Water in Mining – Challenges for Reuse

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Abstract The use of tailings dewatering operations, such as particle aggregation, thickening and filtration, can reduce freshwater consumption in many mineral processing plants. This paper evaluates dewatering of two mineral tailings, from nickel and bauxite-alumina plants, aiming to improve the water recovery and reuse. Results show that natural polymers (humic acid and chitosan) are efficient to aggregate and settle red mud particles, with turbidity reduction of up to 95%. For nickel tailings, high molecular weight polymers are more efficient. The insertion of filtration allowed an extra water recovery up to 65%. Furthermore, it can make suitable dry stacking of tailings.

Key words Tailings dewatering, particle aggregation, filtration, red mud, nickel tailings, water reuse

Introduction

Mining activity demands large volumes of water and, consequently, generates significant amounts of tailings, which must be disposed of in an environmentally sustainable way, with reasonable cost. Mineral tailings are mostly discharged as concentrated pulps or slurries, so dewatering plays an important role in the final characteristics of the tailings produced (Mudd 2008). The use of thickeners near the ore processing plant allows the partial recovery and re-circulation of process water and chemicals at relatively low costs, also helping to reduce new water abstraction, which enables lower operating costs and environmental impact.

Water scarcity, due to environmental issues as well as competition among various uses (e.g., drinking, farming, recreation, etc.) is one of the factors that stimulates the application of new technologies for the disposal of mining tailings (Wang et al. 2014). A distribution of mineral tailings disposal systems is shown in Figure 1 (Davies 2011), where it can be seen that conventional dewatering (thickening and filtration) is still the dominant method.

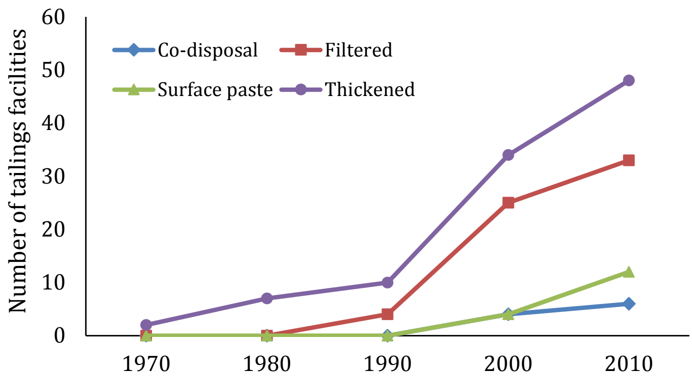

Figure 1 *Tailings disposal systems in the mining industry (Davies 2011)*

The efficiency of solid-liquid separation plants is directly related to the auxiliary chemicals used for particle aggregation (coagulation and flocculation). In the case of solid-liquid separation for recovery of industrial water, pulps or tailings containing clay minerals are more difficult to process because of the lamellar structure of a large part of the silicate minerals present, causing a need for flocculation. Parsapour et al. (2014) report that the increase in molecular weight of flocculant polymers reduces the density of the flocs due to the increase in the amount of water entrapped in the floc structure, whereas polymers with relatively smaller molecular weight can produce flocs of greater density, because they imprison less water in their structure.

Two tailings streams were considered in this study, from nickel and bauxite operations, due to the importance of both minerals to Brazilian mineral production and the challenges faced by these industrial plants regarding tailings disposal and water reuse.

Nickel tailings can contain 40-50% water along with residual Ni (0.3%) left over from the beneficiation process. The processing this material involves regrinding, desliming and metal recovery by column flotation. As a consequence, the new tailings generated by this reprocessing are even finer and can contain chemicals, requiring efficient dewatering for disposal and water reuse.

Disposal of red mud, a residue from bauxite refineries produced in the Bayer process, is a major challenge to the aluminum industry, due to its high toxicity and alkalinity. It is the world's leading industrial waste by volume and its generation is increasing by approximately 120 Mt/year (Kobya et al. 2014). This residue is filtrated before disposal, but small particles still remain in the filtrate, along with dissolved compounds, giving the effluent a reddish color due to the high iron oxide content and causticity ($10<pH<12$), so these particles need to be removed. Due to their surface properties and size, they will not settle naturally, making it necessary to aggregate them to improve solid-liquid separation. Therefore, the use of alternative reagents (coagulants and flocculants) that can promote aggregation into a highly alkaline medium can reduce the cost and improve efficiency, especially regarding water recycling to the processing plant (Aldi 2009).

