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Série Tecnologia Mineral

Froth Flotation: relevant facts and the brazilian case

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PRESENTATION

Froth flotation in Brazil started in Boquira, Paraná, applied to lead and zinc. This system was studied further by Paulo Abib Andery, in a memorable Thesis presented to the Faculty of Mining of the Escola Politécnica da Universidade de São Paulo.

Later, Paulo Abib succeeded in putting into operation the first worldwide apatite/calcite flotation plant for phosphate production.

Brazilian developed jlotation processes including the oxidized zinc ores,jluorspar, talc and coal, were part of the research programmes conducted at CETEM facilities, as well as an integral part of the services and projects contracted by the mineral enterprises in Brazil to the several enginnering consulting companies that were active in the sector (PAULO ABIB, NATRON; PROMON, IESA, THEMAG, OUTOKUMPO, ENGEVIX; MONTREAL and others), as well as Universities (USP, UFRJ; UFMG) and R&D institutions (CETEC, CEPED, IPT).

This work of Professors Clark Peres and Correa de Araújo is a mostvaluable one as a guidingpaper injlotation practice in Brazil and should be very much welcomed by the mineral-metallurgical professionals.

Rio de Janeiro, July, 1995.

Roberto C. Villas Bôas
Director

CONTENTS

RESUMO

Este trabalho faz uma revisão da prática de flotação no Brasil, abordando os aspectos históricos e tendências recentes, incluindo a utilização de reagentes e os tipos de células de flotação. As informações mais importantes sobre as usinas de flotação de minerais metálicos e substâncias não metálicas são apresentadas.

Palavras-chave: *flotação, Brasil*

ABSTRACT

This work reviews the froth flotation practice in Brazil. Both the historical aspects and recent tendencies are outlined, including reagent usage and types of cell. The most important informations concerning the flotation plants of metallic minerals and nonmetallic substances are presented.

Key words: *froth flotation, Brazil*

1. INTRODUCTION

Froth flotation was first applied to the concentration of minerals at the beginning of the century in Australia (Broken Hill, lead-zinc sulfides). In the United States of America, 1912 is accepted as the birth date of the technique. In Brazil the method was first utilized in the fifties in the flotation of lead ores, at Panelas, near the Parana-São Paulo border. After the start-up of the Serrana phosphate ore concentration plant employing flotation in mid sixties, the number of plants grew up steadily.

The following types of ores are (or were until a very recent date) processed with the use froth flotation in Brazil: iron, phosphate, niobium, gold, copper, oxidized zinc, lead-zinc, graphite, coal, sylvite, fluorite, magnesite, kyanite, talc, tungsten and a material that is not an ore, a residue from zinc leaching, but also floated to recover mainly silver.

When froth flotation was first applied in Brazil the only kind of machine in use was the so-called mechanical sub-aeration flotation cell. Most of the cells presently installed are Wemco. The utilization of Outokumpu (Finnish made) machines is increasing in terms of mechanical conventional cells. Other cells in use include Denver, Galigher and Minemet. In the eighties, a trend towards the use of column type flotation cells started in Canada and spread throughout the world in a very fast pace. Several Brazilian companies and plants tested or are testing their ores in pilot scale columns. A few of them have already incorporated columns cells in their industrial circuits (SAMARCO, GYRO, GSN and MBR -iron ore, GBMM-niobium, and Arafértil-phosphate). Besides columns, other non-conventional flotation cells in use Brazil include the Serrana pneumatic cell (with an externally mounted air/pulp contact device, similar to the one presently marketed by EKOF, Germany) and the Outokumpu's flash flotation units at RPM (gold).

2. HISTORICAL ASPECTS

Flotation abroad will soon become a centenary technology. The year 2001 will commemorate the 100th anniversary of the introduction of froth flotation in the U.S.A. Before that date, the Mount Isa flotation plant in Australia, treating a zinc-lead ore will reach its 100th anniversary .In relation to the Brazilian situation, scarce information is available in the literature concerning the beginning of the practice of froth flotation in the country . Indications exist tending to establish the first industrial application of flotation in the early fifties, for the treatment of a lead ore in Parana state (see section on lead and zinc ores). Earlier studies involving froth flotation plausible application are described in the literature. For example Araújo (1947) describes bench scale tests performed to concentrate by flotation gold associated with iron ores. Still earlier, studies for the flotation of pyrite (Araújo, 1945) and for the purification of beach sand for the glass industry (Whale, 1945) are described in bulletins of the National Department for Mineral Production (DNPM).

