Electroflotation of iron ore fines using biosurfactant

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Abstract. Conventional flotation shows low recovery of the fine particles due to the low probability of bubble-particle adhesion and collision, what can be solved with the electroflotation process. Electroflotation uses oxygen and hydrogen microbubbles (<100μm) generated from water electrolysis. In addition, this process can become a biotechnology using a biosurfactant. The present work aims to evaluate the recovery of hematite fine particles from an iron ore using the electroflotation process with a biosurfactant obtained from Rhodococcus opacus. The tests were conducted with an iron ore (−38+20μm) in a Partridge-Smith modified electroflotation binary cell. The parameters used in these tests were current density (16 mA/cm²), agitation (300rpm), electrolyte concentration (0.2mol/L), conditioning time (5min) and flotation time (10 min). The pH range between 3 and 11, biosurfactant concentration (50 to 800mg/L) were evaluated and up to now, the results show that the electroflotation process was able to concentrate the hematite of the iron ore.

Keywords: Electroflotation, biosurfactant, iron ore and hematite.

1. Introduction

Mineral processing has a large amount of waste which is in tailings dams nowadays. These dams occupy big areas, deforesting the local vegetation and may contaminate the groundwater and even if there is a risk of rupture bringing irreparable damages to environment and population (Fontes, et al. 2016). Tailings and slimes of the iron ore concentration (fine and ultra fine particles) are stored in these dams. The recovery of fine (F) and ultrafine (UF) particles continues to generate challenges for the mineral sector, since conventional flotation processes present low recovery. This behaviour can be attributed to low probability of bubble-particle collision and adhesion, difficulty in overcoming the energy barrier, mechanical drag, high adsorption of reagents, low selectivity, surface oxidation, and mineralogical alteration [9]. Another important variable for the flotation process of the F and UF particles is the bubble size. The smaller the bubble size the better the recovery efficiency of F and UF particles due to a large surface area of the bubbles[20]. Some technologies have been studied for recovery of the F and UF particles based on the concept of increasing the efficiency of bubble-particle adhesion and collision. One of these techniques is the electroflotation [19].

The electroflotation process generates bubbles of oxygen and hydrogen smaller than 100 μm from the electrolytic decomposition of the water. This process allows the control of several factors in production and size of bubbles such as: current density, material and electrode type, electrolyte concentration and system pH [19]. This process can become a biotechnology when the synthetic
Surfactants are replaced by biosurfactants (BS) with similar characteristics. Biosurfactants are amphipathic substances equal to synthetic surfactants, however, had different origin, are obtained from the microorganisms such as bacteria, yeasts, and fungi in different carbon sources [1]. An important characteristic of BS is the high degradability when compared to conventional reagents used in flotation [14]. There are different applications already widely disseminated to the uses for microorganisms in industry in leaching and oxidation processes, however, few studies focused on mineral flotation. Therefore, this study aims to evaluate the electroflotation of fine particles of iron ore using a BS extracted from Rhodococcus opacus.

2. Materials and methods

2.1. Iron ore sample and electrodes
The iron ore sample went through the jaw crusher and ball mill to reduce the particle size. Different types of analyses such granulometric (wet-sieving), mineralogical (X-ray diffraction) and chemical (volumetry using potassium dichromate and X-ray fluorescence) were performed. Platinum electrodes were used for the anode and the cathode. The total area of the electrode is 25 cm², with the wire spacing of 0.16 mm and the wire diameter of 0.08 mm.

2.2. Preparing and production of biosurfactant
The biosurfactant uses to the electroflotation tests was obtained from Rhodococcus opacus. First, the bacterium was cultured in solid medium (Yeast Malt Glucose – YMG) in Petri plates. After that, they were used to create a liquid medium (YMG) in a 250 ml Erlenmeyer, staying in the rotating shaker for 7 days. The bacterial solution was centrifuged at 4500 rpm for 10 min (CIENTEC CT-5000). The biomass was washed with deionized water twice and stored in 98% ethyl alcohol for 24 hours. And then, the biomass-alcohol solution was placed in an autoclave (CS PRISMA) for 20 min at 1 atm for extraction of BS. The BS solution stayed at the greenhouse for approximately 48 hours. Finally, the BS was solubilized in deionized water and filtrated. The not-soluble BS was discarded and the soluble BS was used in the electroflotation process.

2.3. Electroflotation tests
Electroflotation of iron ore was performed on a modified Partridge-Smith binary cell with a volume of 380 ml as shown in Figure 1.

![Figure 1. Experimental line of the modified Partridge-Smith binary cell.](image-url)
At first, 190 ml of the indifferent electrolyte sodium sulfate (Na$_2$SO$_4$) was added in cell. A tension was applied to the electrodes initiating electrolysis, generating hydrogen gas bubbles at the cathode and oxygen gas bubbles at the anode. After that, was necessary stabilize the system with the operating conditions used in this study. At the same time, the iron ore was conditioned with the BS in a glass Beaker for 5 min in agitation. After the conditioning, the solution composed by the BS and the iron ore were added to the cathode cell and the total volume was filled with the electrolyte. The electroflotation lasted for 10 minutes. White tests (without BS), were also carried out under the same operating conditions to determinate the mechanical drag. The operating conditions used in the electroflotation test are: pH: 3, 5, 7, 9 and 11, electrolyte concentration of 0.2 mol / L, biosurfactant concentration of 50, 100, 300 and 500mg / L, 1 g of iron ore mass, current density 16mA / cm$^2$, shaking 300 rpm, hydrogen gas bubble (H$_2$), conditioning time 5 min and electroflotation time 10 min.

