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Technical Faculty in Bor



*Ecological  
Truth and  
Environmental  
Research*

EDITOR  
*Snežana Šerbula*



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*Ecological Truth & Environmental Research*

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# ***MONOGRAPH***

## **ECOLOGICAL TRUTH AND ENVIRONMENTAL RESEARCH**

**Dedicated to the memory of Professor Zoran S. Marković**

**Edited by:  
Snežana M. Šerbula**

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### Chapter 3

## THE FLOTATION PROCESS AND CHEMISTRY: A REVIEW

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### ABSTRACT

*Flotation is as viable and effective a separation technique in environmental technology as it is in mineral processing, where it was developed. Flotation occurs in a three-phase system consisting of water, particles and air. The particles to be separated are usually hydrophobic or altered to behave this way. They are composed of different minerals and ions which are absorbed or precipitated on the particle. These particles then get attached to gas bubbles. The latter are generated by different methods including dispersed-air and dissolved-air. The bubble-particle aggregate then floats to the surface to be removed from the system. Fine particles flotation faces certain limits. Various adsorbents were tested, for example in the case of heavy metals (as Cu, Cr, etc.), either common such as layered double hydroxides or some industrial by-products (such as pyrite) and even biosorbents - the respective process was termed (bio)sorptive flotation. A brief discussion is presented in this paper on selected examples of the electrokinetic behaviour of sulphide minerals as an illustration how chemistry's knowledge and application may help not only flotation research but also in the sustainable development in this area.*

**Keywords:** Pyrite, Fines, Heavy metals, Wastes, Sorption, Zeta-potential

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## **1. INTRODUCTION**

Raw materials constitute a hot topic in EU, due to marked imbalance between the production and consumption; economic activities are in fact dependent on traditional raw materials. However, the supply of minerals to the European industry, with a few noteworthy exceptions, is heavily dependent on import [1]. Flotation is as viable and effective a separation technique in environmental technology as it is in mineral processing, where it was developed. Without this technology, many common metals and inorganic raw materials would be exceedingly scarce and costly, because the high grade ores that could be processed by simple physical and mechanical methods have long since been used up. On the other hand, the food-chain pyramid receives metals through man's activities and on top of the pyramid, man (perhaps) receives preconcentrated metal toxicity.

The varying behaviour of particles at air-liquid interfaces were studied in a historical perspective; particles attached to bubble surfaces act as a steric barrier. Their effectiveness is dependent upon many factors: such as concentration, particle hydrophobicity and size, among others [2]. In the flotation process, bubble velocity and turbulence are the key factors affecting particle-bubble interaction; collision efficiency is used as an indicator to assess the extent of these interactions [3]. A new flotation technology, the Jameson cell, has shown (following development) interesting advantages, such as the consistent fine bubble generation, without use of spargers and intensive slurry mixing with the bubbles without mechanical agitation [4].

The presence of stratified flow was accepted in the separation zone of a dissolved-air flotation (termed as DAF) tank, used for drinking water treatment; the effect of bubble-particle clustering was also included in a computational fluid dynamic model of particle removal [5]. Other notable applications of flotation that should be mentioned, apart from the aforementioned are: the flotation deinking in paper industry [6], the aqueous two-phase flotation (based on solvent sublation) of biomolecules [7], and the recovery of microalgae for biodiesel production [8].

Arsenic-rich auriferous pyrite concentrates (stockpiled in the mine area) were shown to be further enriched by flotation to assist in gold beneficiation [9]. The various applied techniques for metal ions removal have been recently reviewed, including a hybrid one [10,11]. Alternative bubble generation methods were also examined, such as electroflotation and dissolved-air flotation. The contribution of physical chemistry to flotation was investigated, zeta-potential measurements, contact angle etc., examining the role of bubble and particle size played in the process as well [12]; the aforementioned will be further elaborated and extended in the following text, including an update of the recent literature. It should be noted that in this review there is not much focus on the flotation engineering aspects, such as hydrodynamics as this area has been rather well addressed in the literature.

## **2. SORPTIVE FLOTATION**

Adsorption is commonly used for the removal of heavy metals, due to its low cost, efficiency and simplicity; focus of this review was the use of inorganic adsorbents engineered

at the nanoscale [13]. However, nanomaterials are expected to act as a froth stabilizer and therefore, detrimental to flotation [14]. On the other hand, the properties, features and role of nanobubbles in (dissolved-air) flotation have been recently investigated, showing potential for the removal of  $\text{Fe}^{+3}$  ions [15]. Furthermore, the interface between biological and geological materials was elsewhere examined; bacteria can immobilize various components of solutions or suspensions, offering remediation, and recovery applications [16]. The ability of microorganisms to remove metal ions from dilute aqueous solutions (as most wastewaters are) is a well-known property. Various types of biological materials were tested and floated efficiently, such as bacteria, fungi, yeasts, activated sludge, grape stalks, etc. [17].