The first large flotation plants only started operation in Brazil in the seventies. These plants included most of the phosphate ore flotation plants and the first iron ore flotation application (SAMARCO, 1977). The Serrana flotation plant was the first to operate with large tonnage. This plant was commissioned in the late sixties, employing an all Brazilian developed technology to treat a low grade carbonatitic phosphate ore with the concomitant partial use the tailings for the production of cement (see more details in the section describing the phosphate applications). Also in the same period the pyrochlore (niobium) flotation plant located in Araxá, Minas Gerais (CBMM) started its operation.

The large copper ore flotation plant of Caraiba (Bahia state) was commissioned in 1980. Later developments in the eighties included the construction and start up of several other flotation plants to treat different types of ores such as oxidized zinc ores,

sulfidic lead and zinc, gold, soluble salt and magnesite, among others. The first operations utilizing non conventional flotation cells, the SERRANA pneumatic flotation cell, flash flotation units and flotation columns, appeared also in the eighties.

3. FLOTATION SYSTEMS

Flotation systems include all three phases of matter: liquid, solid and gas. An ore pulp (which is a mixture of solid particles and water) enters a flotation device where the gaseous phase is added. Flotation technology utilizes the concept of selectively making hydrophobic (water repellent) mineral surfaces (either presenting natural or induced hydrophobicity) to come in contact with gaseous bubbles, thus creating the opportunity to aggregate gas bubbles onto the hydrophobic particles. These bubble-particle aggregates are transfered into a froth phase generally formed on the top of the flotation machines. The froth carrying the selected bubble-particle aggregates is removed constituting one of the products of a given flotation operation, while the particles remaining in the pulp (hydrophilic) are discharged by an appropriate mechanism.

The probability of flotation has been described as the product of three individual probabilities as shown in the following Equation:

$$P=Pa.Pc.(1-Pd)$$

where:

P = probability of flotation,

Pa = probability of adhesion between hydrophobic particles and air bubbles,

Pc= probability of bubble-particle collision,

Pd= probability of bubble-particle detachment.

The probability of adhesion is directly related to the chemical environment prevailing (Pa) in a given flotation system. It is affected by mineralogy, reagents and pulp conditions, being governed dominantly by surface forces. The other two probabilities are related to the hydrodynamics of the flotation systems. The probability of collision (Pc) is especially Influenced by particle size, bubble size and the turbulence of the system.

Flotation reagents are traditionally divided into three broad categories: collectors, frothers and modifiers. A more modern conception would include gases as reagents, especially in the practice of sulfide ore flotation. For the vast majority of plants in operation around the world only air is used to provide the third phase of the flotation systems -the gaseous phase. While for the flotation systems treating oxidized ores the relevance of the pulp oxidation potential (Eh or pE) is minimum (except when the reagents used can be affected by Eh), for the flotation of sulfide minerals (in other words, for the flotation of the vast majority of ores bearing the base metals such as lead, zinc, copper, nickel, etc.) the. understanding of the mechanisms underlying the development of hydrophobicity on the surface of these minerals indicate that by controlling the Eh it is possible to control the hydrophobicity level of such surfaces. In that sense, inert gases such as nitrogen find application in some flotation systems, acting in such a way that by controlling Eh selective development or maintenance of hydrophobicity on certain mineral surfaces is possible.

4. REAGENTS

Collectors are the reagents responsible for making selected mineral surfaces hydrophobic. They adsorb (i.e. concentrate on the surface of the selected particles) onto these surfaces transforming them from hydrophilic to hydrophobic in character. One should recall that the ample majority of minerals is naturally hydrophilic. Exceptions include molybdenite (MoS_2)' talc, graphite and some types of coal. Gold and some sulfide minerals also display a certain level of natural hydrophobicity under particular circumstances. Collectors employed in flotation technology are surfactants, i.e., reagents presenting a dual character: a hydrophobic non polar part (tail) and a polar head and, furthermore, able to concentrate at interfaces (adsorb onto the surface of the selected mineral particles). From the flotation practice point-of-view collectors are divided into classes according to the mineral systems on which they are used. Hence, sulfide mineral flotation generally uses thio-collectors (also known as sulfydrilic collectors). Examples of such collectors include xanthates, dithiophosphates, mercaptobenzo-thiazol, etc. Thio-collectors are chemically characterized by the presence of at least one sulfur atom in their structure that has not been oxidized (i.e. reacted with oxygen).

Flotation of non-sulfide minerals generally utilizes non-thio collectors. The non-sulfide mineral collectors are generally divided into groups according to the nature of the polar head: cationic, anionic and amphoteric. Among the cationic collectors the amines, especially primary amines and primary ether-amines, represent most of the reagents used in this group. Fatty acids and their soaps and derivatives are the most commonly anionic collectors used. Amphoteric collectors (i.e. those presenting polar heads with both cationic and anionic characters) have been introduced in flotation practice in more recent years. The sarcosinates are probably the most common type of reagents that can fit in the amphoteric group of collectors.

