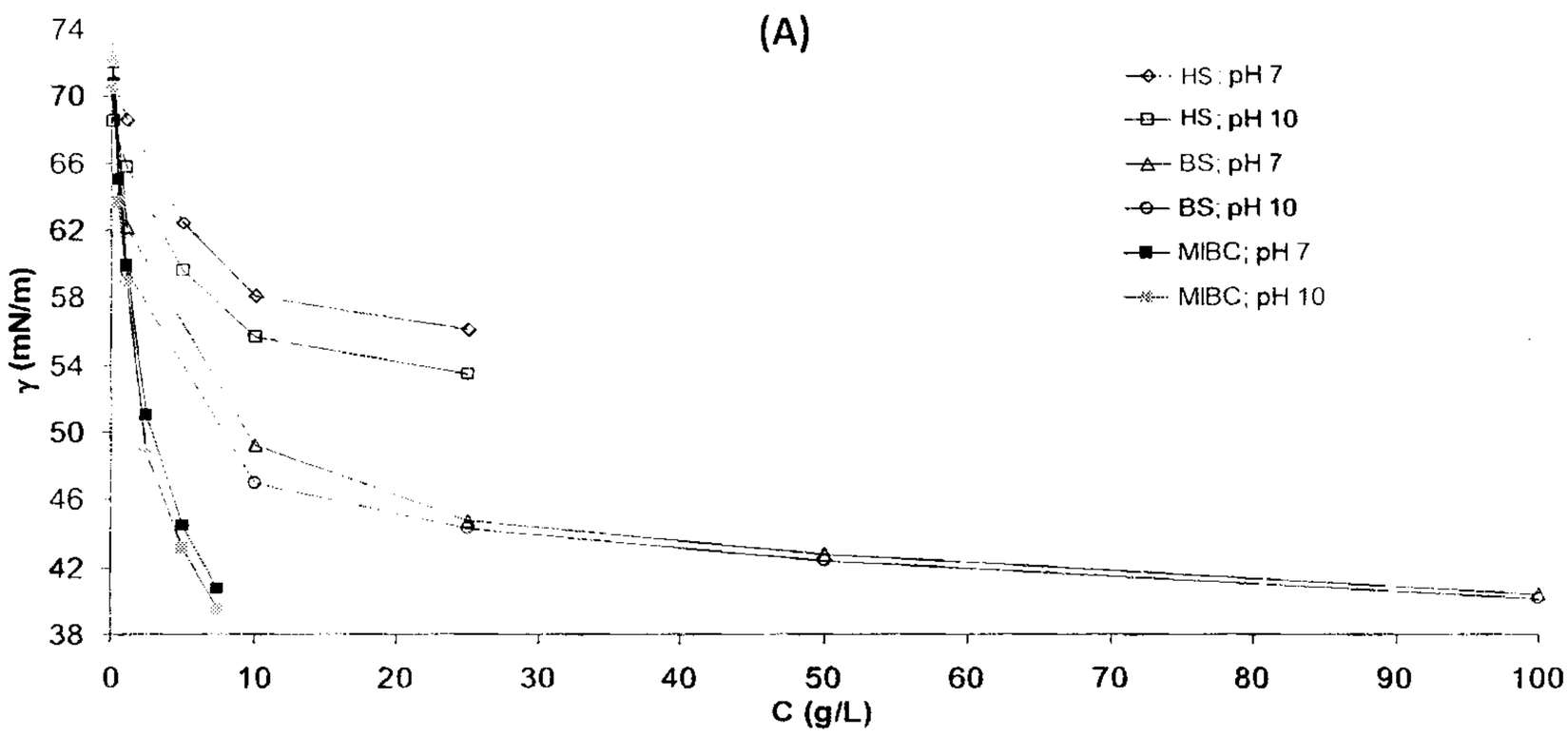
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