



Modelling effects of dissolved ions in process water on flotation performance

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ABSTRACT

The mining and mineral processing industries need water in all of their operations, from exploration, through mining and processing to closure. Flotation is the most affected by the quality of the process water in all of mineral beneficiation applications. Process water contains dissolved ions of almost all types depending on ore characteristics such as surface chemistry, mineralogy and surface oxidation. There is a general understanding about influence of individual ions on flotation performance in literature. However, it is crucial to demonstrate interactive effects of the major ions in a process water quantitatively using mathematical modelling to control the upper limits of ion contaminations. In this study the major ions affecting flotation performance of a complex Cu-Zn ore were determined to be Ca^{2+} , Cu^{2+} and $\text{S}_2\text{O}_3^{2-}$. An experimental design has been done by using Design Expert Software. The statistical experimental design allowed derivation of mathematical models expressing grade and recovery as a function of water chemistry. These models were used to estimate critical concentration of the dissolved ions for an efficient flotation process.

1. Introduction

Recycling of process water became a necessity in plants for a long time due to the water scarcity especially in arid areas and increase in the world population. Water is one of the main items that is essential for ore processing. It is important to understand the effect of water quality on plant performance, since most of the concentration processes use water as a media and the water quality has a direct effect on the process efficiency. In the literature, there are a number of research and review papers focused on effects of water quality and re-use of tailing water on flotation performance (Broman, 1980; Forsberg et al., 1985; Rao and Finch, 1989; Basilio et al., 1996; Levay et al., 2001; Liu et al., 1993, Liu et al., 2013). Recycled process water can be classified, treated and disposed selectively, and then returned to different sections of flotation operations according to its chemical composition and effect on mineral surface reactions. This method could enhance the efficiency, utilize the chemical components of wastewater, and significantly decrease the costs of the water treatment for the process plant.

The sources of recycle waters in mineral processing plants are the tailings dams, classification ponds, thickener overflows, dewatering and filtration units. In addition to residual reagents such as frothers, collectors, activators and depressants; colloidal materials (silicates, clays, precipitated metal hydroxides, etc.), ions of base metals, thiosalts, sulfide, sulfite, sulfate, chloride, magnesium, calcium, sodium and potassium are the typical contaminants in the recycle water (Liu et al.,

2013). In the internal reuse of water systems (i.e. circulation from thickener overflow), flotation reagents may not have enough time to decompose. This may result in a decrease in the plant's reagent usage (Forsberg and Hallin, 1989). However, in cases of selective flotation and pre-flotation of naturally floatable gangue minerals, accumulation of flotation reagents in process water may adversely affect the flotation performance.

Dissolution of minerals and reagent addition cause various compounds to accumulate, which increases the levels of total dissolved ions and solids in solution. The type and concentration of the contaminants may affect the flotation performance negatively (Slatter et al., 2009; Muzenda, 2010; Bıçak et al., 2012). For example, in a complex sulfide flotation plant, small amounts of copper may dissolve but the concentration may increase to detrimental level for flotation after recirculation of water. This is particularly important for process plants where selective flotation is important. Presence of heavy metal ions in process water could adversely affect flotation as they precipitate sparingly soluble hydroxides and metal xanthates (Rao and Finch, 1989). Many studies report the depression effect of the hydrolyzed calcium ions on sulphide flotation (Fuerstenau et al., 1985). Gypsum (CaSO_4) precipitation in the presence of sulphate ions is also common in sulphide flotation, particularly when lime is used as pH modifier. Precipitated gypsum usually results in poor selectivity and recovery (Grano et al., 1995) and also serious scaling problems in flotation cells, pipes, launders, etc.

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Recirculation of process water may cause formation of stable froths, hence measures need to be taken to ensure that a water leading to stable froth formation is not used. Cleaner circuits are sensitive to changes in froth properties since selectivity between sulfide particles and fine-size gangue mainly depends on the water content in the froth. When the froth is stable and has a high water content, selectivity tends to decrease (Forssberg et al., 1985).

As it was summarized in this section, there are a number of research papers in the literature focused on the influence of various ions accumulated in process water. Majority of these studies have focused on individual effects of these ions and mechanism of interactions between the ions and mineral surfaces. However, understanding combined effects of the accumulated ions and determination of their critical concentrations in process water are crucial for the efficiency of the flotation plant. Hence, in this study, combined effects of dissolved ions in process water on the flotation performance of a Cu-Zn ore from Çayeli Bakır İşletmeleri (CBI, Turkey) were investigated by using a statistical experimental design program to derive mathematical models of the relationship between these ions and flotation performance.