Frothers are also surfactants generally of non-ionic nature. They mostly include alcohols, glycols and polymerized glycols (or poly-glycols). Their role in flotation is twofold. Firstly they decrease the surface tension of the liquid surface making possible the formation of a semi-stable froth phase, required to hold and transport the bubble-particle aggregates. Secondly they act as kinetic enhancing agents by accelerating the thinning of the liquid film existing between the bubble and particle surfaces during the collisions occurring in the flotation environment.

Modifiers represent a very broad class of reagents used in flotation in order to alter pulp and mineral surface conditions to enhance the selectivity of the flotation process. They may be divided into groups known as **activators, depressants and regulating agents**. They include chemicals ranging from inorganic salts such as sodium cyanide to organic macromolecules such as starches. The proper selection of modifiers, frothers and collectors account for the success of a given flotation separation. One could say that among the various areas within flotation technology, that of flotation chemistry has been the most vastly explored and researched throughout the various decades since the introduction of froth flotation.

For the major flotation plants presently operated in Brazil, Table 1 shows the main reagents used and their dosages. Although there are some peculiarities concerning the use of cheap by-products or non food quality products, the usage of reagents in the Brazilian plants tends to follow the reagent usage elsewhere in the world. The use rice bran oil, grape oil, corn grits, tapioca starch and other natural products available in Brazil at lower prices than conventionally used reagents reflects the continuous trend of the industry to lower operational costs. Current practice of the Brazilian mineral industry involves constant efforts toward the lowering of reagent consumption and the use of alternate chemicals. It is relatively uncommon to see a given flotation plant operating with exactly the same chemicals used during the commissioning of the plant.

Table 1 -Examples of Reagent Usage in Brazilian Flotation Plants

Mineral Substance (plant/location)	Collectors (g/t)	Frothers (g/t)	Modifiers (g/t)
Iron (SAMARCO//Mariana)	Ethoxylated primary amine (ether-amine) (50-100)	none	Corn Grits, Tapioca and/or Corn Starches (300-600)
Iron (CVRD/Mariana)	as above	none	Corn Starch (250-500)
Iron (SAMITRI/Mariana)	as above	none	Corn Grits (300-600)
Iron (MBR/Pico)	as above	none	Corn starch (600-800)
Iron (CVRD/Itabira)	as above	none	Corn Starch (250-500)
Niobium (CBMM/Araxá)	Primary Fatty C-18-Amine (750)	Polyglycol (n.d.)	Fluorsilicic acid (750) & HCl → pH 3
Gold (RPM/Paracatu)	Amyl xanthate or isobutyl xanthate (5-10)	Polyglycol & MIBC (200)	none
Gold (MMV/Raposos, Queiroz Plant)	Mercaptobenzothiazol (140) & Hostaflot (60) [Dithiophosphate]	Aerofroth 65 (30) & MIBC (50)	Cu sulfate (180)
Phosphate(SERRANA/ Cajati)	Na Sarcosinate (70-80)	none	Corn Starch (600)
Phosphate (FOSFÉRTIL/ Tapira)	Rice bran oil (650)	none	Corn Starch (300)
Copper (CARAÍBA/ Jaguarari)	Dithiophosphate (11)	MIBC (27)	Dextrin (35)

5. OUTLOOK: POTENTIAL AND RECENT APPLICATIONS

Although the arrival of new investments in new mining projects in Brazil is still difficult to perceive due to the difficulties imposed under the 1988 Constitution, some flotation plants should be commissioned during the next 5 years. In many of these cases the plants will be incorporated to existing facilities, mostly responding to production increases.

Companhia Siderurgica Nacional -CSN has already installed at its iron ore mine named Casa de Pedra, located in Congonhas, MG, a new fully-column flotation circuit to process lower grade ores and fines. The plant includes four flotation columns with 10 m in height and 3.67 m in diameter, utilizing CESL (Canada) spargers. This operation is designed to treat 6 million tons annually. Flotation is performed in the conventional cationic reverse flotation configuration. Flotation chemistry to be used by CSN is very much similar to the currently applied by the other iron ore reverse flotation plants already in operation.

A similar development is underway at the Pico Mine (located in Itabirito, MG), operated by Minera96es Brasileiras Reunidas (MBR). This operation will treat initially the fines from a hematitic ore (inter fingered with itabirites) that has to be mined in order to allow the maximum extraction of rich hematitic reserves of that mine, according to the company's expansion plans for this operation. The Pico flotation plant will be the first installation operated by MBR that will involve a more sophisticated processing of iron ores. The circuit will produce approximately 2.3 million tons per year of concentrated pellet feed fines. It employs two 3.67 m in diameter, 14 m in height flotation columns, operated in a rougher-cleaner configuration. Column technology in this case is also supplied by Cominco Engineering Services Ltd. (CESL), Canada. Flotation chemistry is similar to the common practice in other Brazilian iron ore flotation plants.