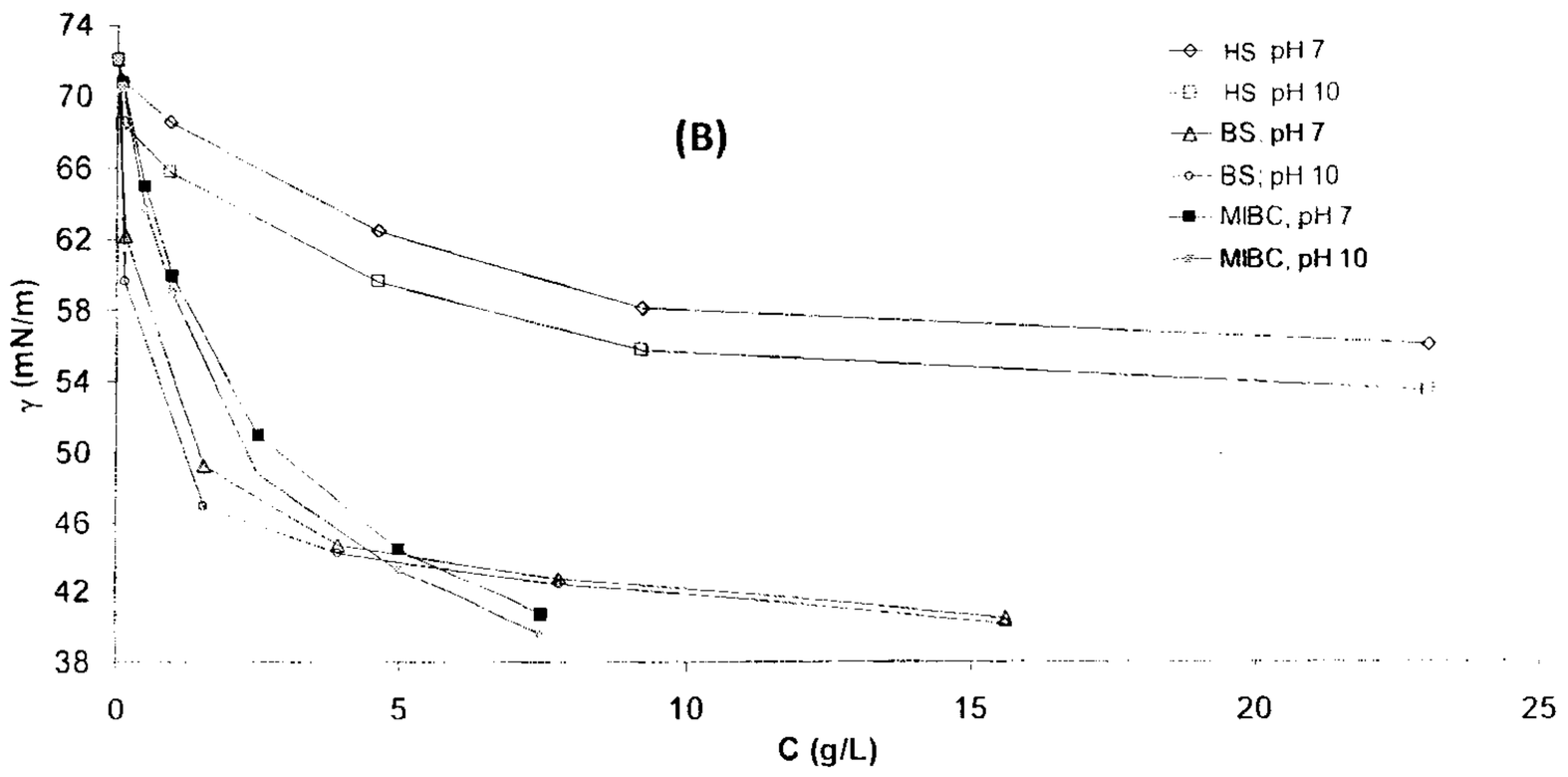
FIGURE 1



