

Article

Sulphate Removal from Flotation Process Water Using Ion-Exchange Resin Column System

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Abstract: Water chemistry is one of the most important parameters affecting flotation performance. Various types of ions can dissolve and accumulate in process water depending on ore mineralogy, reagent scheme, grinding medium and chemistry of mine site water. Sulfur-based ions (sulfate, thiosulfate, polythionate) are generally observed in flotation of sulfide ores. High concentrations of these ions may reduce efficiency of the flotation process, causing scale problems. Removal of these ions from process water often requires complex water treatment plants with high capital and operating costs. In this study, partial cleaning of water was investigated as an alternative approach for decreasing high sulphate concentrations of 3000–3800 mg/L down to 1000–1500 mg/L, an acceptable concentration for most sulfide ore flotation plants, by using an ion-exchange resin. For this purpose, detailed adsorption tests were performed using a laboratory-scale column system to determine the most suitable type of resin for adsorption of sulfate and thiosalts, kinetics of adsorption and regeneration of the resins. A strong base anion ion exchange resin (Selion SBA2000) was used in the experiments. The findings from the laboratory scale studies were validated in a Cu-Pb-Zn Flotation Plant in an Iberian mine using a larger scale of column set-up. The results showed that 60–70% of sulphates could be successfully removed from process water. Adsorption capacity of the resin was determined as 80.3 mg SO₄/g resin. Concentrations of thiosalts and polythionates were also reduced to nearly zero value from 500 mg/L and 1000 mg/L, respectively. Flowrate of water had a significant effect on adsorption performance. The resin could be regenerated successfully using 2% (w/v) NaOH solution and used multiple times for water treatment.

Keywords: ion-exchange resin; sulphate removal; column system; process water treatment

1. Introduction

Conservation and management of freshwater resources is one of the major challenges of this century. In mining, controlling the quantity and quality of water intake and water discharge have become even more critical due to the depletion of freshwater resources and environmental regulations. Most ore preparation processes require a high amount of water use, which reveals the need to implement the closed water loop strategy. Flotation is one of the complex processes affected by many variables such as chemistry, operational and equipment parameters. Water management strategy such as recirculation of water from tailings and use of multiple water resources with some freshwater are becoming more important in most of the flotation plants. Since water chemistry has a significant impact on the efficiency of processes, water is regarded as an important variable, and therefore it is generally recirculated in the plant with some freshwater as makeup water.

Water chemistry may be highly affected by the dissolution and oxidation of ore, the mineral variety, reagent scheme, grinding media, environmental conditions and quality of different water

resources such as recirculated from tailings, pond, seepage, third-party and others [1,2]. Particularly in flotation of sulphide minerals, oxidation and dissolution of ore may change the pulp chemistry significantly due to the dissolved metal and sulphide ions. Bıçak et al. [3] and Öztürk et al. [4] reported that these ions can be found in the pulp, mostly in the form of sulphate and thiosulphate, which both have noteworthy implications on froth stability and surface chemistry of the minerals. Thiosalts are known as the products of oxidation of sulphide minerals and occur as sulfoxyl anions like thiosulfate ($\text{S}_2\text{O}_3^{2-}$), polythionates ($\text{Sn}(\text{SO}_3)_2$) and sulfite (SO_3^{2-}). These metastable sulfoxyl anions are produced as a result of galvanic reactions between grinding medium and minerals in the presence of oxygen in the mill. They may be oxidized by oxygen and generate proton acidity, resulting in a decrease in pH and an increase in dissolution of minerals [5–7]. High concentrations of thiosalts may slow down the sulphidization process of an oxidized Cu-Co ore in case of reusing the process water [8] and have depression effect on sulphide minerals in a Cu-Pb-Zn ore [4]. It is reported that thiosalts and dissolved metal ions also influenced the froth stability. Therefore, effects of sulfur-based ions on flotation performance should be decoupled using assessment based on true flotation and entrainment recovery mechanisms [3,9]. Recirculated streams (like cyclone underflow, scavenger tails, thickener overflow, etc.) and regrinding operations in the circuits may cause high levels of dissolved species like total dissolved solids, sodium, calcium, sulphate, magnesium ions, etc. Such an increase in the ionic strength of the pulp may result in an increase in froth stability, mass pull and water recovery [10]. The concentration levels of these components may also be raised by reagent addition and recirculated organics such as depressants, dispersants and other reagents in the circuit [11]. Calcium is one of the important species that is mostly cited for the source of precipitation, and its concentration in process water may increase due to dissolution of any calcium-bearing gangue mineral and/or to lime addition for pH adjustment. It is known that flotation of sulphide minerals can lead to an increase in sulphate concentration in process water. When these two components are in high levels, gypsum precipitation possibly occurs. Such precipitation may have high potential of a scaling problem in pipes, cells and/or any other units in long-term and also may lead to coagulation on the mineral surfaces reducing the flotation rate [12,13].

Accordingly, developing efficient and sustainable treatment methods for the removal of sulphate is a need to meet the process requirements and environmental restrictions. Biological degradation or adsorption, membrane filtration (reverse osmosis), adsorption and/or ion exchange resins and chemical precipitation are the main processes used for treating sulphate-ion-bearing water streams [14,15]. Dissolved air flotation in which sulphate ions are precipitated using some certain flocculants were also reported to have the potential for the treatment of sulphate-loaded industrial wastewaters [16].

The selective ion exchange resins are widely used both in batch and column tests for removal of different components like nitrate [17–19], boron [20,21], sulphide [22], etc. for different purposes. It was reported that recovering lithium from desalination brines [23] and iron from winery effluent [24] were also possible with ion exchange resins. The use of ion-exchange resins is becoming one of the most important approaches for separating platinum group metals such as platinum, palladium and rhodium from solutions instead of using various extraction methods [25]. For removal of heavy metals such as Hg, Cd and Pb from other co-existing ions in acid mine drainage solution, strong anion-exchange resin was used as a synthesis with metal salts [26].

Selectivity of the common anion-exchange resin is in order of $\text{SO}_4^{2-} > \text{NO}_3^- > \text{HCO}_3^- > \text{Cl}^-$. Strong and weak base anion-ion exchange resins can be used for sulphate removal; however, it is indicated that strong base resins have higher adsorption capacity of sulfate and do not require pH adjustment compared to weak base resins [26]. The selectivity and success of an ion exchange process is highly related to the accurate control of the recycled regeneration solution. The importance of the regeneration solution composition in an anion exchange resin column process in the presence of some competing ions was shown by Duan et al. [27] for selective nitrate removal from groundwater.

In flotation plants treating massive sulfide ores, sulphate content of the process water could be as high as 3000–4000 mg/L and may have some negative implications on flotation efficiency. The process

water used in flotation plants is usually prepared by mixing the water streams circulating from tailings, from other sources in the mine and freshwater in certain proportions. Complete treatment of the process water can be costly depending on type and concentration of ions. It is also not practical for large-scale operations, as it requires large capacity water treatment facilities. Therefore, partial cleaning of recirculated water would be preferred over a complete water treatment approach. In this study, a partial water cleaning approach was tested for removal of sulfur-based anions, mostly sulphate, by using a strong base ion-exchange resin. Laboratory scale column set-up was used for selection of the optimum resin type, kinetics of adsorption and regeneration of the resins. The findings from laboratory-scale experiments were tested and confirmed in a flotation plant by using a large-scale column set-up. The validation tests were performed in a Cu-Pb-Zn Flotation Plant of an Iberian Mine using Process Water and Thickener Overflow streams, which are the major water streams for the process plant.