Also in iron ore flotation, CVRO has included a conventional flotation circuit to its current operation at Conceição in order to allow the production of OR grade pellet feed also from that plant. Also for Conceição, a fully new column flotation circuit is scheduled to be implemented in 1995.

Samitri will also add two columns to its new plant in Alegria Mine. With this expansion almost all major iron ore producers in Brazil will be employing column flotation for the concentration of pellet feed fines. The only exception yet is Ferteco which is presently engaged in flotation pilot scale testing .

As already mentioned, São Bento Mineração will be expanding its flotation plant capacity by installing a single flotation column. This application will represent the first use of flotation columns in sulfide gold ores processing. RPM is also currently running pilot plant scale tests to treat sulfide ore types present in its deposit in Paracatu. However the extraction of such ore types will probably not necessitate expansion in its flotation circuit.

The large Salobo copper deposit, located in the mining district of Carajas (Para state) should become the place for the largest flotation mill in Brazil if the project receives its necessary financing. Presently under a new pilot plant campaign, this project was subjected to an extensive pilot plant testing during the eighties. This previous campaign called for the installation of a large conventional cell flotation circuit to treat the Salobo sulfide copper ore. The proposed flowsheet for treating the Salobo ore encompassed the use of a flash flotation unit in the primary grinding stage and a rougher- cleaner-scavenger mechanical flotation circuit including a regrinding step. This proposed flowsheet contemplated the processing of 26,000 tons of ore per day at an average head grade of 1.11%Cu (chalcocite/covellite and bornite are the major copper sulfide minerals present in Salobo). Recovery was set at 86% for a concentrate assaying 38% Cu. Flotation chemistry utilized amyl xanthate (240g/t) as collector and a polypropylene glycol as frother (30g/t). To produce approximately 230,000 tons of

concentrate per year the circuit incorporated a total of 53 mechanical flotation cells (32 x 84m^3; 18 x 42m^3 and 13 x 8.5m^3 cells).

Other studies presently in development at laboratorial and pilot plant scales include flotation applications to process fluorite, cryolite, phosphate, kaolin, copper sulfide, nickel sulfide, lead- zinc, coal, talc, rare-earth, gold and many other ores. Flotation expertise in Brazil has reached an international level in many areas. Specialized staff and relatively well equipped research facilities allow the country to develop, whenever applicable, flotation processing routes for most of its ores. Non conventional applications of flotation are also being studied in many areas in Brazil. It is worth mentioning the recent efforts to apply flotation related techniques such as precipitate flotation for the treatment of effluents containing heavy metals, de-inking of paper for the recycling of pigments, removal of mercury from heavily contaminated gold "garimpo" areas, etc.

It is also worth mentioning that alternate flotation techniques such as the AIR SPARGED HYDROCYCLONE, LAMELLA FLOTATION and the use of the JAMESON CELL, are currently under investigation in various research centers and universities of the country. Column flotation, the new flotation technique of the eighties can now be considered in Brazilian terms as an alternative technique that has been subjected to extensive examination and that has already been tested in pilot scale on a very large number of ores.

6. FLOTATION PRACTICE: METALLIC MINERALS

6.1 Gold

The use of flotation for the processing of gold ores is relatively new in Brazil. Three companies utilize froth flotation circuits to concentrate either free gold (Rio Paracatu Mineração S.A.- RPM, Paracatu, MG) or to obtain sulfide and/or grafite concentrates bearing gold values (São Bento Mineração S.A., Santa Barbara, MG and Minera9ao Morro Velho S.A. -MMV, Nova Lima, MG). Worth mention is also the Mineração Manati Plant, located in Araputanga, Mato Grosso state, shut down in 1991, that operated a full column flotation circuit to concentrate a copper sulfide ore containing gold. This plant, although small, is a landmark for the use of column flotation in industrial scale in Brazil. The plant was originally commissioned with a fully conventional mechanical flotation circuit that was later on completely refurbished with improvements in grade and recovery to operate a home made column flotation (all stages) circuit. Unfortunately this operation was shut down because of the (unexpected) exhaustion of minable ore reserves.

