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Effect of suspension chemistry onto voltage drop: Application to electro-flotation

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ABSTRACT

Electrochemical processes involving particle suspensions are still ill understood. Electro-flotation is process through which particles or ions can be selectively separated. Although the technique has been widely studied, not much is known about the effect of the chemistry of suspended particles on the process performance which constitutes the aim of the present research work.

A column-type cell was designed to carry out electro-flotation experiments and standard air flotation experiments. Two minerals, Merensky reef and UG2, were tested.

The classic air-flotation operation gave higher recoveries and grade of collected material compared to electro-flotation only when using Merensky reef ore. However, in the case of UG2 ore, the electro-flotation reached similar performance to that of the classic operation. It was found that the electrodes readily interact with the mineral pulp reducing the efficiency to generate bubbles. That efficiency depends significantly on the ore composition. Further electrochemical studies concerning how the voltage is used throughout the process was performed. The conductivity of the pulp formed using UG2 ore increased around 5 times compared to that observed when using Merensky reef ore. Under identical experimental conditions, the froth formed with Merensky reef ore was shallow and precarious compared to the thick and stable froth formed in the case of UG2 ore.

1. Introduction

1.1. Historical purpose of electro-flotation process

Originally, the electro-flotation gained some interest since it could solve the problem of recovering fine valuable particles which cannot be separated using classic flotation operations. Indeed, the froth flotation operation involving particles 10 µm or less makes the overall selective separation process completely inefficient [1,2].

Conventional flotation cells produce large bubbles, ranging in size from 600 to 2000 µm [3]. Some spargers can generate a medium-bubble size (from 100 to 600 µm), but this could be insufficient for ultrafine particle flotation (<10 µm) [4].

Alternative techniques have been evaluated to accomplish the generation of fine bubbles such as dissolved air, electro-flotation, etc. [5–7]. Electro-flotation has been suggested as the process to obtain the smallest bubble diameters, ranging in size from 20 to 40 µm [6,7]. Many applications have been developed with this technique such as wastewater treatment to remove harmful ions and molecules [8,9].

When mineral particles are too small, fluid streamlines formed around bubbles moving upwards act as an implicit shield for particles travelling towards the bubble. This "shield" reduces the collision efficiency and it is considered to be the major reason why the classic froth flotation process is inefficient at recovering fine particles [10,11].

1.2. Fundamentals of electro-flotation

The basic principle of the electro-flotation process relies on water electrolysis process. The reactions taking part can be assumed as follows,

$$4OH^- \rightarrow O_2 + 2H_2O + 4e^- \quad (1)$$

$$2H_2O^- + 2e^- \rightarrow H_2 + 2OH^- \quad (2)$$

The half-reaction 1 (oxygen production) is anticipated to occur at the anode while the second (hydrogen production), at the cathode. Both reactions are described in alkaline conditions normally used in froth flotation operations linked to sulphide minerals assessed in this work. Venkatachalam (1992) has performed an exhaustive analysis of the experimental consequences of producing gas through electrolysis [6].

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During water electrolysis the aqueous speciation or water quality will change significantly, particularly near the electrodes. Therefore, the first design decision would be related to how intimately both electrodes and mineral pulp should be connected. The introduction of membranes or other partially permeable barriers will act as resistances to mass transfer ultimately increasing the required applied voltage. If the solution in contact with the electrodes contains surfactant and/or other reagents commonly used in flotation operations [12–15], further studies concerning current efficiency must be performed to evaluate possible electrode passivation or activation.

Concerning the measuring of gas flowrate, it has been reported that the hydrodynamics plays a significant role [16], therefore a coherent stirring might be an adequate way to avoid bubbles coalescence. The relationship between bubble size and current density has not been yet correctly explained. The bubbles nucleation and subsequent detachment from the electrode are not directly linked to the bubble volume [6]. Yoon and Luttell claimed the turbulent conditions were unfavourable in conventional mechanical flotation machines when particles are fine [17]. New machine designs and processes were proposed such as column flotation, microbubble flotation, agitated column [18], Jameson cell with external contactor, flotation cyclone, flotation centrifuge and turbulent microflotation [19].

From a chemical point of view, one of the major advantages of using pure gases evolving from water electrolysis is their high reactivity. The gas may activate the mineral surface in order to make improvements in its recovery. The case of pyrite has been reported to respond well to electro-flotation [20]. However, it is also important to mention that electrolytic gases might also act against recovery depending on mineral nature [6].

The size of electrolytic bubbles has been found to be pH dependent. In alkali medium, bubbles of oxygen are bigger than those of hydrogen. Under acidic conditions, otherwise holds [21].

The main drawback of using electro-flotation is the electric costs. Other negative aspects such as the need of expensive cooling system to avoid overheating due to charge transfer and the costs linked to the high-quality electrode material have been also pointed out [22]. Nevertheless, the electrode material could be chosen in a way to decrease the costs [6]. For example, stainless steel can be used as the cathode. It has also been claimed that the power consumption could be limited by using a current pulsed system that allows bubble-size control and a reduction of the heat produced [23].

