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A Review on Bioflotation and Bioflocculation of Galena

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Abstract: In recent decades, the application of microorganisms and their products for the bioseparation of minerals, bioflotation, and bioflocculation, has been extensively recognized by researchers and industry. Considering several benefits of the bioseparation, in the current paper, a detailed review has been conducted on the bioseparation of galena from its most common accompanying minerals i.e. sphalerite, chalcopyrite, and pyrite using microorganisms and their extracellular products. Based on the findings, the bacterial cells of the *Thiobacillus* species have a good ability to depress and selectively flocculate galena, but the cells of the *Polymyxa* species have a lower ability. Therefore, they depress and flocculate most of the sulfide minerals present in the pulp. In addition, the adaptation of bacteria, especially *polymyxa* species with galena and other minerals will increase extracellular secretions of protein or polysaccharides. Adapted *Bacillus subtilis* and *Bacillus megatrium* can separate galena. Due to the hydrophobic nature of extracellular proteins, their less absorption on the surface of galena compared to sphalerite, causes the second mineral to be floated and the galena to be depressed. On the other hand, adaptation leads to more protein secretion in the presence of galena compared to pyrite, which will cause galena to float and the second mineral to be depressed. Also, it can be said that the tendency of extracellular polysaccharides to adsorb on galena and the tendency of extracellular proteins to adsorb on sphalerite causes that when the mixture of these two minerals comes into contact with bacterial EPS, galena is usually depressed or flocculated and sphalerite floats to some extent.

Keywords: Microorganism, Bioflotation, Bioflocculation, Galena.

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INTRODUCTION

Galena ore consists of galena mineral with 86.6% lead content and is usually accompanied by economically valuable minerals containing Pb, Ag, Cu, and Zn containing minerals. Ore is usually processed using physical separation methods (i.e., shaking tables, jig, heavy media cyclone, Dayana whirlpool, spiral, etc.) or flotation for the production of 50 to 70% lead content concentrate, which is consequently processed further for pure lead by various methods such as direct melting or leaching.

Conventional flotation uses chemical agents to modify minerals surfaces in a fluid environment to selectively attach valuable minerals to the air bubbles and separate them accordingly. In chemical flocculation, agents such as flocculants and coagulant form flocs of fine particles and enhance their sedimentation rate as well as separation [1]. Recently the new methods of bioflotation and bioflocculation gained attention due to the high chemical agent cost, chemical stability of the toxic agents, and consequently raised environmental issues [2-4]. Numerous research conducted on bioflotation and bioflocculation of galena minerals has proved that the interaction between bacterial cells or extracellular polymeric substances (EPS) and galena modifies mineral surface and could be employed as a biocollector or bioflocculant.

The biological separation of valuable minerals, as a novel method of mineral treatment, has gained attention recently. In such a separation system, the interaction between the mineral surface and the microbial growth culture, cells, and microbial metabolites (i.e., extracellular proteins and polysaccharides) modify the surface and consequent functioning behavior similar to collector, depressant, and flocculants which cause particle separation.

METHODS

Microorganisms participate in varieties of environmental and geochemical processes by energy, electric charge, and material transfer between mineral and solution complexes. Considering the changes raised due to microorganisms’ existence on the mineral surfaces, they are considered suitable alternatives to chemical reagents employed in mineral separation. Among the major classes of microorganisms like fungi, yeasts, algae, and lipids, bacterial species play a stronger role in the biotreatment of minerals [5,6]. Almost 90% of the mass of microorganisms consists of proteins, polysaccharides, lipids, phospholipids and nucleic acids.

Bacillus species such as *Bacillus subtilis*, *Bacillus polymyxa*, *Paenibacillus polymyxa* and *Bacillus megaterium* are the most common heterotroph, mesophile, gram-positive and rod-shape bacteria which are used vastly in the biotreatment of galena as the biocollectors, biodepressants and bioflocculants.

Cellular charge and hydrophilic characteristics of gram-negative bacteria originate from the polysaccharides forming their cellular walls [7-9].

Microorganisms approach mineral surfaces and adhere to them to access nutrition, if feasible. Three major mechanisms could affect the mineral-microorganism interaction: microbial cells’ attachment to the solid surface, the occurrence of oxidation-reduction reactions and the surface adsorption or the chemical reaction between the mineral surface and EPS of microorganisms [10]. Generally, the surface of all microorganisms, due to the presence of phosphates, carboxylate, and sulfides in their cellular walls, presents a negative charge [6].