2. Materials and Methods

2.1. Ion Exchange Resin

In the preliminary tests, adsorption capacity and efficiency of weak and strong base types of resins were tested. The strong base type of resin was found to be more suitable for sulphate removal [28]. Technical grade resins were used in the tests because they are low in cost and suitable for industrial-scale applications. After scanning various types of commercial resins, Selion SBA 2000 resin with a functional group of Type II quaternary ammonium was selected based on its adsorption capacity, grade, commercial availability and price. It is a gel-type, strong basic, Type II anion resin generally preferred for demineralization of aqueous solutions and has much better initial exchange capacity and regeneration efficiency compared to Type I. The basic features and specifications of the resin is summarized in Table 1.

Table 1. Basic features and specifications of the resin [29].

Commercial Product Code	Selion SBA 2000
Matrix	Crosslinked Polystyrene divinylbenzene (DVB)
Functional Group	Type II Quaternary Ammonium
Appearance	Spherical beads
Particle Size Range	0.315–1.25 mm
Type	Anion Resin—Demineralization High Efficiency
Shipping Form	Cl [−]
Moisture Content	45–51% (Cl [−] form)
Bulk Density	680–750 g/L
Specific Gravity	1.07–1.12
Whole Beads	≥95%
Total Exchange Capacity	≥1.30 eq/L (min.)
Uniformity Coefficient	≤1.6 (max.)
Max. Operating Temperature	35–40 °C (OH [−] form) 85 °C (Cl [−] form)

2.2. Column Systems

Two ion exchange resin column experimental set-ups were designed for laboratory (Figure 1a) and plant site applications (Figure 1b). The laboratory-scale plexiglass column was filled with 310 g of resin, which filled 20 cm middle section, and the water was introduced from the bottom of the column [30]. Large-scale tests were performed using two water streams from Cu-Pb-Zn Flotation Plant of an Iberian mine. The column system was designed to serve water from both the top and bottom of the columns and also to operate the two columns in parallel or in series for adsorption and regeneration processes. Dimensions of the large-scale columns were 1 m height and 5 cm diameter with a resin depth of 80 cm. It was possible to fill up each column with approximately 1.3 kg of resin.

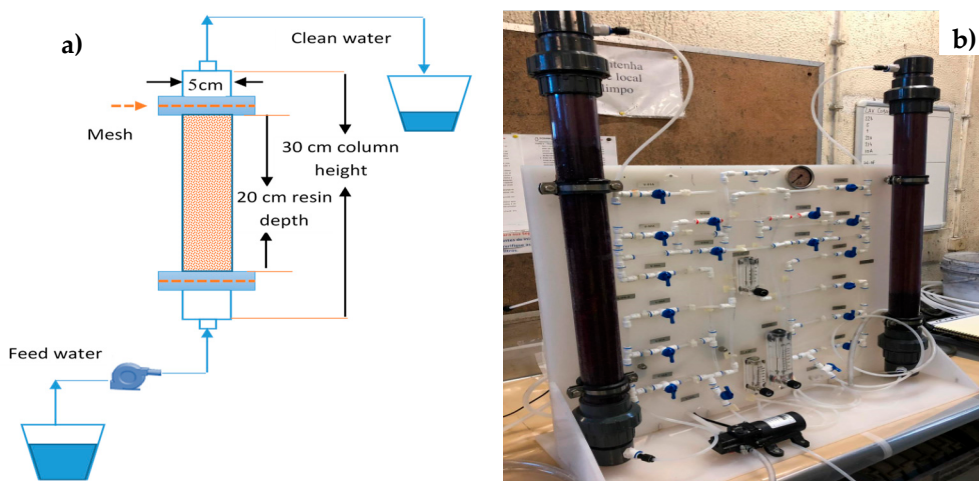


Figure 1. The column systems used in the (a) small laboratory-scale and (b) large-scale experiments used in the plant.

2.3. Conversion to Ionic Forms of Anion Resin

The resin has originally Cl^- active site for ion exchange reactions (Table 1). It was converted to OH^- form for the experimental work because excess Cl^- ions could be detrimental to both flotation performance and mechanical maintenance of the plant due to its high corrosive characteristics. Surface conversion of the resin was performed at four stages using 4% *w/v* NaOH solution. Figure 2 shows that Cl^- concentration in the resin decreased significantly after 2 hours of treatment, indicating almost complete conversion from Cl^- to OH^- form.

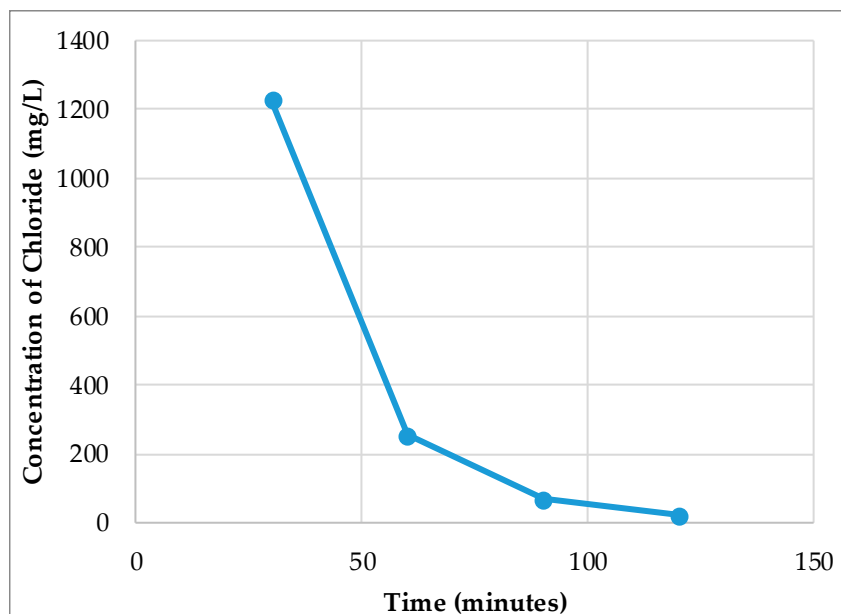


Figure 2. Conversion of Selion SBA 2000 resin from Cl^- to OH^- form.