Methods

Two tailings samples were studied: a red mud sample, with very fine particles (d_{50}=5.7 µm, P_{80} 17 µm) and a nickel tailing, with particle size d_{50}=12 µm, P_{80} 30 µm. Two groups of flocculant polymers were studied: natural polymers (Sigma-Aldrich) with low molecular weight, chitosan ($2.32x10^5$ $g.mol^{-1}$) and humic acid HA ($2.31x10^4$ $g.mol^{-1}$), as reported by Loayza et al. (2015). The second group was composed by three commercial flocculant polymers – polyacrylamides (BASF) identified in this paper as Z7565 (cationic polymer), and R10 and R90 (anionic polymers), with molecular weights ranging from $7.27x10^6$ $g.mol^{-1}$ for R10 to $1.84x10^7$ $g.mol^{-1}$ for R90 (Andrade 2016).

The zeta potential measurements were carried out with a DT 1200 spectrometer (Dispersion Technology™) to determine surface charges for both tailings particles as well as for the polymer solutions. The tailings pulps were prepared with 10% solids (by weight) with the addition of an indifferent electrolyte, KNO_3 0.01 and 0.001 M. The zeta potentials were measured in the pH range of 2.0 to 12.5, adjusted with KOH and HNO_3 dilute solutions.

Flocculant polymers were prepared based on specific methods, as described by Loayza et al. (2015) and Gadelha & França (2015). Flocculation and sedimentation tests were performed in a jar testing device (Nova Ética™). For red mud suspensions, 1.0% solids slurries were prepared using deionized (Milli-Q® system) and tap water to evaluate the influence of ions present in the water. The slurries were prepared in a beaker with 2.0 L capacity at room temperature and stirred for 3 minutes at 190 rpm (rapid mixing). Then chitosan (30 g/t) was added and stirred at the same rotation for 1.2 minutes, followed by HA (10 g/t), maintaining the system under stirring for an additional 1.2 minutes. The stirring speed was reduced to 95 rpm (slow mixing) to promote floc growth, for 1 minute. After stirring, the slurry was allowed to stand at room temperature for a 1-hour sedimentation period.

Nickel tailings slurries were prepared with solids concentrations of 10, 15, 18 and 23% (w/v). Flocculant polymers Z7565, R10 and R90 were used in solutions of 0.5 g/L (Andrade 2016), for dosages of 40, 60, 80, 100 and 200 g/t. For flocculation and sedimentation tests, the nickel tailings slurries were stirred for 3 minutes at 300 rpm; after which the flocculant polymer was added and mixed for 1 minute at 300 rpm, and then at 150 rpm for 2 additional minutes. The slurry was left standing for sedimentation for 1 hour.

After sedimentation, small aliquots of the supernatant liquid were retrieved for determination of turbidity in a portable Hach™ 2100P turbidimeter. With this result, it was possible to calculate the solids removal efficiency of the different polymers used, regarding the solid-liquid aggregation/sedimentation and in relation to Brazilian environmental legislation, which requires turbidity values of 100 NTU for water reuse and 40 NTU for discharge.

Aiming for higher efficiencies on water recovery, filtration tests were run in a Filtratest™ unit, manufactured by Bokela, with a filtration area of 19.63 cm^2. A polypropylene fabric with multifilament yarns and air permeability of 1.5-5 $m^3/min/m^2$ was used, under pressure drop of 2 bar. After the experiment, the filter cake was dried in an oven at 100±5 °C to constant weight for moisture content measurement. In this step, only slurries with 10, 15 and 23% solids concentration (w/v) were filtered, because low concentration slurries did not provide enough solids in the underflow to form cake.

Results and Discussion

Red mud treatment: zeta potential curves for the red mud sample and natural polymers are shown in the Figure 2.

