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Mechanism study of the impact of water-borne bacteria on flotation

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ABSTRACT

Bacteria-containing water is being increasingly accessed by the minerals industry as an alternative water source to improve water efficiency. Water-borne bacteria have been shown to negatively affect the efficiency of froth flotation when using a representative system consisting of *E. coli* as the model bacterium and chalcopyrite as the model mineral. It is essential to understand the underlying mechanisms that could explain the observed effect, to provide guidance on the subsequent solutions to deal with it. This study conducted a systematic investigation into the mechanism by which bacteria affect flotation efficiency using fluorescence microscopy, bubble attachment time measurements, and froth phase characteristics. *E. coli* bacterial cells in solution were found to attach to chalcopyrite surfaces. In turn, the surface hydrophobicity of chalcopyrite particles decreased as the number of the attached bacterial cells increased. Reduction in surface hydrophobicity resulted in less mineral particles attaching to bubbles, leading to decreased froth stability, bubble coalescence rate and froth velocity. Slurry pH and Eh were also affected by the presence of the bacterial cells. These changes were correlated with reductions in flotation recoveries. These experimental results contribute to an understanding of how biotic water constituents impact the operation of flotation plants that choose to use alternative water sources, and provide knowledge towards possible solutions to the negative effect of water-borne bacteria.

1. Introduction

As water resources become scarcer, mine sites have been increasingly accessing bacteria-containing water for their operations. However, water-borne bacteria have been found to have a negative effect on flotation efficiency (Liu et al., 2013). To use this water source without compromising operational efficiency, the negative effect needs to be overcome in a diagnostic way. This requires an understanding of the underlying mechanisms that could explain the negative effect.

The process of particle-bubble capture in flotation can be described by three independent sub-processes: collision, attachment, and stability (Dai et al., 1999). In a flotation cell, hydrophobic mineral particles collide with rising gas bubbles, attach to bubble surfaces and form stable particle-bubble aggregates. The particle-bubble aggregates then rise to the surface of the flotation cell, forming the froth phase. Flotation efficiency depends on the efficiency of each of these sub-processes. Water quality change is among the factors that may influence the efficiency of any of these sub-processes.

A number of studies have shown how abiotic water constituents affect the efficiency of the sub-processes by changing properties of particles, bubbles and aqueous solution. For example, electrolytes favor the formation of smaller stable bubbles due to the influence of the electrolytes on surface tension and gas solubility (Pugh et al., 1997). Smaller bubbles increase the particle-bubble collision probability (Bournival et al., 2012; Pugh et al., 1997), and also improve particle-bubble attachment efficiencies (Hewitt et al., 1994). The presence of electrolytes also improves particle-bubble attachment efficiency through compressing the electrical double layer and thus reducing the electrostatic repulsion between particles and bubbles (Kurniawan et al., 2011). Some metal ions can affect particle-bubble attachment efficiency by forming a hydrophilic barrier of metal hydroxide precipitates on minerals surfaces (Senior and Trahar, 1991). Formation of metal hydroxides is influenced by aqueous pH (Font et al., 1999). Aqueous Eh can also affect particle-bubble attachment through changing mineral surface hydrophobicity by oxidation reactions (Buckley and Riley, 1991; Zachwieja et al., 1989). The presence of dissolved ions in water can change the stability of particle-bubble aggregates in the froth phase (Bıçak et al., 2012; Farrokhpay and Zanin, 2012).

Compared to studies on abiotic water constituents, there is not much study on how biotic water constituents, specifically water-borne bacteria, affect the sub-processes in flotation (Rao et al., 2010). Based on the existing research on abiotic water constituents, this study hypothesized that water-borne bacteria could affect the efficiency of flotation sub-processes through: changes in the particle surface properties, particularly surface hydrophobicity, changes in the froth layer, and changes in solution chemistry. To test the hypothesis, we carried out experiments to study these changes using different techniques in a representative system consisting of *E. coli* as the model bacterium and high-purity chalcopyrite as the model mineral. This paper reports

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the findings of these experiments carried out to study the underlying mechanisms.

2. Materials and methods

2.1. Materials

A pure culture of *E. coli* strain K12 was cultured in LB medium consisting of tryptone (10 g/l), yeast extract (5 g/l) and sodium chloride (10 g/l). The culture was grown in flasks shaken at 37 °C for 16 h. The cells were harvested by centrifugation (Eppendorf Centrifuge 5810R) at 4000 ×g for 15 min. The cell pellets were washed three times with 1 × PBS solution (phosphate buffer saline) and suspended in the same solution. The bacterial cell concentration was measured by optical density (OD600) using a Nanodrop ND-1000 spectrophotometer (Thermo Scientific), where 1 OD equals 1×10^9 cell/ml.

High-purity chalcopyrite was purchased from GEOdiscoveries Company, Australia. The sample was crushed using a roll crusher and screened to collect 0.6–2.8 mm size fractions. The crushed sample was then sealed in polyethylene bags and stored at −20 °C. Just prior to flotation experiments, the sample was dry-ground with a pulverizer to a particle size of D_{80} of 150 μm (i.e., 80% of the particles pass a sieve with 150 μm opening). All chemicals used were of analytical grade.