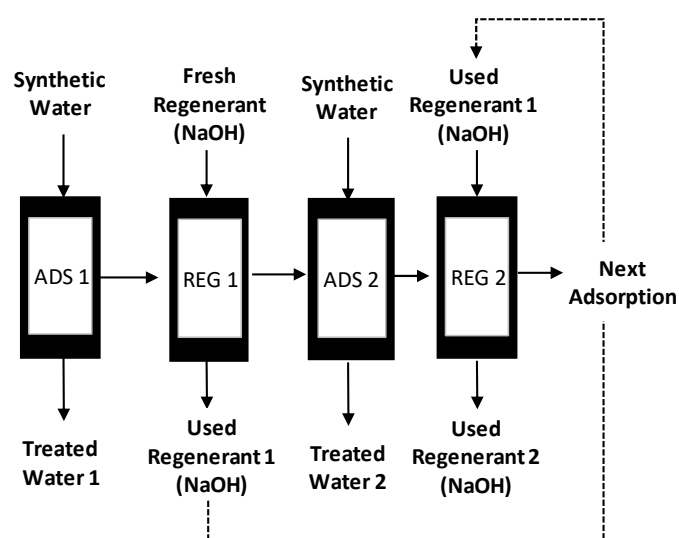
2.4. Adsorption and Regeneration Tests

Synthetic water samples simulating process plant water were prepared by dissolving a certain amount of Na_2SO_4 , $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$, $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ and $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ in de-ionized water. Average chemical composition of a typical synthetic water composition used in the experiments is given in Table 2.

Table 2. Concentration of ions in synthetic water used in laboratory scale adsorption tests.

Sulfate (SO_4^{2-}) mg/L	Thiosulfate ($\text{S}_2\text{O}_3^{2-}$) mg/L	Chloride (Cl^-) mg/L	Nitrate (NO_3^-) mg/L
3500	288	870	593

Adsorption tests were performed with the synthetic water using the laboratory-scale column at a service flowrate of 4.5 L/h. Adsorption (ADS 1, ADS 2, ...) and regeneration (REG 1, REG 2, ...) experiments are shown schematically in Figure 3. Sulphate, thiosulphate, nitrate and chloride concentrations were monitored by taking sub-samples at different time intervals during the adsorption tests. Concentration of these anions was measured using an Ion Chromatography (Dionex Chromeleon ICS-3000, ThermoFisher Scientific, Waltham, MA, USA) for each water sample. Following the adsorption stage, the resin was regenerated using 4% w/v NaOH solution. The same regeneration solution was used after 2nd adsorption and 3rd adsorption stages to determine its regeneration capacity. Effects of volumetric flowrate on adsorption rate and capacity were also investigated (Figure 3).

**Figure 3.** Schematic view of adsorption and regeneration experiments.

In the plant scale tests, adsorption and regeneration tests were performed on two different water streams having different chemical composition. The adsorption and regeneration flowrates were adjusted to 30 L/h and 15 L/h, respectively. In the regeneration stage, 2% w/v NaOH was used as regenerant solution. Incremental water samples were taken during adsorption and regeneration stages to determine kinetics of both processes. All water samples were analyzed for sulphate, thiosulphate and polythionates.

3. Results and Discussion

3.1. Laboratory Scale Studies

Adsorption tests were conducted using the synthetic water, which has the typical ionic concentrations presented in Table 2. The kinetic adsorption tests were performed to determine the rate of adsorption of different ions and volume of water that can be treated per unit weight of resin. The uptake capacity of the resin (Q_e) is generally defined by this equation:

$$Q_e = \frac{V(C_0 - C_e)}{W} \quad (1)$$

where C_0 and C_e are the concentrations (mg/L) of the sulphate in the solution at initial and equilibrium, respectively; W is the mass of resin (g) and V is the volume of the solution (L). The ion exchange reaction between sulphate ions and the resin can be shown by following expression:



The adsorption data were collected in a total time of 90 min. Figure 3 shows the concentration of residual sulphate, thiosulphate, chloride and nitrate ions as a function of adsorption time for the three stages of successive adsorption tests. The results of Adsorption 1 show that in the first 20 min, adsorption process took place, almost all ions were held by the resin; hence, very minor concentrations of the ions were measured in the residual solution. At 45–50 min of adsorption time, nearly 70% of the sulphate was adsorbed. The residual sulphate concentration reached to its original level at the end of adsorption tests, indicating complete replacement of OH^- ions on the resin by the contaminating ions. The resin was regenerated by using 4% *w/v* NaOH solution and used in Adsorption 2 experiment. The same procedure was applied for Adsorption 3 using the same NaOH solution for regeneration of the resin. In Adsorption 3, contamination of the resin started after 50 min and adsorption capacity was measured as 63% at that time. In addition to the sulphate, the other ions were also successfully adsorbed by the resin, particularly the thiosulphates, which were completely removed from the water.

The purpose of water treatment by ion exchange resins was partial cleaning of process water and reducing the concentration of harmful ions for the flotation process to acceptable levels. This concentration was determined as <1000–1500 ppm for sulfate according to laboratory scale flotation tests and plant performance data [4]. Figure 4 shows that the target ion concentration can be achieved in 45–50 min, which means 3.38 L of process water can be treated with 310 g resin (11 L water per 1 kg resin), and adsorption capacity of the resin for this particular example was calculated as 80.3 mg SO_4/g of resin.

The sulphate adsorption data of the three adsorption experiments were plotted in the form of breakthrough curves with respect to the volume of treated water for sulphate ion, which was the target ion for water treatment in this study (Figure 5). The breakpoint was found to be approximately 2.25 L for the three experiments. The adsorption was completed at 7 L for Adsorption 2 and Adsorption 3 experiments. The curve of Adsorption 1 was different, and C/C_0 stabilized at about 0.8, which could be due to chemical analysis of the water samples taken in the final stages of the experiment.

After each adsorption stage, the resin was regenerated to restore the exhausted resin back to its hydroxide form. NaOH was used as the source of hydroxide ions. The sulfur-based ions adsorbed by the resin were replaced by OH^- ions through an ion exchange reaction. Figure 6 shows regeneration performance based on desorption of sulfate ion from the resin. The same regenerant was used to demonstrate use of the same solution several times. The results show that the resin was completely regenerated after 45 min in the first and second regeneration stages. Performance of the second regeneration was similar to the first stage; however, in the third stage, desorption rate and concentration decreased substantially, because the regenerant reached an almost saturated concentration of sulfate ions after second regeneration. In order to use the same regenerant continuously, the sulfate ions should be removed from the solution by precipitation and/or extra NaOH should be introduced to the solution.

Interaction between resin and ions in water determines the efficiency of water treatment. Efficiency of interaction changes as a function of residence time (adsorption time), amount of resin (i.e., surface area for ion exchange reaction). For a constant quantity of resin, the volumetric flowrate of water determines the residence time in the column. The flowrate of 4.5 L/h was used in the previous tests and accepted as a reference to evaluate the effects of volumetric flowrate of water on the efficiency of adsorption. The flowrate was increased to 9.8 L/h and 16.8 L/h. Figure 7 shows residual sulfate concentration as a function of adsorption time for three different flowrates. The results show that the residual sulfate ion concentration was very high even in the initial stages of adsorption in the tests with high flowrate. This was attributed to insufficient contact time between the resin and water components.

These findings may be explained by the fact that a slow flowrate through the column facilitates the reaching of ion exchange sites in the resin with targeted sulphate ions [31]. Therefore, it is concluded that the service flowrate of the water has a significant effect on adsorption, and it should be optimized based on the target anion concentration in the water.