DRAWING 2/4

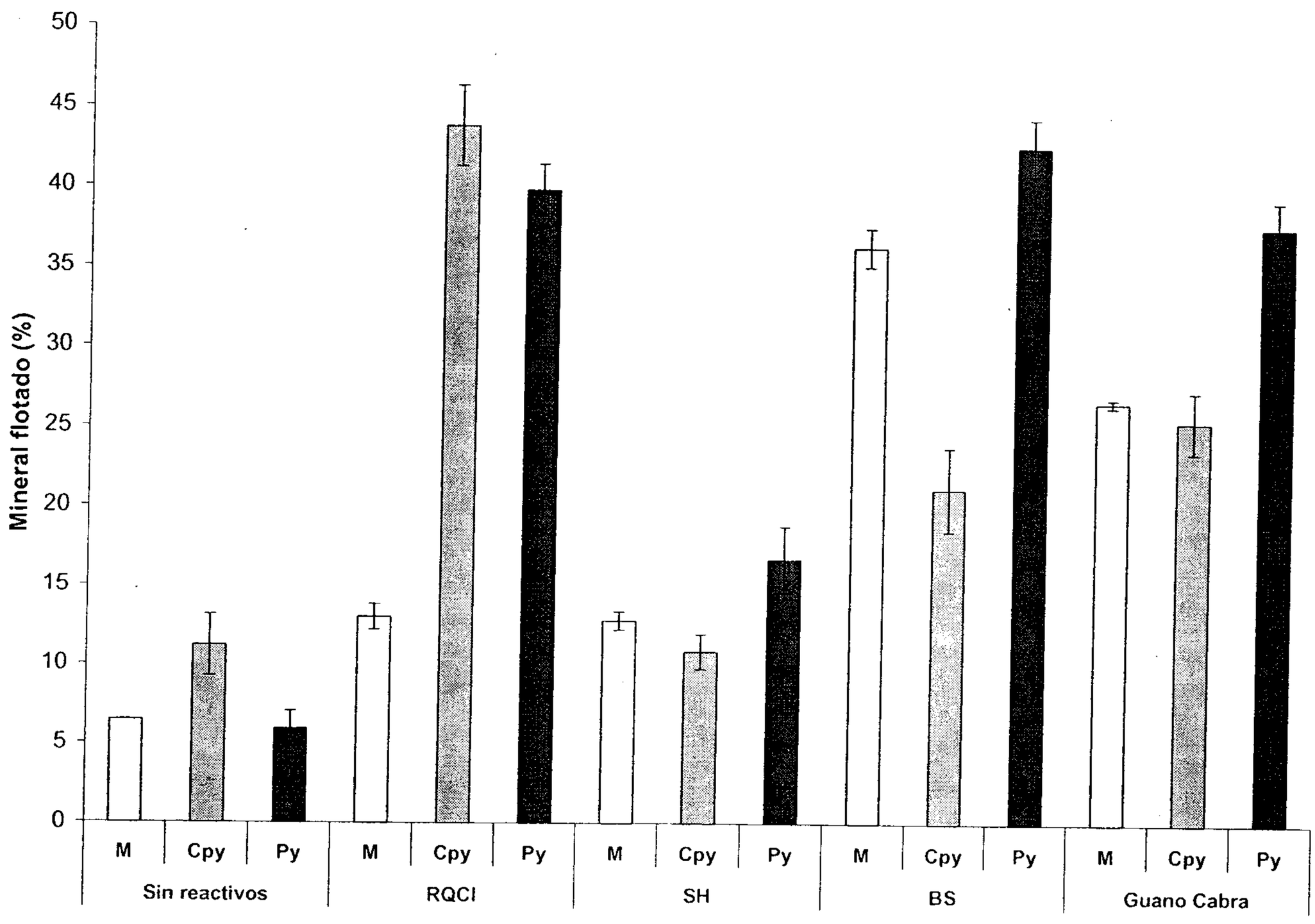
FIGURE 2





DRAWING 3/4

FIGURE 3



Floated Mineral (%)

