Challenges in predicting the role of water chemistry in flotation through simulation with an emphasis on the influence of electrolytes

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ABSTRACT

As the mining industry is facing an increasing number of issues related to its fresh water consumption, a series of water-saving strategies are progressively being implemented in the processing plants, such as increasing the recirculation of process water. This recirculation is associated with a modification of the process water chemistry, which can be detrimental to the process performance, in particular flotation. This modification is, unfortunately, hardly predictable and often constitutes an obstacle to the implementation of the highly-needed water-saving strategies. However, a large amount of knowledge has been accumulated over the years to better understand how the process water chemistry can affect different parts of the flotation process, yet much of this knowledge still needs to be digitalized in a practical and suitable form to be of use in mineral processing simulators. Such digitalization requires the linking of water properties to the flotation process parameters, in particular the flotation kinetics of the different particles present in the system. This paper discusses a variety of mechanisms through which electrolytes can modify the flotation performance, and how those mechanisms translate into a modification of the flotation kinetics when this link can be made. A series of missing relationships needed for the knowledge digitalization in mineral processing simulators are being highlighted throughout this paper, hence addressing the challenge of predicting the role of electrolytes on the flotation plant performance through simulation.

1. Introduction

The mining industry is facing a series of potential issues related to its fresh water consumption, such as fresh water scarcity (Rijsberman, 2006; World Bank Group, 2016), competition for water with the local populations (Castro and Laskowski, 2011), and increasingly stringent water release policies (Levay et al., 2001). As a result, fresh water is being progressively considered by the industry as a highly valuable resource and strategies are being implemented to reduce its consumption. Those strategies typically consist in increasing internal water recirculation or using unconventional water sources, such as sea or sewage waters (Liu et al., 2013; Schumann et al., 2003).

In mineral processing, water is being used as both a transport and a process medium. Its properties are, therefore, of great importance to all processes where it is involved. The flotation process, which exploits the physico-chemical properties of solid and liquid interfaces, is particularly affected by the extent of dissociation of water molecules and of other dissolved species, the adsorption of ions dissolved in water, their hydration, etc. (Rao, 2004a). As a result, increasing the recycling rate of process water or using alternative sources often leads to relevant

changes in the flotation performance, yet those changes are rarely known beforehand. Consequently, it is necessary to develop appropriate methods that can quantitatively predict how a modification of the process water chemistry will impact the efficiency of a whole flotation plant, thus allowing a smart implementation of the water-saving strategies.

To achieve this goal, mineral processing simulators are a particularly pertinent tool. Indeed, once the relationship between process water chemistry and the flotation performance is digitalized in a mineral processing simulator, it becomes a powerful decision-making tool for the plant engineer through scenario simulation. A possible use of such tool is schematically presented in Fig. 1, where the mineral processing simulator helps determining whether the currently used process water should be reused, discarded from the circuit, or undergo treatment before reuse based on the simulated performance of the flotation circuit (illustrated here with a grade – recovery curve), hence avoiding the rejection of potentially "process-friendly" water and helping reduce the fresh water consumption.

The digitalization of the water chemistry influence on the flotation performance is, however, a great challenge that needs to be addressed.
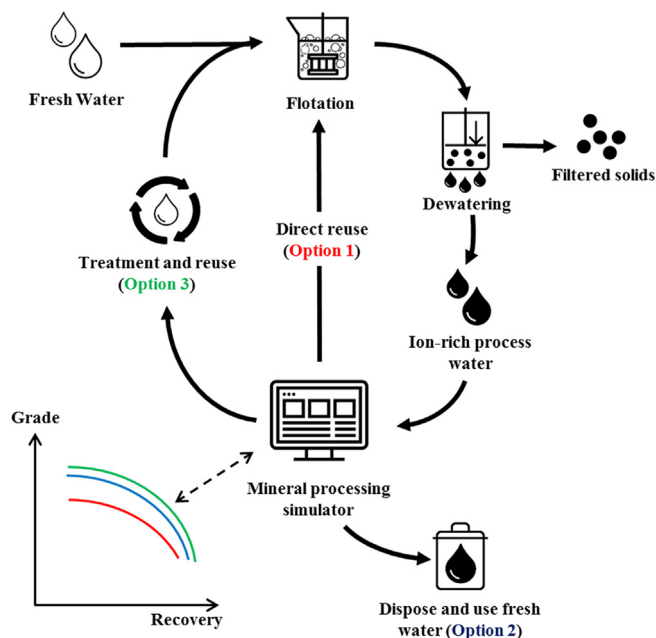

Fig. 1. Integration of a mineral processing simulator in the flotation circuit as decision-making tool.

In their current state, mineral processing simulators do not consider water properties for the simulation although a large amount of knowledge has been accumulated to better understand its role in flotation. Therefore, to digitalize this knowledge into mineral processing simulators, the influence of water chemistry on the flotation process first needs to be expressed through the flotation rate constant k, which is the main input parameter required for the simulation to be performed in flotation.