Specific information on each flotation circuit per company follows.

a) RPM, Paracatu

1. Cell Type:	
Outokumpu flash flotation	8 m^3 (300 ft^3)
Wemco	(8) 16 m^3 (600 ft^3)
2. Flotation:	
feed grade	0.5 g Au/t
concentrate grade	600g Au/t
3. Ore basic mineralogy:	
quartz	43%
muscovite	40%
siderite	6%
dolomite	1%
hematite	4%
pyrite	1%
others	5%
4. Recovery:	
total	85%
flotation	90%
5. In operation since 1987, recently introduced modifications including new regrinding circuit and expansion in flotation cell capacity, CIP/CIL for gold hydrometallurgy	

b) MMV - Queiroz Plant - Cuiabá Circuit

1. Cell Type: Wemco	8.4 and 14 m^3 (300 and 500 ft^3)
2. Flotation:	
feed grade	5.2 g Au/t
concentrate grade	25 g Au/t
3. Ore mineralogy:	
quartz	49%
dolomite	4.4%
hematite	9%
pyrite	14.5%
calcite	5.4%
feldspar	5.7%
arsenopyrite	2.1%
pyrrothite	1%
magnetite	0.5%
pyroxene	4.5%
chorite	2.9%
others	1%
4. Recovery:	
total	94%
flotation	97%
5. A pre-flotation step for graphite/ carbonaeous minerals occurs depending on ore type; sulfide concentrate proceeds to roasting steps followed by cyanidation of calcine.	

c) São Bento Mineração, Santa Bárbara

1. Cell Type: Wemco	 8.4m^3 (300 ft^3)
2. Flotation: feed grade	 7.0 g Au/t
3. Ore basic mineralogy: quartz muscovite siderite dolomite hematite pyrite others	 43% 40% 6% 1% 4% 1% 5%
4. Recovery: total flotation	 85% 90%
5. In operation since 1987, recently introduced modifications including new bio-oxidation step prior to pressure oxidation; it will be introducing column flotation (one cell with 2 m in diameter and 9 m in height): CIP/CIL for gold hydrometallurgy.	

6.2 Niobium

Brazil holds the largest world reserves of niobium ores. At the present demand pattern, Brazilian proved reserves are sufficient to supply the entire world for at least 500 years. It is worth noticing that Mineração Catalão (located in Catalão, Goiás state) even with a production capacity 20 times smaller than CBMM (Companhia Brasileira de Metalurgia e Mineração, located in Araxá, MG) is still the second largest niobium producer in the world.

a) CBMM, Araxá

1. Cell Type:	
Galigher	8.4/4.8/1.7m^3 (300/171/61 ft^3)
Deister column	one unit
2. Flotation:	
feed grade	2.5% Nb_2O_5
concentrate grade	60% Nb_2O_5
3. Mineralogy composition:	
barite	20%
limonite	35%
pyrochlore	4.5%
magnetite	16%
quartz	5%
others	19.5%
4. Recovery:	
total	66.1%
flotation	72.2%
5. Reserves: 8 million tons of Nb contained	
Concentrate production capacity:	42,000 t/year

b) Mineração Catalão, Catalão

1. Cell Type: Denver	1 m^3 (36 ft^3)
2. Flotation: feed grade	1.2% Nb_2O_5
3. Recovery: total	55%
flotation	70%
5. Reserves: 6.15 million tons of Nb contained	
Concentrate production capacity:	2,100 t/year

6.3 Copper

Two companies produce copper concentrates in Brazil: MineraQ8o Caraiba e Companhia Brasileira do Cobre -CBC, with foreseen lives of eight and two years, respectively. The only large reserve is located in the Carajas area (Salobo -see previous chapter).

Available pieces of information on Caraiba and CBC operations follows.

a) Mineração Caraíba, Jaguarari

1. Cell Type:	
Wemco	8.4/14 m^3 (300/ 500 ft^3)
Deister column	one unit
2. Flotation:	
feed grade	0.9% Cu
concentrate grade	34% Cu
3. Mineralogy composition:	
hypersthere	90%
plagioclase	5%
magnetite	2%
chalcopyrite + bornite	2%
other	1%
4. Recovery:	
flotation	90.0%
5. Plant capacity per year:	5.7 million tons of ore

b) CBC, Camaquã/Caçapava do Sul

1. Cell Type:	
Wemco	14m^3 (500 ft^3)
2. Flotation	
feed grade:	1.0% Cu
concentrate grade	30% Cu
3. Recovery:	
flotation	90.0%
5. Plant capacity per year:	1.9 million tons of ore

Columns are presently being tested at this plant.

6.4 Oxidized zinc

Most of the zinc produced in the world comes from sulfide ores. Brazil and Italy are exceptions. Zinc concentrates are produced, via flotation, from willemitic ores at Companhia Mineira de Metais (CMM) in Vazante, MG. This companies produced in 1989 163,000 tons of concentrate. It also produces a calamine concentrate that does not employ flotation in its processing. The other company currently producing zinc from oxidized ores is located in the same area. MASA (Mineração Areiense S.A.) exploits a calamine ore assaying approximately 17% Zn. Flotation start up at MASA is predicted for early 1993. The ore to be processed by flotation encompasses two zinc minerals: calamine (also known as hemimorphite) and smithsonite. Due to the rivalry between the two companies very little information has been disclosed regarding their operations. It is known that both flotation circuits employ sulfidization of zinc minerals with sodium sulfide or sodium hydrogen sulfide followed by cationic amine flotation of the sulfidized zinc minerals at an alkaline pH.