The red mud particles and chitosan had similar surface charges in the entire pH range studied. For the HA, the surface charges were the opposite to those of the red mud in the $3<pH<6$ range. Considering that the natural pH of red mud tailings is around 10.5-12, the largest difference between zeta potential of red mud particles and polymers, at this pH range, was observed for chitosan.

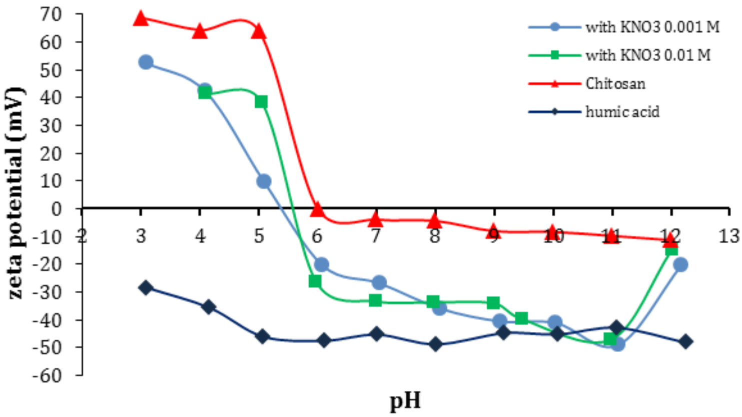

Figure 2 *Surface charge of red mud (with KNO3) and natural polymers (chitosan and humic acid)*

The unflocculated red mud slurry presented average turbidity range of 500-550 NTU. At this pH, the flocculation efficiency was low for both types of water and flocculant, with high values of turbidity (up to 300 NTU), even after treatment (flocculation and sedimentation), as can be observed in Figure 3. These results might be due to the poor adsorption of polymers on the red mud particles' surfaces. Therefore, for pH in the range of 7 to 8, the flocculation of particles was efficient and produced supernatants with turbidity of 10 NTU, with chitosan as flocculant, corroborating the findings of Yang et al. (2014). The co-flocculation effect could be noticed also at pH 7-8 with the use of chitosan and HA, resulting in supernatants with less than 5 NTU, equivalent to 99% turbidity removal, allowing immediate water reuse.

Since the natural pH of red mud from refineries is around 10.5-12, another important aspect to highlight is that at pH near the isoelectric point (pH~12), the adsorption was efficient, especially in the presence of both chitosan and HA. A turbidity value around 33 NTU was attained, showing the potential of using a combination of these polymers, at natural red mud pH, for wastewater treatment and water reuse, improving the process in economic and environmental terms.

The zeta potential curves of the nickel tailings are shown in Figure 4. As can be noticed, nickel tailing show negative surface charge in most of the pH range, including the natural pH 6.5. An isoelectric point was observed around pH 10.5 and up to this value, charges were positive. In the range 6.5<pH<8.5 the surface charge reached values below -30 mV, corresponding to an unstable region, making aggregation more difficult (Loayza et al. 2015). In this case, high molecular weight polymers can be more efficient for particle aggregation.

Despite the highly negative surface charges in this tailings sample, Deniz (2014) reported that an advantage exists of using high molecular weight anionic polyacrylamide – in contrast to cationic polymers – to flocculate negatively charged particles, because the primer can produce flocs with increased settling rate and a distinct sediment structure. Considering the