This paper thus aims at discussing various mechanisms through which electrolytes can affect the flotation performance, and how the effect of those mechanisms can be expressed as a function of the flotation rate constant. The influence of electrolytes on the water structure, the reagent properties, the bubble size, the mineral surface properties in general, and the froth stability are discussed separately to highlight the different levels at which those dissolved species can interfere with the flotation process. When available, the relationship between the discussed mechanisms and a modification of the flotation rate constant is brought forward, hence highlighting various missing links necessary to implement the current knowledge in mineral processing simulators.

2. Influence of electrolytes on water structure

The distinctive structural features of water are generally ascribed to hydrogen bonding considerations. Many solution properties, such as viscosity and solubility, are determined by the influence ions have on the short-range hydrogen bonding of water molecules (Hancer et al., 2001). The water structure is significantly altered by both the type and concentration of ions present in the aqueous phase. Based on their influence on the water structure, inorganic ions can be divided into two different groups (Hancer et al., 2001; Lukanov and Firoozabadi, 2014; Rao, 2004a; Weissenborn and Pugh, 1996):

- Structure-making ions (also called kosmotropes), which are small inorganic ions of high surface charge density (*e.g.* Na^+ and F^-), capable of holding enough water molecules around them to increase the overall amount of structured water. Those highly hydrated ions thus increase the viscosity of water (*e.g.* NaF in Fig. 2).
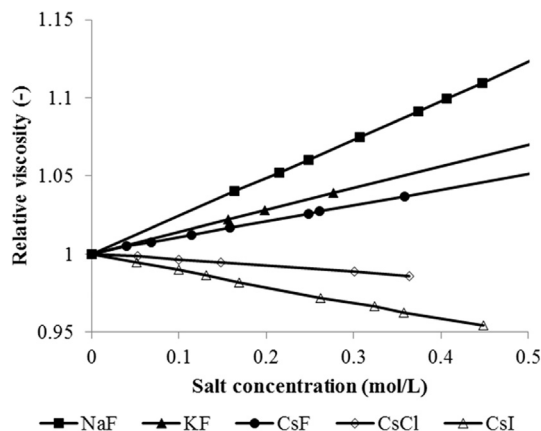- Structure-breaking ions (also called chaotropes), which are large

Fig. 2. Influence of several structure-making and structure-breaking electrolytes on water viscosity, based on data from Desnoyers and Perron (1972).

inorganic ions of low surface charge density (*e.g.* Cs^+ and I^-), have the opposite effect on water structure. Those weakly hydrated ions thus tend to increase the water fluidity (*e.g.* CsI in Fig. 2).

2.1. Impact on water viscosity

The overall effect of electrolytes on the water viscosity is determined by the net contribution of structure makers and structure breakers in the solution (Ozdemir et al., 2007; Rao, 2004a). In general, the variation of the relative viscosity η_r with the electrolyte concentration C can be represented by the Jones and Dole equation (Hancer et al., 2001; Ozdemir et al., 2007; Weissenborn and Pugh, 1996):

$$\eta_r = \frac{\eta}{\eta_w} = 1 + A_\eta C^{0.5} + B_\eta C \tag{1}$$

where η is the viscosity of the electrolyte solution and η_w the viscosity of pure water. The coefficient A_η represents the role of electrostatic forces, and the coefficient B_η is representative of the retardation of solution flow due to hydration of ions. Structure making (resp. structure breaking) ions take positive (resp. negative) values for B_η (Hancer et al., 2001; Weissenborn and Pugh, 1996).

The importance of the pulp viscosity on the flotation process is for example reflected by the role the hydrodynamic conditions play in the cell. In one of its simplest forms, the rate of collision Z_{PB} between bubbles and particles in a flotation cell can be expressed as a function of the number densities of bubbles and particles (N_B and N_P, respectively), the sum of bubble and particle radii (d_{PB}), the energy dissipation ε and the kinematic viscosity of the fluid ν as follow (Abrahamson, 1975):

$$Z_{PB} = \frac{4}{3} N_P N_B d_{PB}^3 \left(\frac{\varepsilon}{\nu} \right)^{1/2} \tag{2}$$

In other words, increasing the solution viscosity leads to a lower particle – bubble rate of collision, thus to lower flotation kinetics.

2.2. Impact on gas solubility in water

As the solvent action of water is related to the orientation and stability of the water dipoles, an increase in ionic concentration leads to an increased utilization of water molecules in the hydration of the dissolved ions (Bulatovic, 2007; Rao, 2004a), thus reducing the amount of water molecules available for dissolving gases. This effect is highlighted in Fig. 3 for oxygen in salt chloride solutions.

A decrease in gas solubility can play a major role in the flotation process, especially when dissolved gases (generally oxygen) influence the collector adsorption on the mineral surface. This effect was exemplified by Kuopanportti et al. (1997), who showed that the rate of