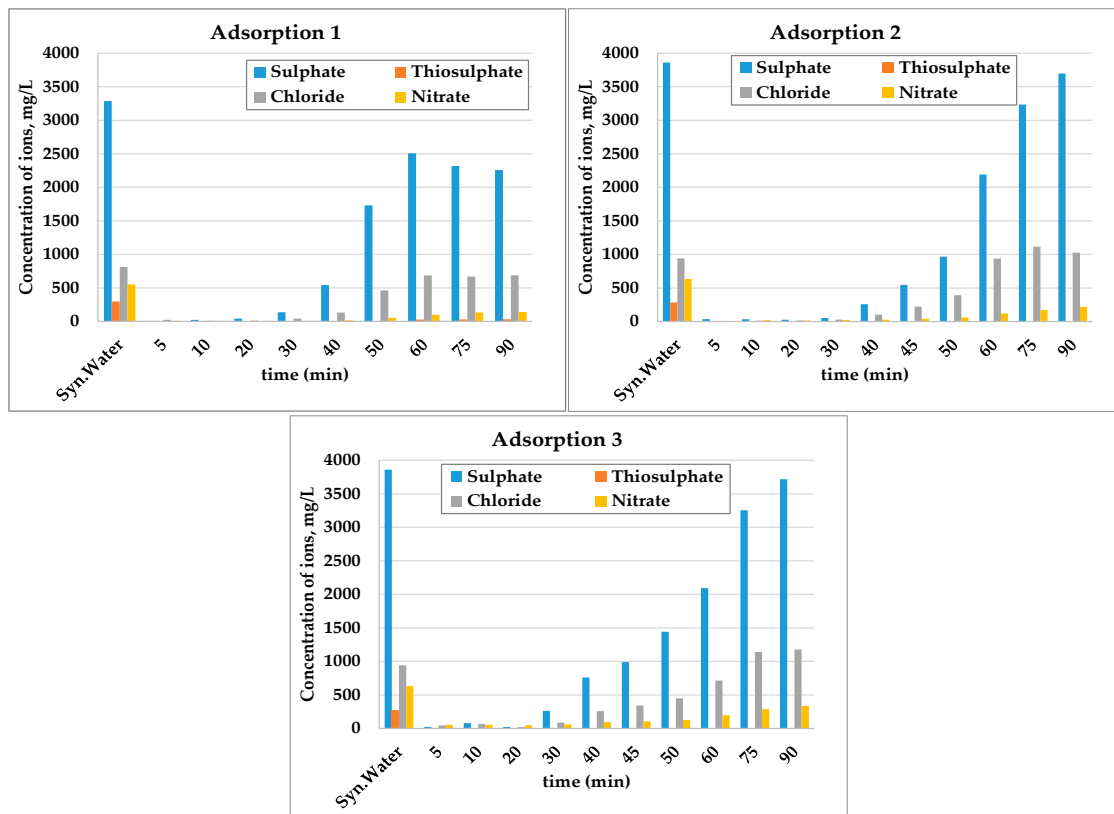


Figure 4. Residual anion concentrations in adsorption stages.

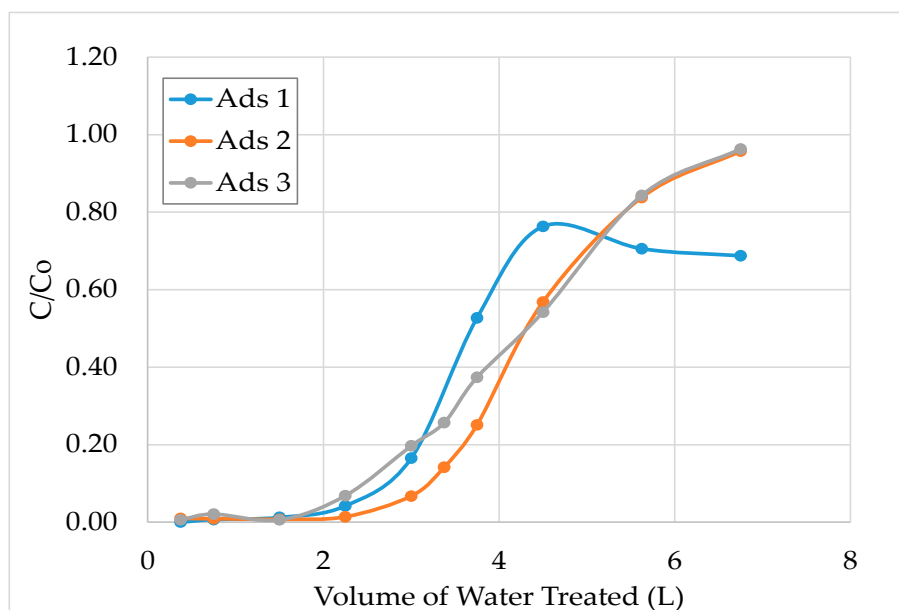


Figure 5. Breakthrough curves of the three adsorption experiments for sulphate ion.

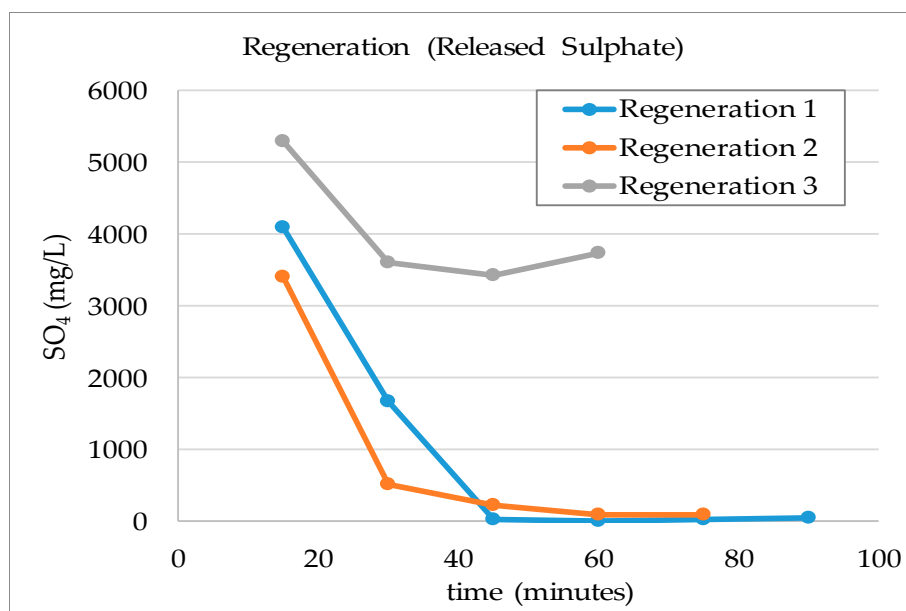


Figure 6. Desorption of sulphate ions from the resin at regeneration stage.