6.5 Lead-zinc

Lead and zinc sulfides (sphalerite and galena), the first type of ore to be floated in Brazil, are no longer important in the Brazilian mining scenario. The flotation plants of Morro Agudo (Pb/Zn sulfide), located in Paracatu, MG and Boquira (Pb/Zn mixed sulfide/oxide ores), located in Boquira, BA, are no longer in operation. Small operations in Parana state are still producing lead concentrate via flotation. For instance, the Rocha mine runs a flotation circuit with 12 tlh capacity located in Cerro Azul, producing a lead/silver concentrate from an ore with average grades of 4% Pb and 130g Ag/t.

At the Zinc metallurgy operated by Companhia Paraibuna de Metais in Juiz de Fora, MG, there is a flotation circuit that recovers silver and lead values from residues generated during the hydrometallurgical steps Uarosite-sulfuric acid process)

employed to produce zinc from imported zinc sulfide concentrates.

6.6 Tungsten

Tungsten mines in Brazil produced concentrates mostly from scheelite (Ca tungstate) based ores. Although flotation was not employed directly for the concentration of scheelite, the removal of pyrite (iron sulfide) that contaminated scheelite gravity (table) concentrates was practiced at least in one operation - Tungstenio do Brasil, located in Currais Novos, RN (Boca do Lage Plant).

6.7 Iron

The rich Brazilian iron ores deposits, discovered at the beginning of this century, are well known worldwide. These formidable reserves of iron ores are concentrated in two states: Minas Gerais (in the so-called IRON QUADRANGLE, near Belo Horizonte) and Para (in the Carajas Mining District).

Basically Brazilian currently mined iron ores belong to two broad groups. The first group includes the HEMATITIC ores. This type of ore is related to supergene enrichment and is used for the production of coarser sized iron ore products such as lump ore, pellet ore, sinter feed, etc. The second group includes the ITABIRITIC ores, lower in iron content and generally needing concentration steps for the production of salable final products. Itabirites presenting fine liberation size as a rule have to be concentrate by flotation.

The first company to operate a flotation plant to treat an itabiritic ore in Brazil was SAMARCO in 1977. Since its start-up, the Germano plant has employed only flotation to concentrate various types of itabiritic ores. The final flotation concentrate is pipelined 396 km to a pelletizing plant also owned by

SAMARCO, located on the coastal city of Anchieta, in the state of Espirito Santo.

Since the commissioning of the Germano plant in Mariana, three other flotation circuits were installed by two other companies. CVRD added flotation to its high intensity magnetic separation unit in Itabira and started up a flotation plant in Timbopeba, also located in Mariana. Samitri also included a flotation circuit to its facilities at the Alegria Mine, also located in Mariana, MG.

All iron ore flotation operations in Brazil utilize the reverse flotation configuration, i.e. the froth product contains the tailings, mostly composed by quartz. The use of the reverse cationic flotation should be viewed as the most commonly resorted alternative worldwide for the concentration of low grade iron ores. There are very strict specifications for the final products (concentrates) generated by the iron ore mining industry, especially regarding iron, silica, alumina and phosphorus contents. To succeed reaching all product specifications, the intrinsic operational flexibility of flotation makes the application of this process in treating iron ores the most widely used choice.

A brief description of the flotation operations follows:

a) SAMARCO, Mariana

1. Cell Type: Wemco Column - recleaning 3.66m diameter x 13 m height, scavenging 2.2m diameter x 11.2m height	$14m^3$ ($500\ ft^3$)
2. Flotation: feed grade concentrate grade	45-55% Fe (depending on ore type) 66-68% Fe; 0.8 to 3% SiO_2 (depending on type of product)
3. Mineralogy composition: hematite goethite magnetite quartz clay minerals	
4. Recovery: flotation	70.0%
5. Plant capacity per year:	9 million tons of ore

b) SAMITRI, Mariana

1. Cell Type: Wemco	$14m^3$ ($500\ ft^3$)
2. Flotation: feed grade concentrate grade	55-60% Fe (depending on ore type) 66-68% Fe; 0.8 to 3% SiO_2 (depengin on type of product)
3. Mineralogy composition: hematite goethite magnetite quartz clay minerals	
4. Recovery: flotation	75.0%
5. Plant capacity per year:	2 million tons of ore

SAMITRI is expanding its flotation capacity at Alegria by adding two flotation columns to the existing flotation circuit.