3. Results and discussion

3.1. Sample of iron ore

The sample of iron ore was submitted to the granulometric analysis by CILLAS 1190. The results of the particle size fraction used (-38 +20 µm). The average particle size was of 30 µm. The results of the chemical analysis by X-ray fluorescence (FRX) indicated that the sample was consisted by 82.5% hematite and 16.5% quartz. The mineralogical analysis made by the X-ray diffraction (Figure 2) showed that the sample was composed of hematite and quartz.

![Figure 2. X-ray diffracttion of iron ore.](image)

3.2. Fourier transform infrared (FTIR) spectroscopy

FTIR analysis of hematite, quartz and iron ore were done (Figure 3). The mineral hematite spectrum shows the adsorption bands between 450 and 470 cm$^{-1}$ that can be attributed to the vibration mode of the Fe-O group, characteristic of the hematite phase. The adsorption band in 540 cm$^{-1}$, and the bands between 670 and 680 cm$^{-1}$ are associated with the vibration mode of the Fe-O group [10]. The mineral quartz spectrum shows bands ranging from 400 to 1200 cm$^{-1}$ that can be attributed to Si-O bonds [8]. It was observed that the 1085.74 cm$^{-1}$ vibration is due to the asymmetrical stretching of the Si-O, the adsorption band of 778.49 cm$^{-1}$ corresponds to the symmetrical Si-O stretch vibration, the adsorption band of 690.49 cm$^{-1}$ can be attributed to symmetrical Si-O flexion vibration, and the adsorption band of 460.18 cm$^{-1}$ can be attributed to asymmetric vibration of Si-O bond [8]. The iron ore spectrum shows that the absorbance bands close to 3400 cm$^{-1}$ can be associated with water molecules [6]. The
adsorption bands between 1083.84 and 797.96 cm\(^{-1}\) can be related to the Si-O bonds, and the bands of 544.13 and 463.23 cm\(^{-1}\) can be attributed to Fe-O groups.

![Infrared Spectrogram](image)

**Figure 3.** Infrared Spectrogram.

### 3.3. Electroflotation Test

White tests (without BS) were performed under the same operating conditions (Table 1) to determine the entrainment. Under these conditions, entrainment was less than 5% of total mass.

#### 3.3.1. Effect of pH

The pH effect in the system is very important for flotation processes, mainly for electroflotation. This variable influences the mineral surface because the surface charge is determined by the solution pH [16]. The system pH can also influence the microorganism surface properties. Some functional groups present in the biosurfactant can go through changes depending on the pH system; these changes can influence the mineral/BS interaction [6]. The tests were performed at a pH range of 3 to 11 with BS concentration of 300 mg/L and current density of 18 mA/cm\(^2\) (Figure 4). Under these conditions, recovery around 78% and Fe grade close to 59.4% at pH 3 were observed. The recovery decreased as the pH increased up to pH value of 7. This behavior can be attributed to the electrostatic interactions between the hematite and the BS in this pH range [3]. This can be also explained with the help of hematite zeta potential. The hematite PIE is generally found at pH values from 5 to 8. The pH values below of the hematite PIE exhibit positive surface charge and the pH values above of the hematite PIE exhibit negative surface charge [11]. The BS presents anionic characteristics allowing a greater interaction in acidic medium (below the PIE) with hematite favoring the recovery. The not-soluble surfactant species are found in higher concentrations. At pH 11 the recovery was around 51.33% with an iron grade of 51.37%.
3.3.2. Effect of biosurfactant concentration. This evaluation was performed with different BS concentrations from 50 mg/L to 800 mg/L at pH 3 and current density 18 mA/cm². The recovery depends directly of the BS concentration (Figure 5), the increase of the BS concentration favors the increase of the recovery up to 300 mg/L. In this concentration value was achieved a recovery of 78% with iron grade of 59.4%. Above this concentration, the recovery decreases, this reduction can be attributed to the critical micellar concentration (CMC) of the BS. The biosurfactant CMC was around 100 mg/L [11]. CMC is the surfactant concentration, where organized molecular assemblies known as micelles are formed, decreasing the interactions of the biosurfactant with the mineral surface and consequently negatively affecting the flotation recovery [13].

Figure 4. Effect of pH on the grade and recovery. BS concentration: 300 mg/L; current density: 16 mA/cm².

Figure 5. Effect of BS concentration on the iron grade and recovery. pH 3; current density: 16 mA/cm².

4. Conclusion
The results obtained in the electroflotation study of fine particles of iron ore with the use of the BS extracted from *Rhodococcus opacus* allow concluding that the recovery was satisfactory. Satisfactory
conditions of electroflotation were found at pH 3 and with a BS concentration of 300 mg/L, under these conditions a recovery of 78% and an iron grade of 59% were achieved. Further studies are needed to understand the behaviour of the electroflotation process of fine particles of iron ore using the BS extracted from *Rhodococcus opacus*.

5. References

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