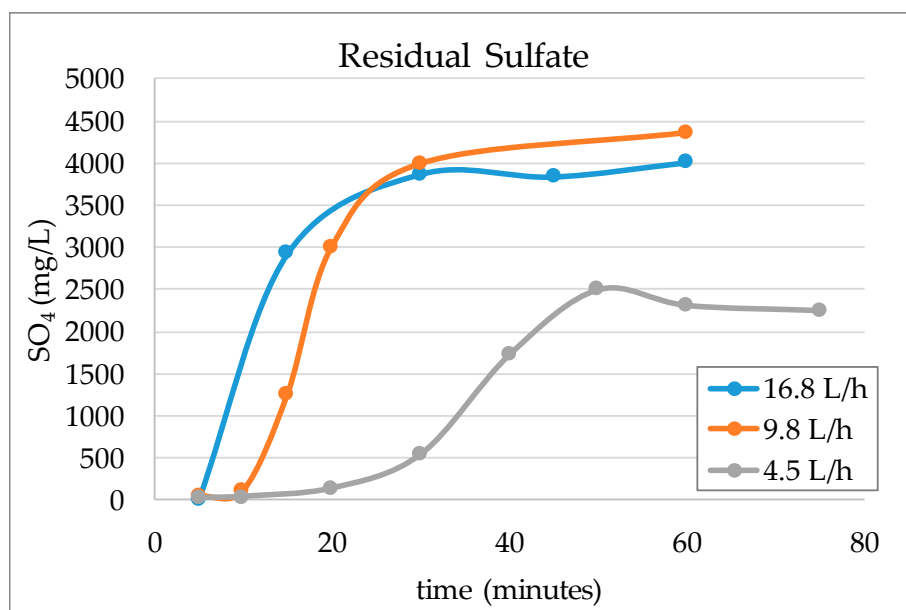


Figure 7. Effect of different water flowrates on adsorption.

In this methodology, the excess ions are adsorbed by the resin, and then the loaded resins should be regenerated for multiple use. The regeneration solution, which is essentially a NaOH solution of 2–4% concentration, should be reused multiple times to eliminate/minimize wastewater production. A series of batch adsorption/desorption/regeneration tests were conducted to demonstrate the limits for reuse of the same regeneration solution. Figure 8 shows the amount of adsorbed ions from the synthetic water in eight adsorption stages. The results show that not only the sulphate ions, but chloride, nitrate and thiosulphates were also effectively adsorbed. After each adsorption stage, the resins were treated in a 4% (*w/v*) NaOH solution for regeneration of the resins, and the same solution was used until adsorption stage 8 (Ads.8). First regeneration stage (Reg.1) in Figure 9 corresponds to regeneration of the resin used in adsorption stage 1 (Ads.1) in Figure 8. The results show that the adsorption efficiency of the resin was similar in the first three stages and decreased gradually starting

from adsorption stage 4. Regeneration efficiency decreased at this stage because the ion concentration of the regeneration solutions reached almost the saturation level and lost the ion exchange capability. However, after adsorption stage 7, the addition of 4% (*w/v*) fresh NaOH solution to the regeneration solution restored its regeneration capacity. The resin regenerated at this stage (Reg.8) could effectively be used again for water treatment. These results showed that the same regeneration solution could be used multiple times by adjusting the equilibrium between contaminating ions and hydroxide ions, in favour of hydroxyl ions, by fresh NaOH addition. In addition to that, removal of sulphate and the other ions from the regeneration solution could be done by precipitation and chemical saturation of gypsum, barite or ettringite [14].

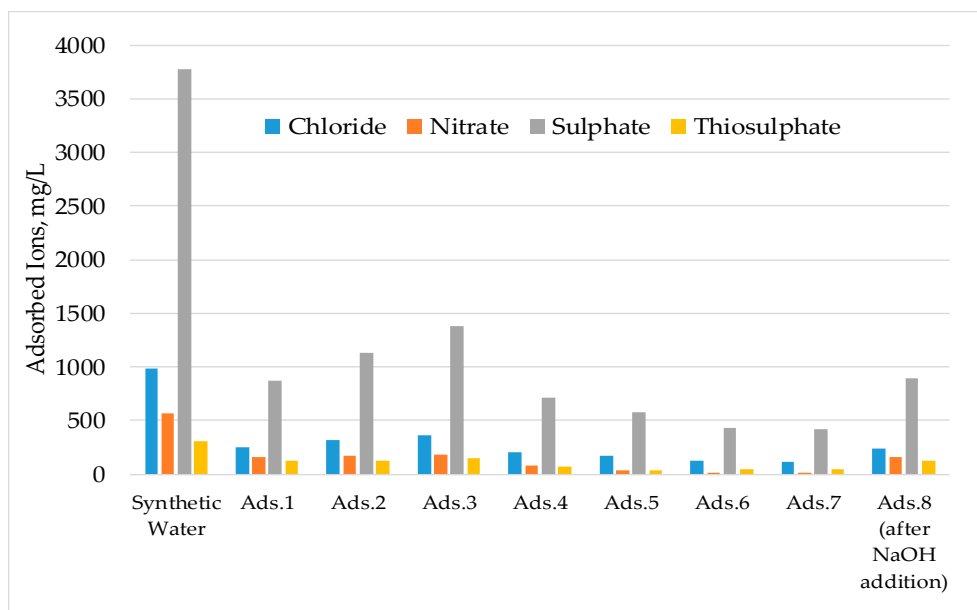


Figure 8. Adsorption capacity of the regenerated resin.

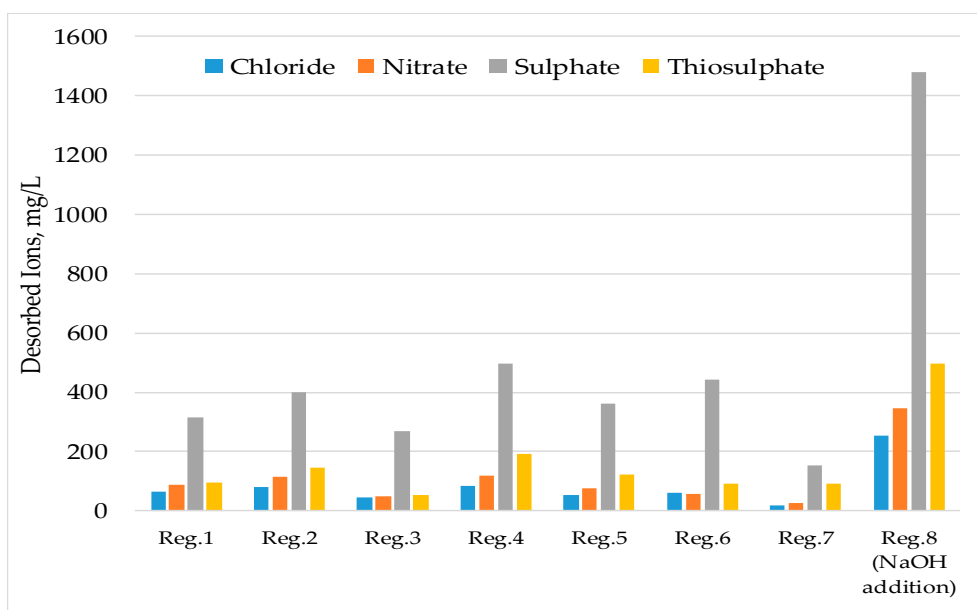


Figure 9. Regeneration of the resin using the same regenerant (4% *w/v* NaOH solution).

3.2. Validation Tests on Plant Site

The objectives of the validation experiments were to verify the laboratory results and test efficiency of resin by using different quality of water streams from flotation plant feed (Process Water) and final tailing (Thickener Overflow (O/F)). Figure 10 shows the residual sulphate concentration at different adsorption stages of the Process Water stream.