c) CVRD, Timbopeba, Mariana

1. Cell Type: Wemco	$14m^3$ ($500\ ft^3$)
2. Flotation: feed grade concentrate grade	 55% Fe 66-68% Fe; 0.8 to 3% SiO_2 (depending on type product)
3. Mineralogy composition: hematite goethite magnetite quartz clay minerals	
4. Recovery: flotation	 70.0%
5. Plant capacity per year:	3 million tons of ore

d) CVRD, Cauê and Conceição, Itabira

1. Cell Type: Outokumpu	$16m^3$ ($600\ ft^3$)
2. Flotation: feed grade	>55% Fe (depending on ore type)
concentrate grade	66-68% Fe; 0.8 to 1.0% SiO_2 (depending on type of product)
3. Mineralogy composition: hematite, goethite, magnetite, quartz, clay minerals	
4. Recovery: flotation	70.0%

As previously mentioned, CVRO is planning to include a column flotation circuit to its present circuit at the Conceição plant in order to increase the plant capacity to produce OR grade pellet feed fines.

e) CSN, Casa de Pedra, Congonhas

1. Cell Type: Columns (CESL design) (4)	3.67 m x 10 m
2. Flotation: feed grade concentrate grade	>55% Fe 66-68% Fe; 0.8 to 1.2% SiO_2
3. Mineralogy composition: hematite goethite magnetite quartz clay minerals	
4. Recovery: flotation	90.0%
5. Concentrate production capacity:	4 million tons/year

f) MBR, Pico Mine, Itabirito

1. Cell Type: Columns (CESL design) (2)	3.67 m x 14 m
2. Flotation: feed grade concentrate grade	>60% Fe 67-68% Fe; 1.2% SiO_2
3. Mineralogy composition: hematite goethite magnetite quartz clay minerals	
4. Recovery: flotation	95.0%

7. NONMETALLIC SUBSTANCES

7.1 Phosphate

Phosphate ores playa prominent role in the history of flotation technology in Brazil. Serrana operation was an outstanding landmark due to the fact that it included full process development. The freight costs increase, caused by the first oil crisis, encouraged the Brazilians to expand the phosphate industry .The external dependence dropped from 80% in 1977 to zero in 1983.

Five companies float phosphate ores in Brazil: Arafertil, Copebrás, Fosfertil, Goiásfertil and Serrana. The largest one - Fosfertil -and Goiásfertil (the second largest in installed capacity) recently changed from the hands of the government to the private enterprise sector. Goiásfertil and Copebrás mine phosphate ore from the same deposit. The group who owns Copebrás also operates a concentration plant for niobium (Mineração Catalão, already discussed).

All phosphate ores currently treated by flotation in Brazil are of igneous origin, being associated with carbonatitic rocks. This peculiarity promoted the need to develop specific technological routes to treat the Brazilian phosphate ores. Most of the phosphate deposits around the world are sedimentary. Flotation, as applied to the sedimentary ores, especially in the U.S.A., bears no similarity to the processing of Brazilian lower grade, complex mineralogy ores. Besides Brazil, phosphate ore of igneous origin are treated via flotation in Russia, Finland, Senegal and R.S.A.

An overall picture of the phosphate ore segment is presented next, showing weighed average operation conditions and parameters for the five companies:

Exploitable reserve:	890 million tons
Average grade:	8.2% P_2O_5
Cutoff grade:	5.1% P_2O_5
Mine life:	30 years
Feed tonnage:	27 million tons
Plant feed grade:	10.2% P_2O_5
Concentrate grade:	36% P_2O_5
Concentrate yield:	4.5 million tons per year
Recovery:	
Magnetite removal	97.3%
Desliming	85.1%
Flotation	82.1%
Overall	68%

Specific information per company follows:

a) SERRANA, Cajati/Jacupiranga

1. Cell Type:	
Wemco-Fagergren	1.7m^3 (60 ft^3)
Pneumatic (Serrana)	39m^3 (1320 ft^3)
2. Flotation:	
feed grade	5% P_2O_5
3. Mineralogy composition:	
apatite	12%
calcite	57%
dolomite	21%
magnetite	7%
phlogopite	2%
other	1%
4. Recovery:	
flotation	86%
overall	74%
5. Flotation tailings feed a cement plant	

b) ARAFÉRTIL, Araxá

1. Cell Type: Wemco-Fagergren First column installed in 1992. In 1994 the conventional circuit was replaced by a new full-column circuit utilizing 4 rectangular flotation columns.	$8.4m^3$ ($300\ ft^3$)
2. Flotation: feed grade	5% P_2O_5
3. Mineralogy composition: apatite magnetite micas barite gorceixeite quartz goethite other	 30.2% 9.8% 8.0% 3.0% 11.2% 8.4% 20.4% 9.0%
4. Recovery: overall	 65%
5. Barite flotation circuit; high intensity magnetic separation used to remove iron oxide/hydroxides from apatite concentrate; column flotation unit installed and under testing; continuous efforts to process refractory ore types.	