2.2. Methods

2.2.1. Changes in particle surface hydrophobicity

2.2.1.1. Adsorption experiment. Microflotation was used to study the adsorption of the bacterial cells to chalcopyrite surfaces and the resulting modifications to surface hydrophobicity. Microflotation is a well-accepted means of studying mineral surface changes due to the simplicity of the system (Botero et al., 2008; Mishchuk, 2005; Shackleton et al., 2007). The attachment of the bacterial cells to mineral surfaces was calculated by measuring the change in bacterial concentrations upon the addition of mineral particles. Different initial concentrations of the bacterial cells were added to the microflotation unit. The suspensions were conditioned for 2 min and filtered through Whatman No. 1 filter paper (11-μm particle retention). The residual concentrations of the bacterial cells in the filtrates were measured and used as the bacterial concentrations before addition of mineral particles. This treatment ensured that the bacterial cells attached to the glass wall of the microflotation unit and the filter paper were taken into account. Prior to use, 3 g of the high-purity chalcopyrite -50 + 53 μm size fraction was deslimed three times to remove ultra-fine particles. The same initial concentrations of the bacterial cells together with the deslimed chalcopyrite particles were added to the microflotation unit. The slurry was conditioned and filtered according to the same procedure as above. The filtrates were collected for bacterial concentration measurements. These measurements were used as the bacterial concentrations after addition of mineral particles. The bacterial attachment was calculated by subtracting the bacterial concentrations after addition of mineral particles from the original bacterial concentrations. The collected chalcopyrite particles were used for fluorescent microscopy. These particles were transferred to a 10 ml test tube containing 5 ml of distilled water. To the test tube was added 1 μl of DAPI fluorescent stain. The particles were stained with DAPI for 40 min. After staining, the chalcopyrite particles were transferred to a glass slide. Images were taken using a fluorescence microscope (Olympus BX 61) with a 40 × objective.

2.2.1.2. Particle-bubble attachment time. The change in particle surface hydrophobicity after bacterial attachment was quantified by measuring particle-bubble attachment time. The attachment time was measured using the Attachment Timer (University of Alberta, Canada). Chalcopyrite particles were conditioned with different concentrations of the bacterial cells and sodium ethyl xanthate collector. The treated particles were transferred to a rectangular optical glass cell to form a bed of mineral particles. The glass cell was then placed on the moving stage of the microscope of the Attachment Timer for measurement. A bubble of about 2 mm in diameter was generated using a microsyringe. The bubble was moved against the bed of mineral particles. Different contact times were preset in the computer program. Ten measurements were performed at each given contact time on different spots of the bed. This machine can only measure whether there are particles attached to the bubble, but could not measure the weight of the particles attached. The computer recorded each time the bubble picked up a minimum of one particle. The number of successful attachments out of ten tries was used to calculate the percentage of the contacts that picked up mineral particles. Then the relationship between the preset contact time and the percentage of the contacts that picked up mineral particles was established. There has been other research where the attachment time was defined as the contact time at which 50 per cent of the observations resulted in bubble-particle attachments (Ozdemir et al., 2009; Ye et al., 1989). However, in this work particle-bubble attachment time was defined as the contact time at which 100 percent of the contacts picked up particles. The reason was that the apparatus used in this work could not measure a contact time of less than 10 ms.

2.2.1.3. Microflotation experiments. Changes in particle surface hydrophobicity were correlated with mineral recoveries from microflotation experiments. Microflotation experiments were conducted with a standard microflotation unit (Bradshaw and Connor, 1996). Despite repeated screening, the chalcopyrite sample contained a significant amount of very fine poorly floating particles that had to be removed prior to the microflotation experiments. For each microflotation experiment, 3 g of the −150 + 53 μm size fraction was placed in a 250 ml beaker and mixed with 150 ml of distilled water. The beaker was placed in an ultrasonic bath for 1 min. Fine poorly floating particles were removed by decanting the suspension. The sonication and decantation steps were repeated three times. *E. coli* cells were added to the microflotation unit to different concentrations. The slurry was conditioned for 2 min to allow the bacterial cells to interact with the mineral. Then, sodium ethyl xanthate collector was added into the microflotation unit, followed by another 2 min of conditioning. No frother was added in microflotation. Air flow rate was maintained at 18 ml/min for 90 s of flotation time. Concentrates and tails were collected from the top and bottom of the microflotation unit. The products were filtered, dried at room temperature and weighed for analysis.

2.2.2. Changes in froth phase — batch flotation

For each flotation test, 100 g of the ground mineral sample with a particle size of D_{80} of 150 μm was mixed with 500 ml of distilled water to form slurry with an approximate pH of 8. The slurry was transferred to a 1.5 l flotation cell. The bacterial cells were added to the flotation cell to different concentrations. The slurry was conditioned for 2 min to allow the bacterial cells to interact with the mineral. Then, sodium ethyl xanthate was added as the collector to a final concentration of 200 g/t. The slurry was conditioned for 2 min, followed by the addition of MIBC (methyl isobutyl carbinol) frother to a final concentration of 200 g/t. The slurry was then conditioned for another 1 min. Air was supplied through the bottom of the cell at a flow rate of 5 l/min. Before collecting a froth sample, twenty froth images were taken using a Metso Visiofroth camera positioned over the flotation unit. Concentrates were collected at 1, 2, 4, and 8 min cumulative time with a scraping rate of once per 10 s. The concentrates and tails were filtered, dried in an oven at 70 °C overnight and weighed for the analysis. The froth images were analyzed using the Metso software to obtain information on changes in froth color, texture, bubble size, bubble collapse rate, froth stability and velocity. This information was then correlated with the final mass recoveries.