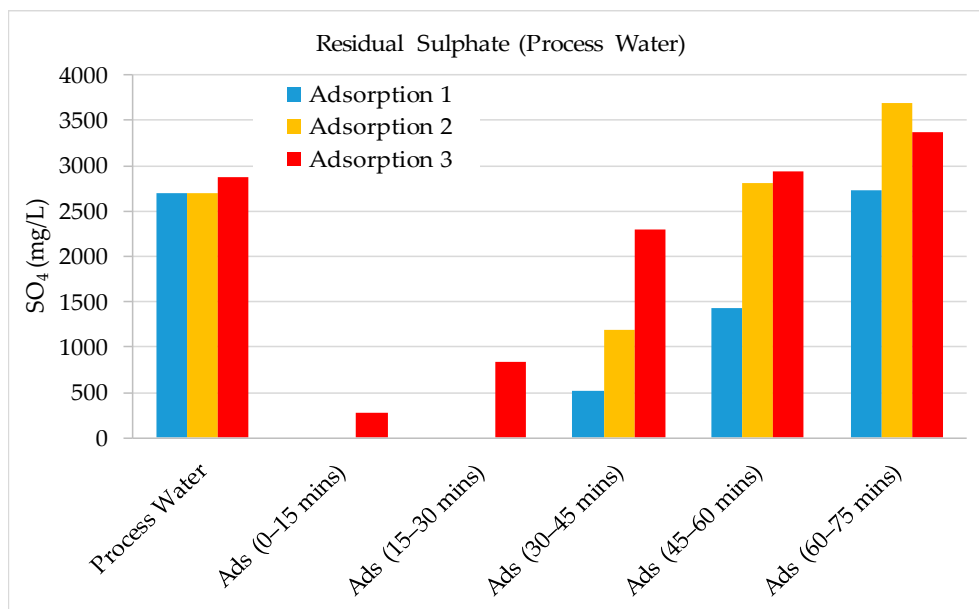


Figure 10. Concentration of residual sulphate from three adsorption experiments conducted on the Process Water.

The sulphate concentration in the Process Water was measured as over 2500 mg/L for each adsorption experiment. The target sulphate concentration for a partial cleaning (1000–1500 mg/L) was attained in 60 min in the first adsorption experiment in 45 min and 30 min for the second and third adsorption experiments, respectively. The adsorption is a continuous process; the sulphate ions accumulate in time, and after a certain adsorption time, the resin was not able to hold all ions due to high loading. As a result of that, the residual sulphate ion concentration increased as a function of time, and after a critical time, the ion exchange reaction occurred in reverse direction, releasing the previously adsorbed ions back into solution. This was observed in 60–75 min in the second and third adsorption experiments.

Figure 11 shows the breakthrough curves of sulphate for the three adsorption experiments. The breakthrough volume and saturation volume were different in the three adsorption experiments. The breakthrough volume was approx. 15 L for Adsorption 1 and Adsorption 2 experiments and decreased to about 5 L in Adsorption 3. The volumes required to reach saturation were 37.5 L for Adsorption 1 and 30 L for Adsorption 2 and Adsorption 3 experiments. The fresh resin performed better, and differences in adsorption performance of the same resin in these experiments were attributed to the performance of the regeneration step as discussed below.

After each adsorption stage, the resin was regenerated using NaOH solution (2% w/v) for 45 min. NaOH concentration was reduced from 4% w/v applied in laboratory experiments to 2% w/v in the plant tests. For the second and the third stages of regeneration, the same NaOH solution was used to demonstrate multiple use of regeneration solution. Majority of sulphate was released in the first 15 min, and the resin was almost completely regenerated after 45 min in the first stage (Figure 12). Performance of the second and third regeneration stages decreased when the same solution was used. This was compatible with the laboratory-scale test results given in Figures 6 and 9. The same regenerant could be used up to a certain extent due to depletion of hydroxide ions available for ion exchange. The

results show that extra NaOH solution should be added for an effective regeneration in the second and third regeneration stages.

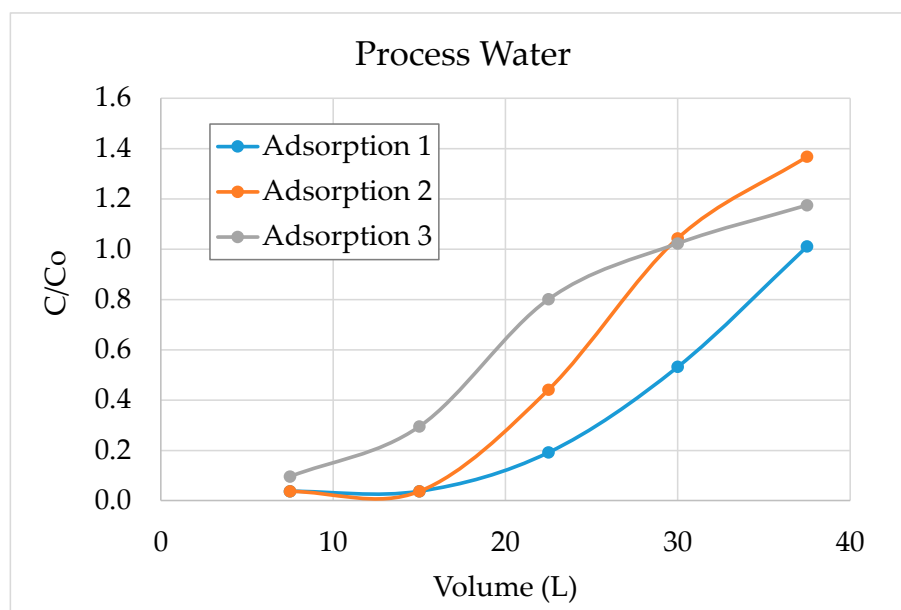


Figure 11. Breakthrough curves of the sulfate ion for the three adsorption experiments conducted on the Process Water.

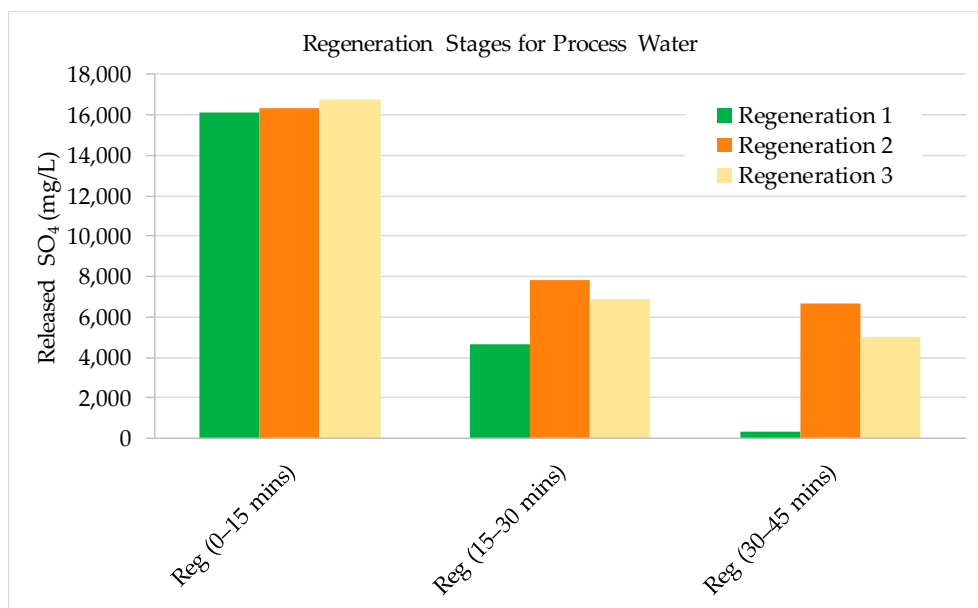


Figure 12. Desorption of sulphate ions from the resin in the regeneration stages applied after adsorption experiments on the Process Water.