The application of mineral particles by-products for the induced removal of toxic metals from aqueous solutions was also proposed [18]; nowadays, the problem of industrial wastes handling and disposal is increasing continuously, as more strict environmental considerations have to be taken into account. Success in developing novel technologies will be greatly improved when we can confront the chemical complexity in flotation systems [19].

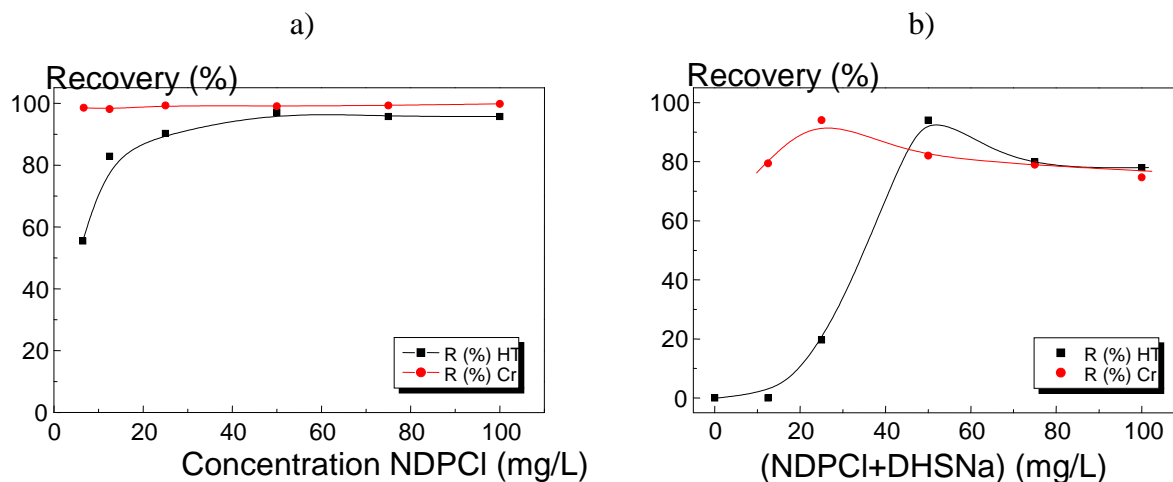
The impact of chemical speciation was stressed during various flotation applications for metal separation from the effluent [20]. Toxic metals exist in the effluents of many industrial operations. The removal of soluble ionic species, such as heavy metal cations or oxyanions, from dilute aqueous solutions has been in-depth investigated by applying the sorptive flotation technique mainly in laboratory-scale experiments, batch and continuous mode. For the latter, a countercurrent flow is advisable [21]. This innovative separation technique involved the initial abstraction of heavy metal ions onto a sorbent (including a biosorbent), at first. The application of a flotation stage followed, for the efficient downstream separation of metal-laden particles – i.e. a two-stage process. Typically, dispersed-air flotation was mainly used as the bubble generation method. The process yielded a metal-loaded sorbent stream and a clean water underflow.

Figure 1 presents such an example, where chromium oxyanions was removed by a typical inorganic ion exchanger (synthesized and then calcined at 500 °C for 10 h) combined with recovery by flotation, applying different surfactants. Heating hydrotalcite numerous fine pores are formed perpendicular to the crystal surface from which the  $\text{CO}_2$  gas vented. This is accompanied by an increase in the surface area and a doubling of the pore volume. Although this favors chromate sorption, it may possibly explain the difficulty faced in floating hydrotalcite particles [22].