c) FOSFÉRTIL, Tapira

1. Cell Type:	
Wemco	8.4 m^3 (300 ft^3)
Circuit is presently being refurbished with rectangular columns	
2. Flotation:	
feed grade	
fines:	10.0% P_2O_5
coarse:	12.6% P_2O_5
3. Mineralogy composition:	
apatite	19%
calcite	3%
anatase	2%
magnetite	18%
micas/clays	20%
perovskite	2%
pyroxene	14%
serpentine	1%
silex	5%
other	7%
4. Recovery:	
flotation	80.2%
overall	65.5%

d) COPEBRÁS, Catalão

1. Cell Type:	
Wemco	8.4 m^3 (300 ft^3)
2. Flotation:	
feed grade	21.5% P_2O_5
3. Recovery:	
flotation	88%
overall	70%

e) GOIASFÉRTIL, Ouvidor

1. Cell Type: Wemco	8.4/14 m^3 (300/500 ft^3)
2. Flotation: feed grade	11% P_2O_5
3. Recovery: flotation	80%
overall	65%

7.2 Graphite

Only one company, Nacional de Grafite, produces concentrates by flotation in two plants locates in the towns of Itapecerica and Pedra Azul (Minas Gerais). Graphite is one of the few minerals naturally hydrophobic. The ore mineralogy in both mines operated by Nacional de Grafite includes besides graphite mostly silicate minerals, dominantly quartz. The company in its plant in Itapecerica (the older one) utilizes WEMCO 1.1 m^3 (40 ft^3) mechanical cells. It also employs some Denver (modified) and Kopex-Conventos IZ mechanical cells.

7.3 Fluorite

Fluorite ores are treated by flotation in three plants in Brazil. The newest operation is the one owned by Mineração Del Rey (DuPont group) located in Cerro Azul (Parana state). The feed grade is 55% CaF_2 and a concentrate assaying 97% CaF_2 is produced at a recovery of 60%. The circuit utilizes conventional mechanical cells WEMCO of 2.8 m3 (100 ft3).

Another example is located in the town of Morro da Fumaya in Santa Catarina state, operated by Mineração Santa Catarina Ltda. This company treats a blended ore from three different mines. The average head grade is 36% CaFc The flotation chemistry include tall oil as collector (200g/t), sodium silicate

(water glass) as depressant (300g/t) and soda ash as pH regulator (1900g/t to reach pH 9.5). Flotation is performed in DENVER mechanical cells of 0.7 and 1.4 m^3 (24 and 50 ft^3). The tailings stream after classification in hydrocyclones is pumped to the mine and used as back fill. The concentrate assays 96% CaF_2 at an overall recovery of 87.4%.

Another flotation plant for the concentration of fluorite was in operation for some years in the town of Itaborai, State of Rio de Janeiro, owned by Mineração Sartor Ltda.

7.4 Coal

Brazilian coal industry is presently in very bad shape. Beyond the low quality of the ores, the companies did not prepare themselves during the over protection taxation period for the new policy of free importation. Only one company operates a preparation plant that includes flotation. This company is the Carbonifera Criciuma, at its Verdinho Mine. The flotation circuit employs Kopex-Conventos IZ 12m^3 (430 ft^3) conventional mechanical cell. The run of mine coal assays 3% S and 40% ash. Flotation concentrates assay 12% ash and 1.4%S for the first rougher and 18% ash and 1.4%S for the second rougher.

7.5 Other

Other types of nonmetallic substances also subjected to flotation concentration in Brazil include: potash -sylvinite (sylvite + halite), magnesite (which also includes a talc flotation step), talc and kyanite.

The only application of flotation of soluble salts occur in the industrial complex of Taquari-Vassoura (State of Sergipe). The mine (underground) was operated by a Petrobras subsidiary - PETROMISA until very recently when CVRD bought its rights. Flotation is performed in a fully-mechanical circuit employing

DENVER flotation machines with 2.8 m^3 (100 ft^3) capacity. The company utilizes cationic collectors to float selectively sylvite (KCI) from halite (NaCI).

Magnesita S.A. runs a magnesite flotation operation in Brumado, Bahia state. This circuit contemplates a previous talc flotation step followed by magnesite flotation. Flotation feed assays 86% MgO (calcined basis) and recovery reaches 95%. Overall recovery, including desliming reaches 88%. Flotation cells are Denver 1 m^3 (36 ft^3), mechanical. There are indications that Magnesita may install flotation columns in a near future.

Details on talc and kyanite flotation operations were not available. It is known that the kyanite flotation plant has been in operation for a long time and that talc flotation is restricted to a single plant located in Ponta Grossa, Parana state. Talc is another example of a naturally hydrophobic mineral.

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