Similar adsorption/regeneration tests were performed using the water from Thickener Overflow (O/F) stream. Adsorption and regeneration trends were similar for both water streams. After each adsorption stage, the regeneration process was applied using the same regenerant in all stages. Figure 13 shows the breakthrough curves of the sulphate ion for the three adsorption experiments conducted on the Thickener O/F stream. Performance of Adsorption 1 experiment was better than the following adsorption experiments due to use of fresh resin. The breakthrough volume and saturation volume

decreased gradually in Adsorption 2 and Adsorption 3 experiments, where the regenerated resin was used.

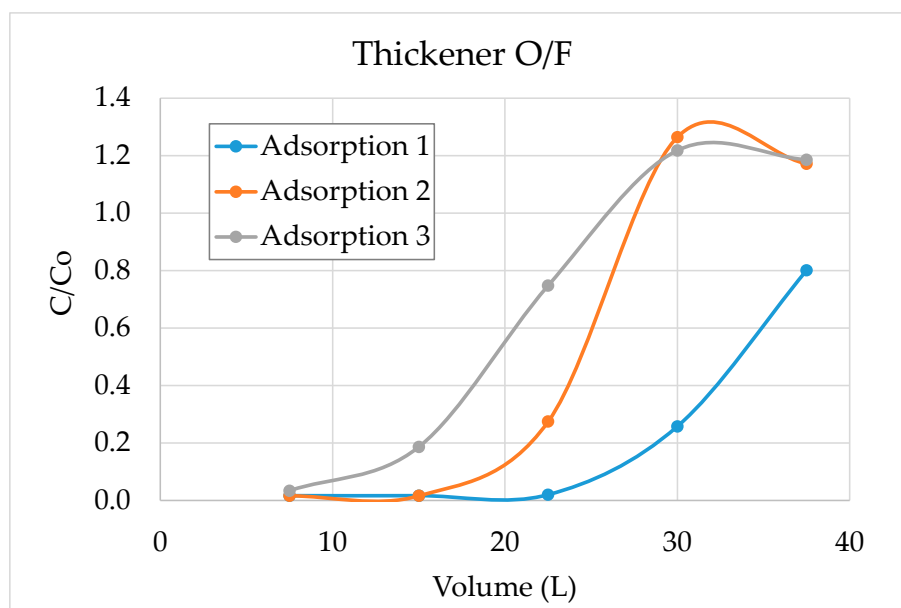


Figure 13. Breakthrough curves of the sulfate ion for the three adsorption experiments conducted on the Thickener Overflow.

Figure 14 shows the efficiency of the regeneration stages following the adsorption experiments. Almost all sulphate ions were desorbed from the resin in Regeneration 1, where fresh NaOH solution was used. The same solution was used in the second and third regeneration stages. It was clear that efficiency of the regenerant decreased gradually in the second and third stages due to accumulation of sulphate ions. To use the same regenerant for the resins, fresh NaOH solution should be added as makeup solution and the excess sulphate should be removed by precipitation.

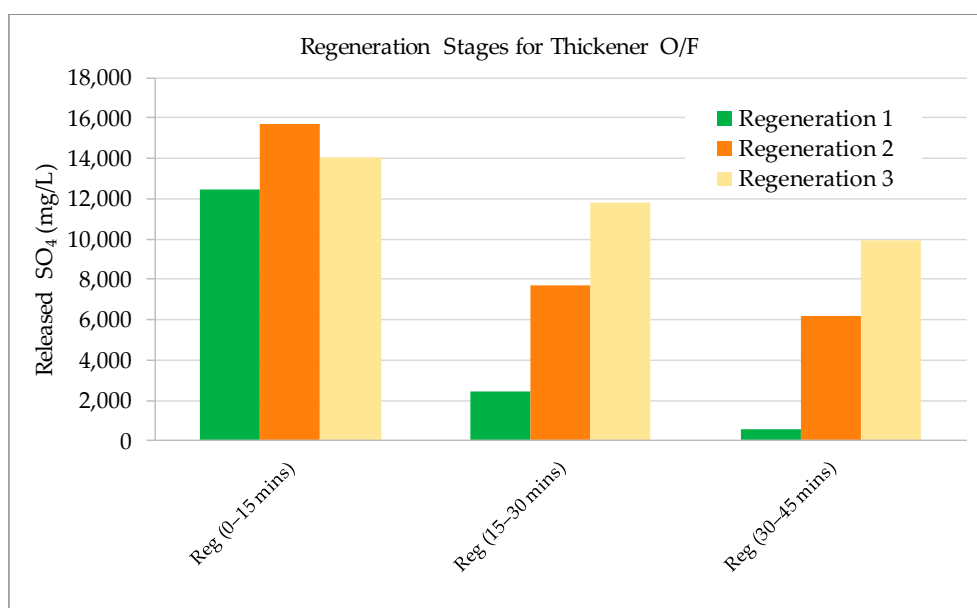


Figure 14. Desorption of sulphate ions from the resin in the regeneration stages applied after the adsorption experiments on the Thickener Overflow (O/F).

In addition to sulphate ion, the water samples were analyzed for thiosulphate and polythionates. Concentrations of sulfur based ions in Process Water and Thickener Overflow water streams are given for the first stage of adsorption in Figures 15 and 16, respectively. The results show that both the concentrations of thiosalts and polythionates were reduced to nearly zero value from 500 mg/L and 1000 mg/L, respectively, in 75 min of adsorption time. This could partly be due to relatively low concentrations of these ions compared to sulfate ions and also preferential adsorption to some extent. Further works should be conducted to investigate preferential adsorption of thiosalts on the resin.

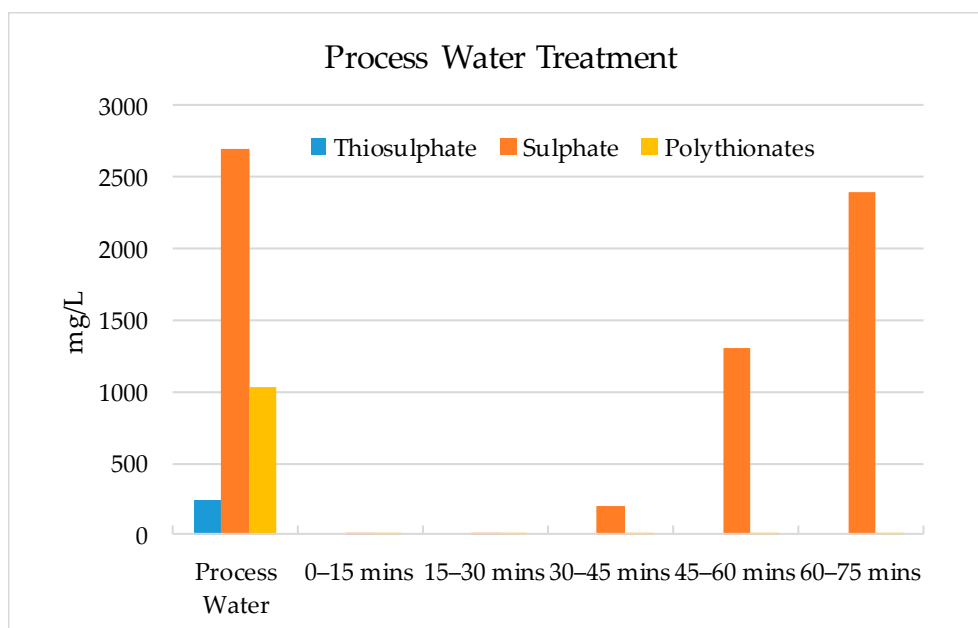


Figure 15. Concentration of residual anions at adsorption stages of Process Water.