A review on the bioseparation of galena declared that mostly the heterotroph and mesophile bacteria and their products were considered for the biotreatment of galena compared to the other microorganisms. It should be mentioned that most of the studies focused on the separation of lead and zinc sulfide minerals (i.e., galena and sphalerite). the interaction of galena and bacterial cells or their EPS improves its hydrophilicity. This will result in the depression of galena in the flotation process and will improve its floc formation in separation through flocculation.

FINDINGS AND ARGUMENT

The effect of bacterial cells

Heterotroph and autotroph bacterial cells can modify the galena surface. Heterotrophic bacteria have rapid growth kinetics, high cell density and more EPS compared to autotrophic bacteria which attain their energy through the oxidation of mineral surfaces. Due to the consumption of organic carbon by heterotrophic bacteria, their attachment to the mineral surfaces is less probable and is strongly affected by environmental conditions [11,12]. Due to the abundance of necessary chemicals, room temperature adaptability and lower energy requirements, in most bioflotation and bioflocculation studies, heterotrophic mesophilic bacteria are utilized. In the case of sulfide minerals, especially galena, since iron and sulfur-oxidizing bacteria are chemo-autotroph that require an acidic environment where biooxidation of galena surface as well as dissolution of other sulfide minerals occurs, heterotrophic bacteria are preferred.

Considering the published research results, *Thiobacillus* species present strong capacities for depression and selective flocculation of galena, but *Polymyxa* species act less selectively and depress all sulfides. Adsorption of *Thiobacillus* species is through the formation of insoluble lead sulfide on the galena surface that is pH-independent in the case of *Polymyxa* sp. proving the chemical adsorption of the bacterial cells on the sulfide minerals.

Effect of bacterial cells adaptation

Studies showed that bacterial cell adaptation improves bioseparation efficiency. During the adaptation phase, bacterial cells are in contact with minerals at the growth stage and produce certain compounds on the cell surface or in the form of EPS relevant to the contacted mineral. Adaptation might cause morphological changes in the bacterial cells, EPS production and also bacterial surface charge [7,13,14].

Studies showed that the adaptation of the microorganisms with galena and other minerals will increase the protein or polysaccharides portion of the produced EPS. The adapted *Bacillus subtilis* and *Bacillus megaterium* presented strong selective separation capacities for galena. Due to the lower hydrophobic characteristics of extracellular portions and their higher adsorption tendencies for the galena surface, they encourage sphalerite flotation while discouraging galena. On the contrary, more protein production in the presence of galena compared to pyrite, causes galena flotation against pyrite.

Effect of protein and extracellular polysaccharides

The EPS produced by bacteria has been tested for the selective separation of galena from other minerals. EPS consists of proteins, carbohydrates and organic acids, which could attach to the mineral surface, create a biofilm and alter surface characteristics. In general, amino acids of proteins reinforce surface hydrophobicity, while carbohydrates in the EPS strengthen the hydrophilicity of the minerals [6,15]. EPS characteristics are determined by the culture medium, bacterial growth and growth duration. Maximum production of protein and polysaccharides is obtainable if growth is kept at the exponential phase and there are no limitations on the necessary nutrition and elements for bacterial growth. Studies showed that the adaptation of the bacterial cells with galena enhances EPS production [13,16].

A thorough review of the reports reveals that the extracellular polysaccharides tend to be adsorbed on the galena while extracellular polymers are attracted to the sphalerite surface once both minerals are in contact with EPS. Therefore, galena is depressed or flocculated and sphalerite tends to float under the mentioned conditions. The floatability of sphalerite is significantly improved once some chemical collector is added to the process.

CONCLUSION

A review of the published papers and reports suggests a successful bioseparation of galena from the most common minerals accompanying it by bioflotation and bioflocculation processes. The adsorption of bacterial cells and their metabolic products on galena, sphalerite, chalcopyrite and pyrite surfaces occurs due to electrostatic, hydrophobic, Van der Waal's and acid-base forces.

Reviewing the available literature implies that extracellular proteins generally improve hydrophobicity, while extracellular polysaccharides enhance the hydrophilicity of the galena surface, which could be used in selective bioflotation or biodepression (i.e., bioseparation) of galena from accompanying minerals. It has been proved that the adaptation of the microorganisms with minerals improves bioflotation or bioflocculation of the mineral with bacterial cells or the produced EPS, compared to the independent growth of the microorganisms.

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