Additionally, most of the published research on electro-flotation has been performed using traditional flotation cells [7,22] or even mixing electro-flotation and classic flotation procedures which may mask the real effect of pure electro-flotation technique.

It is important to bear in mind that large scale water electrolysis is not an untested process. It has been implemented to produce hydrogen; however, the industrial conditions used for that purpose are dramatically different to those used in minerals recovery by froth flotation [24].

According to our present knowledge, no formal studies have been reported using electro-flotation for platinum group minerals (PGMs). In the present work, the electro-flotation process is applied to PGMs, particularly Merensky reef and UG2 ores, both belonging to the Bushveld Complex in South Africa. Scanning electron microscopy studies were performed to establish how the different mineral phases included in the ore are associated. Industrial reagents (collectors, depressants and frothers) normally used in plant were used throughout all the experimental work performed at real concentrations.

2. Experimental

2.1. Materials

A column-type cell (Fig. 1) was built which could work either using air passing (classic flotation) or electro-flotation. The column-type cell design was chosen to be able to study the floatability of the ores, similarly to Hallimond tube operation. The cell height and diameter are 25 and 5 cm, respectively. The effective volume used of the cell was 400 cm^3, which is around 80% of the total cell volume. The electrode materials were platinum and stainless steel for anode and cathode, respectively. The anode and cathode surface areas were 50 and 850 cm^2, respectively. The electrolysis of water was performed by using a power supply capable of delivering voltages up to 30 V and a maximum current of 1 A.

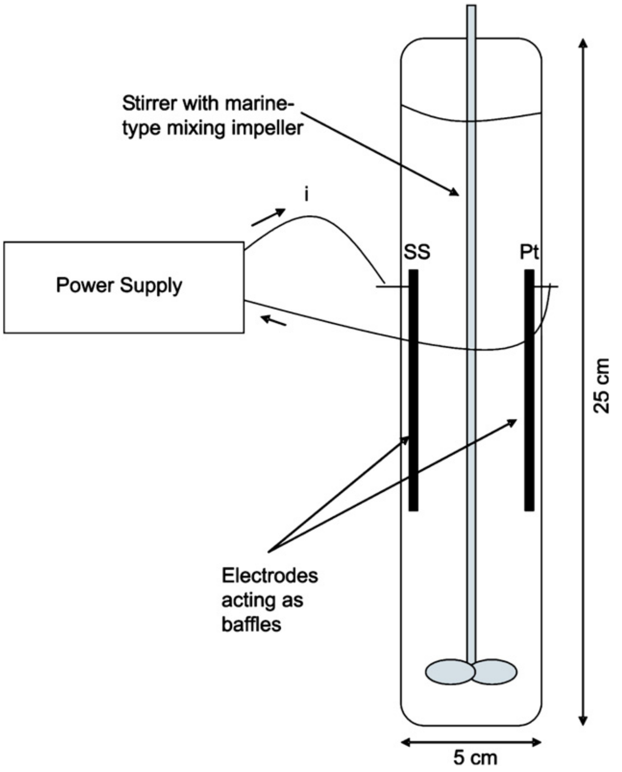

Fig. 1. Column-type cell with two electrodes (SS: stainless steel; Pt: platinum) and an axial stirrer marine-type mixing impeller. The stirrer speed was set at 800 rpm.

The ores used were Merensky reef and UG2 with grades in sulphur equal to 0.24 and 0.014, respectively. The collectors used were SIBX and Senkol 5 (in mixture), guar gum was used as the depressant and Dowfroth 200 as frother. The concentrations used in this work are in agreement with previous published literature dealing with the same ores [25–28]. SIBX, Senkol 5 and guargum were procured by Senmin (South Africa), while Dowfroth 200 was obtained from NASACO International LLC (Switzerland). High purity sodium hydroxide was used as a pH modifier to ensure enough solution conductivity.

Before assessing the flotation of the ores, the particle size was reduced by using a rotatory mill achieving the following particle size distributions: 100% −75 μm (90 min milling) and 75% −75 μm (70 min milling) for Merensky reef ore; while, 65% −75 μm (70 min) for UG2 ore.

The following aspects were considered when designing the cell:

i. The marine-type impeller is used as it produces the desired homogeneous solid suspension [29]. The axial movement is dissipated once the streamlines reach the level of electrodes. Radial movement of liquid is avoided since that may result in battery behaviour of the system where the products formed at the anode will be consumed at the cathode which is undesirable. Classic electrode arrangement used for example in electrowinning reduces the possibilities to stir the pulp avoiding particles settling and increasing the interactions between bubbles and particles. On other hand we allow the electrodes to reduce the turbulence mid-way up to the lip. In