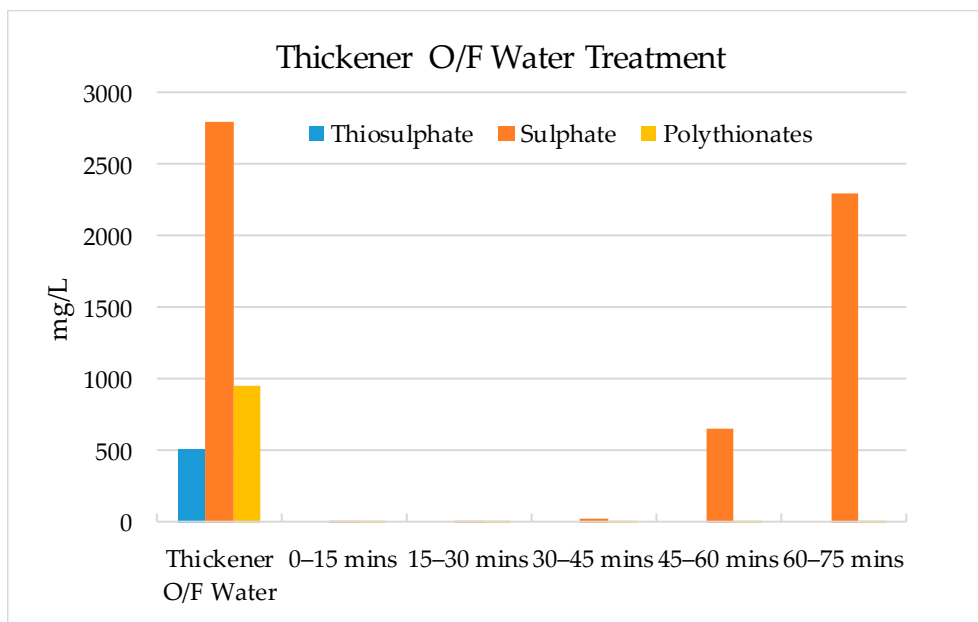


Figure 16. Concentration of residual anions at adsorption stages of Thickener O/F.

Effects of water flowrate on adsorption characteristics of the resin were tested using Thickener O/F stream. The flowrate was increased from 30 L/h up to 60 L/h, and the samples were collected at same time intervals as applied in the experiments given above. Figure 17 shows concentration of

the residual sulphates, thiosulphates and polythionates from the adsorption test at high volumetric flowrate. The results showed that residual ions could be detected even in the first stage of adsorption. Even thiosulphates and polythionates were not properly adsorbed on the resin. This was attributed to the insufficient contact time between the resin and water components at high water flowrate. The test results show clearly that both amount of resin/volume of adsorption column and water flowrate are the most important parameters affecting the efficiency of adsorption. These parameters should be optimized depending on the chemical characteristics of water and plant capacity.

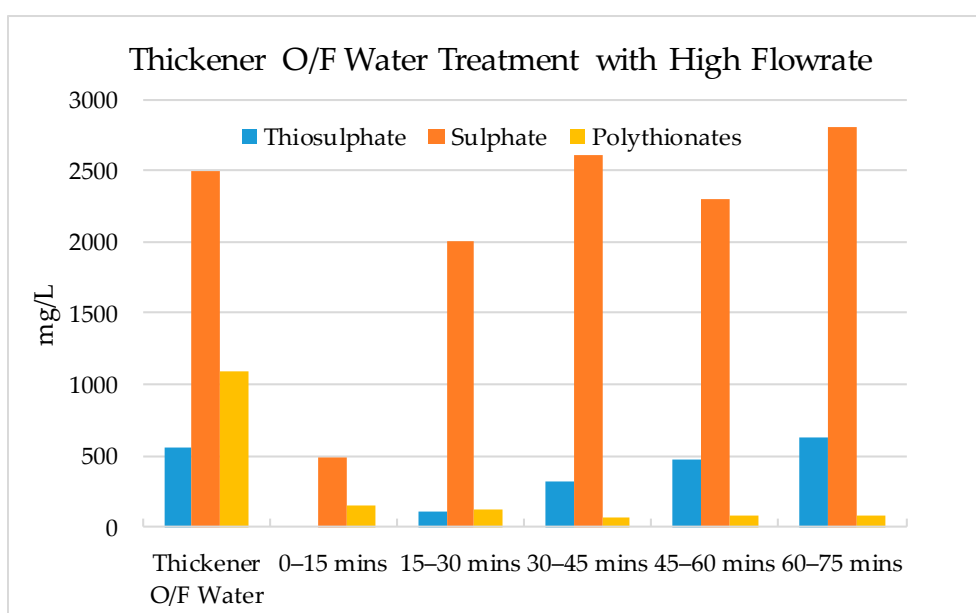


Figure 17. Effect of high water flowrate (60 L/h) on adsorption performance of the resin.

4. Conclusions

Application of ion-exchange resin within a column system was tested in different conditions in laboratory and validated in an Iberian Cu-Zn Plant. Based on the findings the following conclusions were deduced:

- Water treatment with ion-exchange resin had a significant potential for successfully decreasing concentrations of sulfur-based problematic ions for flotation of sulfide ores.
- Partial cleaning of the process water was successfully applied using strong base type ion exchange resin after conversion from Cl^- to OH^- form.
- The results show that 60–70% of sulphate could be removed by strong base-type resin from the process water. The concentration of sulphate ions in the process water could be reduced from 3000–3800 mg/L to 1000–1500 mg/L. The adsorption capacity of the resin was determined as 80.3 mg SO_4/g of resin. In addition to the sulphate ion, the thiosulphates and polythionates could also be successfully removed from the process water.
- It should be noted that the flowrate of water had a significant effect on the performance of adsorption. Chemistry of process water is unique for each mine and hence, the required contact time between the resin and water components should be optimized for each case.
- The resin could be regenerated using a solution containing 2% (*w/v*) NaOH and reused for water treatment processes many times. The same regenerant solution can be used continuously if fresh NaOH solution was added to increase hydroxide concentration in the solution when required and the excess sulphate ion was removed from the solution by precipitation.

Pilot-scale flotation-water treatment processes would be useful to evaluate practical and economical aspects of water treatment using ion exchange resin.

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