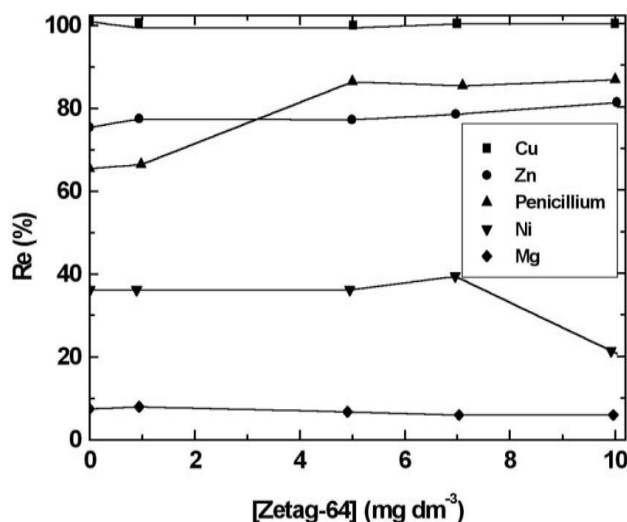
Layered double hydroxides are lamellar mixed hydroxides containing positively charged main layers and undergoing anion exchange chemistry. These sorbents usually exist in powder form, thereby exhibiting high surface area and rapid kinetics for adsorption, but presenting appreciable problems in the subsequent solid/liquid separation process.

Biosorption is considered as the attachment of adsorbates (of the metal ions), onto a non-living biomass surface, being usually bacteria, algae or fungi, or onto a material containing natural biopolymers, acting as bio sorbents, e.g. chitin. This process should be distinguished from bioaccumulation. Figure 2 gives an example from this research area. The residual turbidity after flotation was remarkably improved using the polyelectrolyte, from 126 decreased to 0.4 NTU. Effective flocculation is a prerequisite, mainly for dissolved-air flotation. The biomass reuse after elution was examined as well as the multi-cycle tests.

Filamentous fungal biomass was in this case a waste by-product from industrial fermentation (Synpac Ltd, UK) [23].



**Figure 1** (a) Effect of the concentration of collector lauryl-pyridinium chloride on the separation of hydrotalcite (1 g/L) and chromates (0.2 mM Cr initially), for ionic strength of 0.001 M KNO<sub>3</sub>; (b) Flotation by a surfactants mixture of lauryl-pyridinium chloride / sodium lauryl-hydrogen sulphate: at 0.1 M KNO<sub>3</sub> ionic strength, in presence of a frother and also of 50 mg/L cetyl-trimethyl ammonium bromide. Reprinted with permission, copyright Elsevier [22]

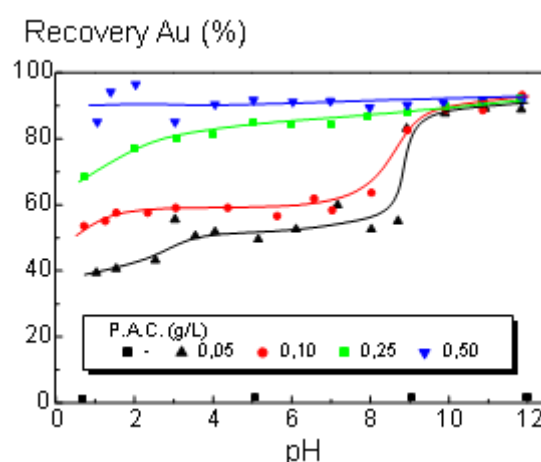


**Figure 2** Influence of flocculant concentration on biosorptive (dispersed-air) flotation of *Penicillium chrysogenum* fungi (6 g dm<sup>-3</sup>) and on the removal of toxic metals, by dodecylamine (1·10<sup>-3</sup> mol dm<sup>-3</sup>). Reprinted with permission, copyright Elsevier [23]

It was concluded that biosorptive flotation seemed a viable and effective separation process for the aqueous system under investigation, no matter the type of biosorbent applied. Measurements of surface tension, contact angle and zeta-potential correlated quite reasonably with the observed results of separation by flotation [24].



Activated carbons certainly are among the effective adsorbents in pollution prevention, because of their excellent sorption capacity; their use has been often prohibited due to their relatively high cost, low selectivity and regeneration problems. Powdered activated carbon (PAC) offers, apparently, more surface area for adsorption and is less costly to manufacture. On the other hand, thiourea applied for gold recovery presents an important alternative lixiviant to the commonly used cyanide, especially for cyanide refractory ores, but also as it was then thought due to the severe environmental constraints on cyanide, related to tailings disposal, water quality and environmental impact; the dissolution of gold in acid thiourea solutions is a rather complex process. Motivation for the above was the possible application of the process in gold leach solutions, for instance, after heap leaching. The solution pH, as shown in Figure 3, was not found to be a significant parameter in the acidic pH range, which was of more practical interest.



**Figure 3** Effect of the solution pH on the gold adsorption process, at various powdered activated carbon additions; Au = 20 mg/L, thiourea = 400 mg/L, contact time = 600 s.