Without Reagents

ICCR

HS

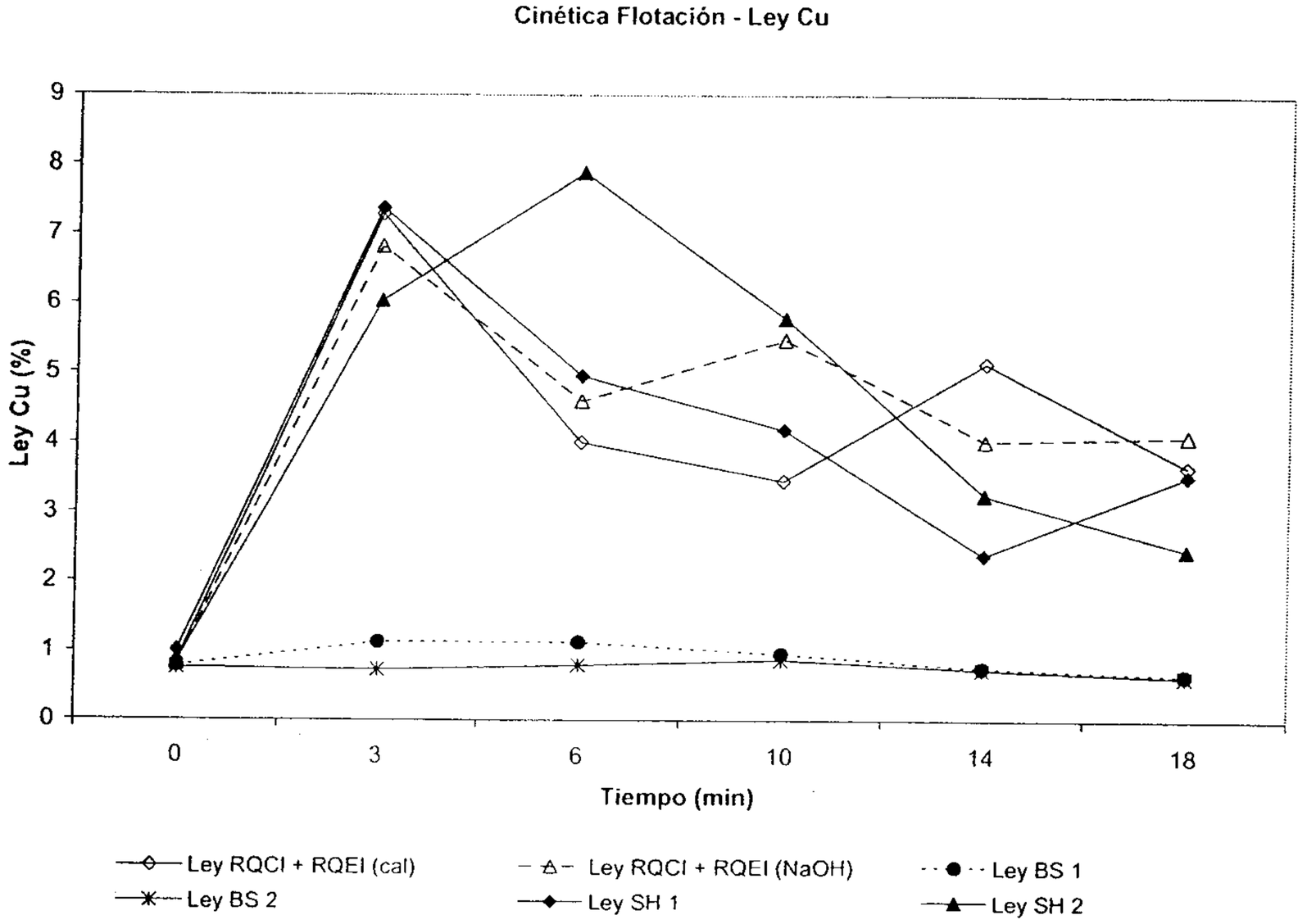
BS

Goat Manure

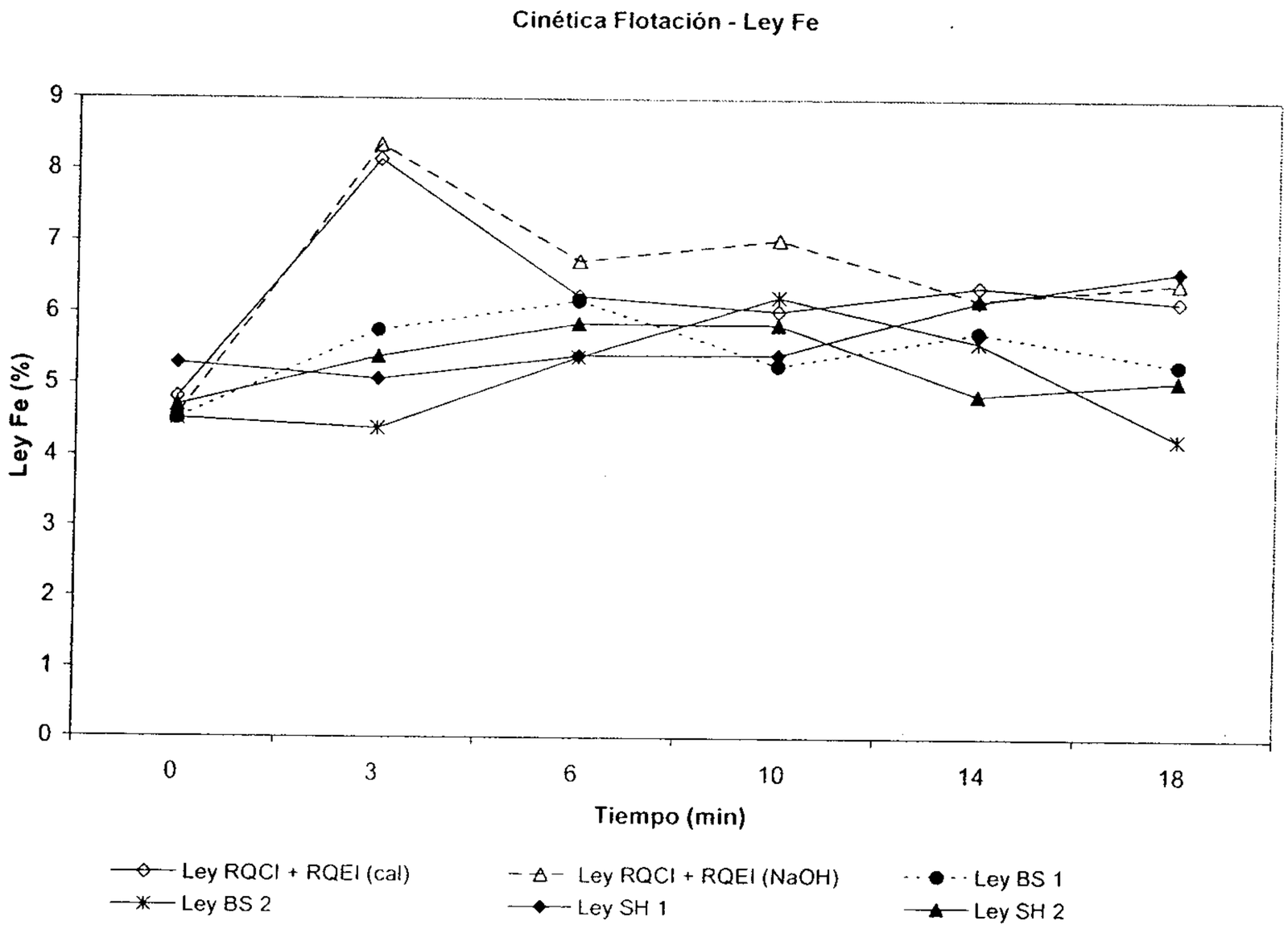
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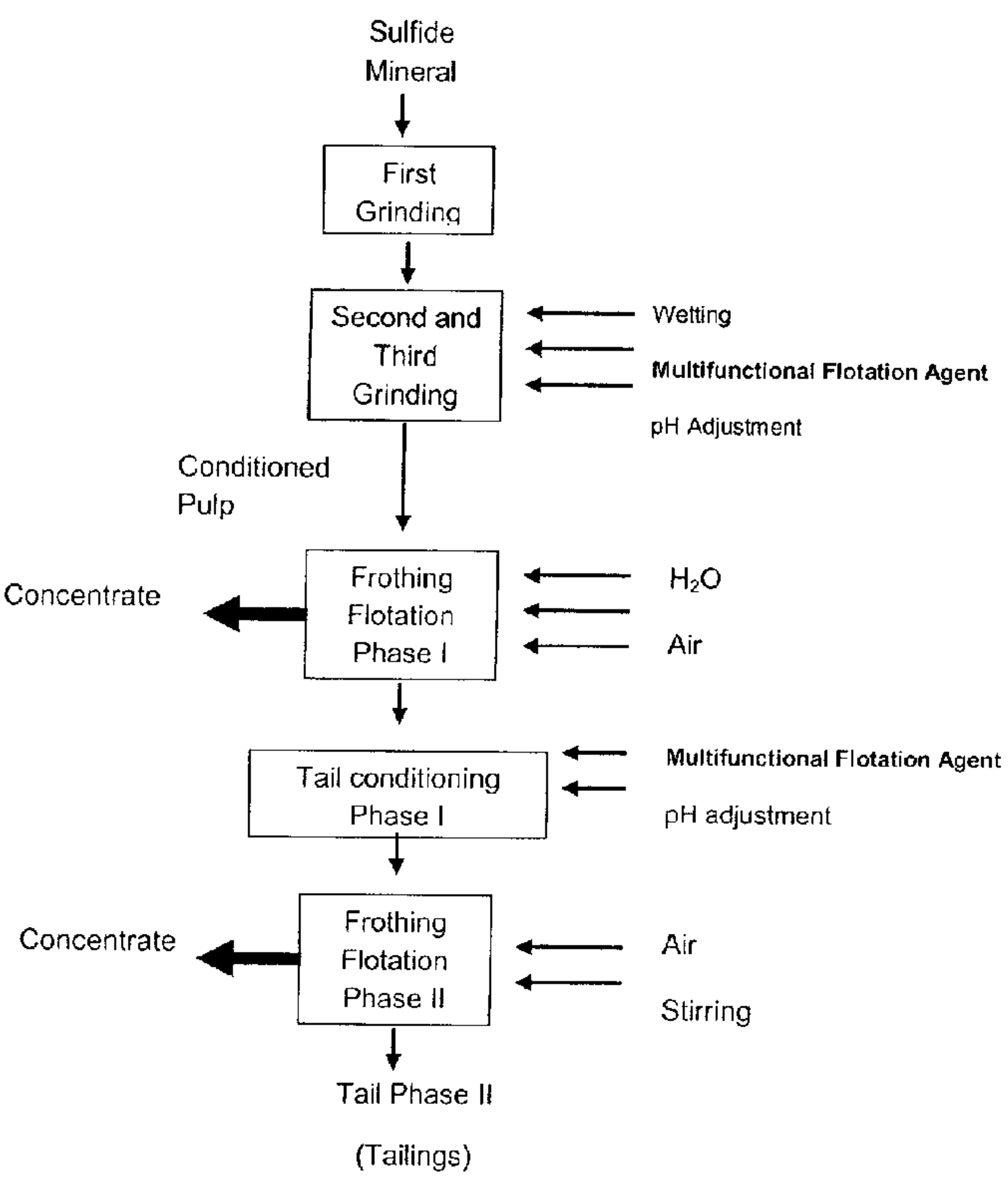
FIGURE 4

(A)



(B)


Cinética Flotación - Ley Fe
Ley Fe (%)
9
8
7
6
5
4
3
2
1
0
0
3
6
10
14
18
Tiempo (min)
Ley RQCI + RQEI (cal)
Ley RQCI + RQEI (NaOH)
Ley BS 1
Ley BS 2
Ley SH 1
Ley SH 2


Sulfide
Mineral
First
Grinding
Second and
Third
Grinding
Wetting
Multifunctional Flotation Agent
pH Adjustment
Conditioned
Pulp
Concentrate
Frothing
Flotation
Phase I
H2O
Air
Tail conditioning
Phase I
Multifunctional Flotation Agent
pH adjustment
Concentrate
Frothing
Flotation
Phase II
Air
Stirring
Tail Phase II
(Tailings)