2. Experimental

The statistical experimental design was done by using Design Expert computer software. The list of experiments and their codes are given in Table 1. The experimental design was done at three level of concentrations for each ion to derive mathematical models. The upper and lower concentrations of ions are used from the previous studies performed as part of the same project (Bicak et al. 2012; Ozdemir et al., 2014). Synthetic water samples having different concentrations of Ca^{+2} , Cu^{+2} and $\text{S}_2\text{O}_3^{-2}$ ions were prepared by using $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, CaO , $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ and $\text{Na}_2\text{S}_2\text{O}_3$. CuSO_4 used as the source for Cu^{+2} , CaO and $\text{Ca}(\text{NO}_3)_2$ used as the source for Ca^{+2} and $\text{Na}_2\text{S}_2\text{O}_3$ used as the source for $\text{S}_2\text{O}_3^{-2}$ ion. The amount of each chemical required for a given water quality was calculated and the chemicals were introduced in the following order to prevent precipitation of the ions; $\text{Na}_2\text{S}_2\text{O}_3$, CuSO_4 , $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, CaO . De-ionized water was used for preparation of synthetic water samples. Chemical specification of the Cayeli Cu-

Table 1

Experimental design testing the three independent parameters at three concentrations.

Run	Cu (ppm)	Ca (ppm)	S_2O_3 (ppm)
TB101	0	4300	700
TB102	0	25	0
TB103	0	8600	700
TB104	8	8600	700
TB105	0	4300	0
TB106	8	8600	0
TB107	8	4300	1400
TB108	8	25	1400
TB109	0	8600	1400
TB110	0	8600	0
TB111	8	8600	1400
TB112	4	25	700
TB113	8	25	0
TB114	4	8600	1400
TB115	4	25	0
TB116	8	25	700
TB117	0	25	1400
TB118	4	4300	1400
TB119	8	4300	0
TB120	0	4300	1400
TB121	4	8600	0
TB122	0	25	700
TB123	4	4300	700
TB124	4	25	1400
TB125	4	4300	0
TB126	4	8600	700
TB127	8	4300	700

Table 2

Standart deviations of the studied parameters.

	Water Rec %	Mass Pull %	Gcu %	GZn %	Rcu %	RZn %	RPy %
St Dev	0.73	0.95	0.86	1.02	0.97	3.76	0.84

Zn flotation plant process water was the benchmark for selection the range of concentration for each ion in this study. The upper, intermediate and lower concentrations were selected to determine the critical concentrations of ions for an effective flotation operation. The lower and particularly the upper values in the range may not be observed in practice, but chosen to derive mathematical models predicting influence of water chemistry for a large range of ion concentrations.

Repeat tests were performed in the scope of the test program (four of flotation tests were done in triplicate) to ensure reproducibility of the tests. The standart deviations of these tests are given in the table below (Table 2). However, these were not included in the manuscript to prevent confusion about the experimental codes and number of tests but Design Expert program used these repeat tests in the experimental design for the statistical analysis, and only average values were given in the results section of this manuscript.

A complex Cu-Zn sulfide ore from Çayeli Region in Turkey was used in laboratory scale batch flotation tests. The ore contains 2.99% Cu, 6.13% Zn, 0.31% Pb and 25.90% Fe. According to the mineralogical analysis, the ore contains 7% chalcopryrite, 0.4% bornite, 10% sphalerite, 54% pyrite, 0.4% galena and 28% other minerals. The main copper mineral is chalcopryrite associated with sphalerite, pyrite and minor amounts of galena. Cu and Zn assays were used to evaluate flotation behaviour of chalcopryrite and sphalerite. Mineralogical analysis of the ore showed that more than 90% of total iron was distributed between chalcopryrite and pyrite, and sphalerite did not contain iron. Therefore, pyrite content was calculated using total iron assay after subtracting the iron coming from chalcopryrite.

The ore sample was crushed down to 2 mm using a roll crusher. The sample was divided into representative sub-samples (1.2 kg) for flotation experiments. Then, these samples were placed into vacuum bags and stored in a freezer to avoid surface oxidation of the sulfide minerals. In flotation experiments, the ore was ground to 80 μ m passing finer than 38 μ m with a mild steel ball mill. The flotation tests were performed at 35% pulp density with a 2.5 L bottom driven Magotteaux flotation cell. The impeller rotation speed and air flow rate were set at 850 rpm and 5 L/min respectively. Magotteaux bottom driven flotation machine with Plexiglas cell was used in the flotation tests. The froth height was kept constant at 1 cm in all of the tests. The cell is a transparent cell and the froth-pulp interface can be easily seen and controlled by make-up water addition during the tests. The synthetic water was used as make-up water and the chemical composition of the make-up water and the test water was the same. Therefore, the chemical composition of the water was maintained throughout the test.

During grinding 2 g of lime was added and further lime addition has been done in the cell to adjust pH to 11.5. Mixture of Aero 3418A (20 g/t) and SIPX (10 g/t) were used as collectors, and MIBC (10 g/t) as frother. Type and concentration of the reagents used in the batch flotation tests were selected based on the reagent scheme used in the CBI flotation plant. Froth concentrates were taken after 1, 3 and 8 min, respectively. The mass pull and water recovery data were calculated for each concentrate. Feed, concentrate and tail samples were filtered, dried and analyzed for Cu, Fe and Zn by using AAS (Atomic Absorption Spectrometry).

In order to determine effects of grinding and flotation steps on water chemistry, pulp samples of 50 cc volume were taken in selected experiments after grinding as feed water and after flotation as tail water. The synthetic water was also analyzed to control precipitation and/or dissolution of ions. The samples were filtered and the filtrate was split into two subsamples. The first subsample was immediately analyzed by

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