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As the solution pH was increased above pH 4, formamidine disulphide decomposes irreversibly to elemental sulphur and cyanamide. Flotation of gold from thiourea solutions was also investigated and gave promising results [25]. Nevertheless, after this early work, thiourea has been shown to be a carcinogen in rats.

### 3. SUSTAINABILITY

Green technologies are environmentally friendly operations which limit the negative impacts of traditional industrial activities and can contribute to solving the challenge of sustainable water management. Apart from the previous comments related with sustainable development, sustainability in the field of water separation processes and its significance for the chemical and process industry is discussed in detail in the literature as the need for fresh sources of drinking water is becoming urgent worldwide [26]. This topic was also addressed in the context of minerals and mining in the plenary lecture at the previous conference in Bor [1].

The mining industry is often criticized for generating large amount of solid wastes, among other, with a significant environmental impact; one study presented a feasible approach of recovering residual coal from its mine waste rocks, and reusing the derived tailings to produce eco-friendly fired bricks [27]. The Raglan mine ore concentrator in Canada produces acid-generating tailings, which contain pyrrhotite (FeS) that need to be properly managed; the option of using desulphurized material as a component of a cover to control acid mine drainage generation was assessed [28]. Various guidance tools and practices have been proposed to improve the sustainability of mining activity while maintaining the economic viability.

Extensive use of electrical and electronic devices in modern life and for industrial purposes produces a large amount of wastes; plastic material (polyvinyl chloride and acrylonitrile butadiene styrene) in this mixed waste accounts for 30-50% of the content, containing brominated flame retardants. Therefore, a selective and sustainable separation was proposed using microwave and/or mild-heat treatment followed by flotation [29]. Water treatment of cyanobacteria and natural organic matter was examined by natural based products, i.e. coagulant and activated carbon, in a process sequence of coagulation/flocculation, dissolved air flotation and adsorption [30].

Two main bubble generation techniques were examined and compared [31]: dissolved-air flotation, which is a common technique in water treatment, and quite different from the dispersed-air flotation. In the latter category electroflotation (or better, electrolytic flotation) is also included. Elsewhere [32], derivatives of modified octyl glucoside were used as flotation collectors to remove various metallic cations from a water phase, due to their excellent biodegradability and the absence of toxic effects (hence, replacing other known surfactants derived from petrochemical industry).

Cheap and plentiful, water was for centuries a manufacturing tool that industry took for granted. But population growth, globalization, and climate change are drivers in a new water-constrained era. Good, clean water just cannot be replaced-and it is getting harder to come by.

## **4. SULPHIDE MINERALS**

The flotation of mixed sulphides is a common application in mineral processing used for selective separation: the encyclopedia of colloid science, as flotation was called [33]. For instance, in the mines at Chalkidiki (Greece) we practiced the consecutively froth flotation separation of mainly galena (PbS), sphalerite ((Zn,Fe)S), and pyrite (FeS<sub>2</sub>) (also copper sulphide, arsenopyrite, gold and silver), with the appropriate chemical conditioning (activation or depression) at set conditions; extensive related work was carried out at AUTH [34]. In the mineral processing plant, the first circuit (of six flotation banks in series with at least two stages of cleaning) usually use the zinc sulphate, cyanides, sodium sulphite etc. for sphalerite depression and xanthates as collectors together with frother, pine oil. Xanthates and dithiophosphates are the most commonly used collectors in the flotation of sulphide minerals. Many other collectors have been also developed.

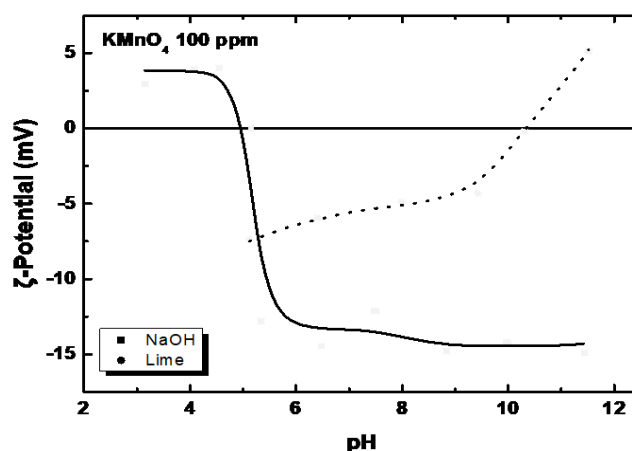
On the other hand, in the second circuit (usually eight banks with two stages of cleaning of the liquid underflow and one stage of the concentrate), copper sulphate is used as activator,

with careful pH control (pH 9.5-10) by lime, in order to depress pyrite, is further discussed below. Preceding these circuits (and after the appropriate size reduction, crushing and grinding in order to achieve mineral liberation, there is often one flotation unit that recovers most of the lead (70-80%). It should be noted that the specific gravity of the minerals is different, the gangue minerals usually being quartz or calcite rock. The main properties of modifiers in flotation are their great capability for dispersion, modification of froth properties, control of pH, precipitation of metallic ions which result in modification of collector action.

During galena flotation, the presence of slimes such as lead sulphate or pyrite, which adsorb or precipitate the collector, cause a depletion of the latter and hence, depression. Slime depression occurs when there is no energy barrier to heterocoagulation and is dependent on the zeta-potentials and size of the mineral and slime [35]. The interactions between the amino acid glycine and also a polymer with a glycine functional group and three sulphide minerals (chalcocite, galena and pyrite) were investigated, using settling tests, electrokinetic measurements and dissolution studies [36].

Another study in Melbourne [37] of ZnS and NiS by detailed electrokinetic methods showed that by careful control of experimental parameters much information on sulphide-water interfaces could be obtained. Sphalerite activation with  $\text{Cu}^{2+}$  ions, including the role of pH in this phenomenon, was examined assisted by zeta-potential measurements; from the flotation point of view, the fast activation was emphasised [38]. The native and induced surface hydrophobicity of several sulphide minerals was published elsewhere [39]; zeta-potential measurements showed that in the presence of EDTA the isoelectric point of the minerals was shifted considerably to lower pH values.

The level of dissolved oxygen concentration is a critical parameter in differential flotation of sulphide minerals, which arises from the instability of the sulphur they contain [40]. A common oxidant, potassium permanganate was used as pyrite modifier; results of electrokinetic measurements are shown in Figure 4. The point of zero charge was at pH 5, and the presence of  $\text{Na}^+$  ions did not affect the zeta-potential.  $\text{Ca}^{2+}$  ions, in contrast, shifted the zeta-potential to less negative values and even changed the sign of it. So, the selection of the pH regulator is important as well.



**Figure 4** Influence of pH on  $\zeta$ -potential of pyrite, in the presence of 100 mg/L permanganate, using different pH regulators. Reprinted with permission, copyright Soc. Chem. Ind. [40]

The point of zero charge observed at pH ~10.2 clearly shows that calcium ion is specifically adsorbed on pyrite. It should be noted that the zeta-potential measurements were conducted in the Lab by a particle electrophoresis apparatus (Mark II by Rank Brothers, UK), using a flat cell, with the microscope connected to a video monitor through a camera.

Compared to arsenopyrite, pyrite requires a lower dissolved oxygen concentration to balance the anodic oxidation of xanthate to dixanthogen, which leads to its flotation. This means that pyrite flotation (by xanthate) is possible in a less anodic potential range than that required for the flotation of arsenopyrite. The manipulation of the redox potential of a flotation pulp is possible by electrochemical treatment of the pulp, applying an external potential through metallic electrodes [9].

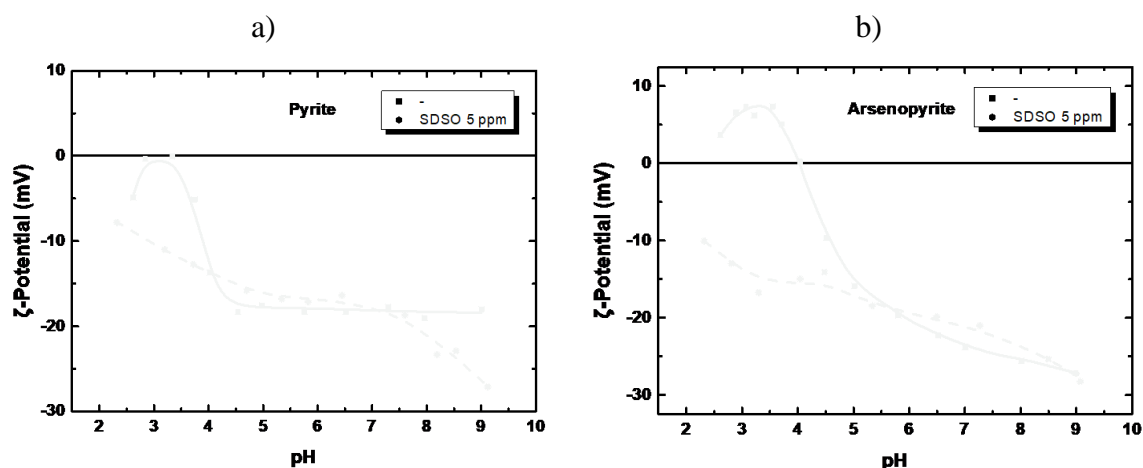
Electroflotation offers certain advantages over other flotation techniques of bubble generation; among other, the following points are perhaps the most important: (i) the electrode grids can be arranged to provide good coverage of the whole surface area of the flotation tank, avoiding any bypass, (ii) the electric field gradient between electrodes aids flocculation and flotation, even without the presence of any surfactant, (iii) gas production (evolution), flotation time, and the other operating conditions can be checked quickly and are relatively easily controlled [10].

Arsenopyrite (FeAsS) was also selectively floated from pyrite by an unconventional anionic collector, sodium dodecyl-sulphonate, at the pH of ~4. The industrial concentrate, used in this work, was an auriferous bulk pyrite-arsenopyrite flotation concentrate from Olympias Chalkidiki commercial plant, which was considered as a problematic "waste" due to its arsenic content [41]. The separation was further enhanced by the use of methyl isobutyl-ketone as a frother; a synergism of the surfactants was noticed. Based on the experience achieved in the Hallimond tube experimentation, a flotation separation test was designed using a conventional laboratory flotation cell.

In a strongly acidic environment, pyrite was positively charged or about neutral; with the addition of the collector alone, the zeta-potential of pyrite shifted to more negative values and pure arsenopyrite had similar behaviour. Figure 5 shows the comparison of the measurements, while permanganate was also added as modifier.

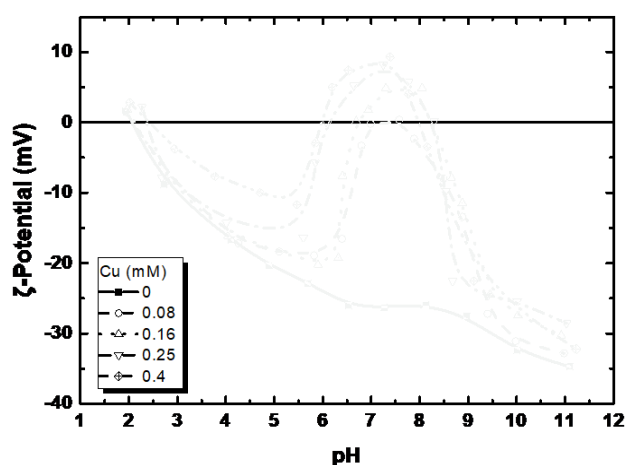
Arsenopyrite displayed a greater shift at pH range from 3-4 with the addition of collector, indicating stronger interactions with the collecting species. An Eh-pH equilibrium diagram of manganiferous species was also shown in [41]. The manganese oxides are expected to precipitate on the mineral surfaces where the redox process takes place, mainly that of arsenopyrite, altering its surface features.

A possible utilization of an industrial by-product such as iron sulphide, as discussed in the previously, may be as an adsorbent/solid substrate material, which may be followed by their (dissolved-air) flotation as the scavenging mechanism [42]. Copper, among other heavy metals, is a common toxic ion encountered in many dilute leach solutions, spent process streams and liquid effluents in industry. A copper ionic equilibrium diagram was also published. A further aim of that paper was the transfer of mineral processing know-how to environmental technology and vice versa. Ideally, fine mineral particles should be produced only for the purpose for the liberation of valuable materials from gangue minerals.



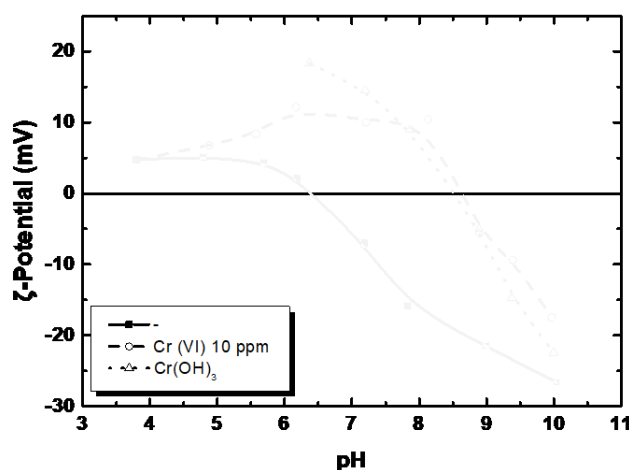
**Figure 5** Zeta-potential of modified iron sulphides (with 5 mg/L  $\text{KMnO}_4$ ) in the presence and absence of collector dodecyl-sulphonate. Results reprinted with permission, following modification from Kydros *et al.* [41]

The respective electrokinetic measurements, illustrated in Figure 6, had applied increased quantities of copper ions. A reversal of zeta-potential of pyrite was observed around the neutral and slightly alkaline pH region, which was due to the coverage of the mineral surface by hydrolysed copper cationic species. A surface-induced hydrolysis reaction mechanism was suggested. A detailed analysis in the phenomenon of interfacial precipitation was done by Hunder [43].



**Figure 6** Zeta-potential measurements of pyrite in the presence of copper ions. Reprinted with permission, copyright Taylor & Francis [42]

In another environmental study [44], chromium oxyanions were the target. The latter, particularly in its hexavalent form, is a known highly toxic priority pollutant, used in industry as strong oxidant. A computer-assisted calculated speciation diagram for trivalent chromium was published, too. As shown in Figure 7, in presence of chromium, an excessive positive surface charge of pyrite was observed, indicating a reduction process, since  $\text{Cr(VI)}$  exists in aqueous solution only as anionic species. For reasons of illustration, the behaviour of chromium hydroxide precipitate ( $5 \cdot 10^{-2}$  M) is also presented. The resulted hydroxo- $\text{Cr(III)}$  species were found to be precipitated and removed onto the pyrite particles.



**Figure 7** Zeta-potential studies of the system Cr(VI)/pyrite and also of chromium hydroxide precipitate ( $5 \cdot 10^{-2}$  M dispersion);  $\text{KNO}_3$  was applied as conductivity regulator.

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A comparison between the two removal processes, namely the traditional reduction-precipitation and the present one, was briefly given [44]: (i) conventional reduction-precipitation (use of costly chemical reagents for Cr(VI) reduction and pH control, two-stages process, removal of Cr(III) species only in alkaline pH values (9-10)); (ii) using pyrite fines ( $-45 \mu\text{m}$ ) (use of an industrial solid waste, possibilities for its reuse, one-stage process, removal of Cr(III)-species even in acidic pH values (4-6)).

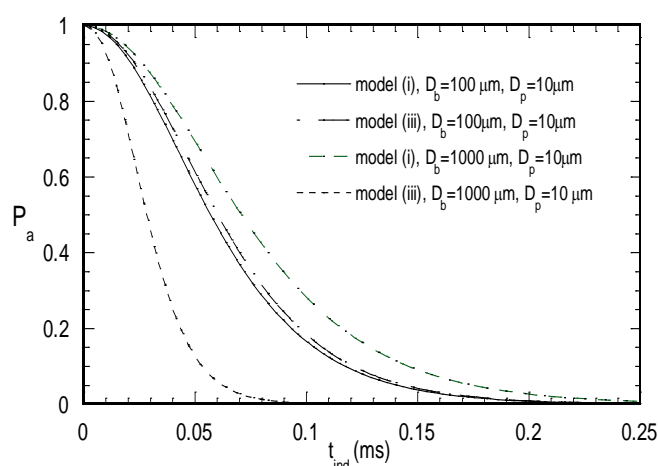
## 5. FINE PARTICLES

In mineral processing, with the increasing demand for minerals, continuously diminishing ore grades and various economic pressures (cost of fuel, energy, etc), the problem of fines processing is becoming more important. Will the field succeed to pass the crossroads [45]? There are numerous examples of processing systems in which the ore must be deslimed, as the conventional separation methods are inadequate in the sub-sieve range. Understanding the limits of fine particle flotation is the key to the selective separation of fine mineral particles. Fine particles have low collision efficiencies with gas bubbles and float slowly. A decrease in the bubble size can increase the bubble-particle attachment efficiency. These factors also increase the flotation rate and recovery of fine particles. Of course, there are drawbacks, such as low rising velocity, long flotation times, etc. - as it might be expected [46].

It was stated that there has been a large body of experimental evidence showing that bubble-particle collection efficiency increases with decreasing bubble size. The published studies concerning the effect of bubble size on flotation of fines are rather limited, in comparison with those on particle size. For instance, in Newcastle, Australia, the flotation rate of fine particles was found to be strongly affected by the bubble size; an increase of up to one hundred-fold was observed when the bubble size was reduced from 655 to 75  $\mu\text{m}$  [47]. In a classical handbook, in fact Volkova and Eigeles [48] were certainly one of the first scientists proposing that fines can be collected more effectively by finer bubbles.

The behaviour of bubble clusters in a well-controlled turbulent flow was also examined [49]. An early work presented plant-site evaluations of six different feeds comprising very fine particles (80% passing sizes 8-23  $\mu\text{m}$ ). Five of the streams contained mainly sulphides, and one contained oxide minerals. The testwork was performed using pilot-scale columns. For each stream, column metallurgical performance was compared with plant and laboratory mechanical cells. Column results were better [50]. In wastewater treatment, centrifugal flotation systems have been applied; hydrocyclone mixing was also combined with small dissolved-air flotation bubbles, leading to the development of a hybrid technique [51].

Dissolved-air flotation of magnesite ( $\text{MgCO}_3$ ) and dolomite  $\{\text{CaMg}(\text{CO}_3)_2\}$  fine particles was undertaken (using a jar tester by Aztec, UK), in the presence of modifiers (such as carboxymethyl cellulose, sodium hexametaphosphate and sodium pyrophosphate) for their selective recovery with promising results [52]. These two salt-type minerals are by nature hydrophilic; they have the same crystal structure, similar surface characteristics and flotation properties. Salt-type minerals are slightly soluble in water and in aqueous dispersion, ions are transferred to solution and then further hydrolysed, changing the pH. A differential gravimetric bubble separation method has been used for the estimation of the bubble size distribution in dissolved-air flotation [53].



**Figure 8** Attachment efficiency,  $P_a$ , from models (i) and (iii) versus induction time,  $t_{\text{ind}}$ , for several pairs of bubble and particle diameters. Reprinted with permission; copyright Elsevier [55]

Inside flotation machines, the operation takes place in a highly turbulent flow [54]; it should be noted that in mineral processing usually there is a larger amount of heavier particles compared to wastewater treatment. Despite the significance of turbulent fluid motion for enhancing the flotation rate in several industrial processes, there is no unified approach for the modeling of the flotation rate in a turbulent flow field [55]. The attachment efficiency computed by two models are shown versus the induction time for two pairs of particle and bubble diameters in Figure 8; where typically, the efficiency  $P$  consists of two components (i.e.  $P = P_c P_a$ ), the first ( $P_c$ : collision efficiency) expresses the probability of the particles and bubble collision. Model (i) was a modification of the classical Yoon-Luttrell [56] approach by King [57], and model (iii) was developed by Nguyen [58]. As expected the attachment efficiency (i.e. the probability of the collided particle to drain the thin liquid film and



eventually aggregate with the bubble) decreases as the induction time (being a parameter which collectively includes all physicochemical interactions between a bubble and a particle) increases since the time spent by the particle on the bubble surface is not enough for permanent attachment. For small bubbles, where the Reynolds number for the flow around a bubble is small, the predictions of the two models for  $P_a$  were very close.

Inverse gas chromatography has been recently studied as a method to determine specific surface free energy components and their distributions of particulate surfaces; the latter being a more fundamental flotation parameter, related to the contact angle via Young's equation [59]. A first principle model was developed to predict flotation from both surface chemistry and hydrodynamic parameters (such as bubble size, particle size, energy dissipation rate, contact angles, etc.) [60]. Very small bubbles, which partially coat the surface of particles, influence if heterocoagulation between a particle and a bubble occurs [61]. Research on the mechanisms of particle-bubble interaction provided valuable information on how to improve the flotation of fine (and coarse particles) with novel flotation machines, which provide higher collision and attachment efficiencies of fine particles with bubbles and lower detachment of the coarse particles [62]. Attention is always required to differentiate, perhaps due to turbulent flow currents, between true flotation and entrainment in the flotation of submicron particles by fine bubbles [63].

## 6. OBITUARY

Finally, the first time one of the authors (KAM) met with Prof. Zoran Markovic was in 2002, actually twice that year: first time during an international conference in High Tatras, Slovakia and second time in Bor, during one of the October conferences that he organized - the latter was after seeing the ruins in Belgrade, due to the bombing of Yugoslavia. Two more meetings followed, in 2004 in Bor (36<sup>th</sup> Conf.) and at the XXIII IMPC at Istanbul, as well as our communication with regards to his Journal. Zoran had solid background in Mining and Metallurgy, with an extensive theoretical knowledge, a he was hard-working, intelligent and dedicated scientist/engineer and member of academic staff; a nice character. We were really shocked by his death. May he rest in peace.

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