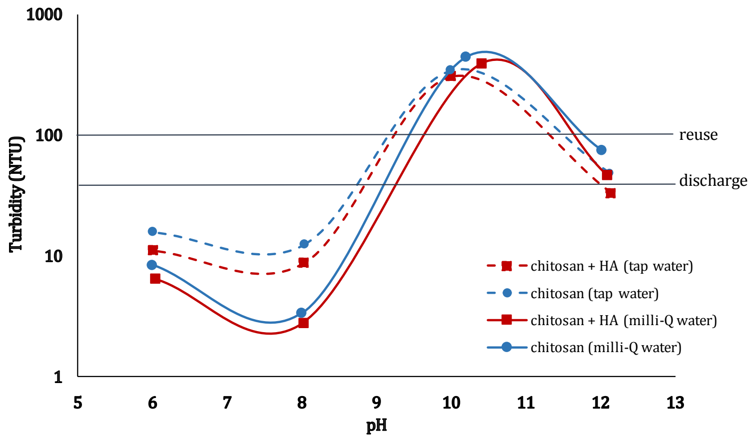

Figure 3 *Turbidity removal of flocculated red mud*

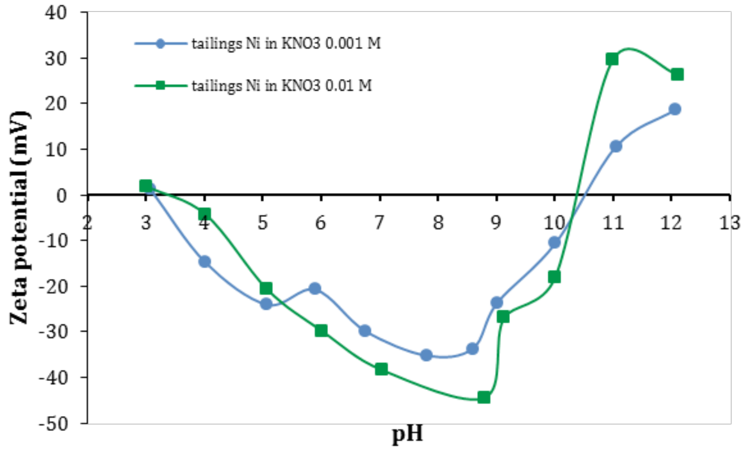

Figure 4 *Surface charge of Ni tailings*

presence of clay minerals (kaolinite) in the nickel tailings sample, the anionic polymers can also avoid the re-stabilization of clay particles by excessive polymer adsorption driven by strong electrostatic attraction.

The significant increase of the settling rate due to the use of flocculant polymers is depicted in the sedimentation curves (Figure 5). In addition, Table 1 shows the results for residual turbidity after nickel tailings treatment. Based on the results presented in Table 1, it can be seen that the Z7565 and R10 flocculant polymers promoted efficient solid-liquid separation, with high sedimentation rates and turbidity values below 40 NTU in the overflow. Regarding the settling velocity, the results show the importance of using flocculant polymers to improve settling rates and enable faster reuse of process water. The flocculant polymer R10 (100 g/t) promoted an increase of 21% in floc diameter in relation to polymer Z7565, and 54% in relation to polymer R90.

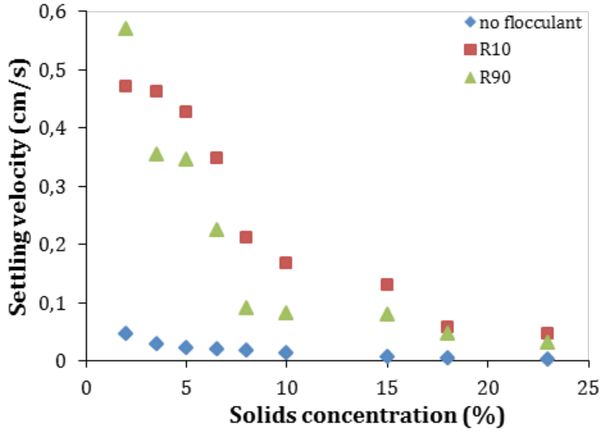

Figure 5 *Settling velocity for natural and flocculated nickel tailings*

Table 1 *Residual turbidity of thickened nickel tailings flocculated with different polymers*

	Slurry characteristic	Polymer dosage (g/t)	Solids concentration (%) 10	15	18	23
Residual turbidity (NTU)	Natural	No polymer	43432	44160	63872	80000
		40	108	226	332	266
		60	44.5	113	203	81.7
	R10	80	42.1	64.4	201	303
		100	6.11	10.2	4.04	5.33
		200	3.43	3.12	4.77	6.38
		40	187	202	181	311
		60	79.4	155	225	262
	R90	80	108	113	238	296
		100	6.00	36.0	7.65	14.8
		200	2.39	1.93	3.75	6.44
		60	68.3	123	241	324
	Z7965	100	5.87	13.3	7.03	5.84
		200	1.78	4.62	2.40	2.45

After thickening, tailings (underflow) are usually pumped into tailings ponds where the particulate matter will settle, with slow rates of water release and solids compaction. To improve the dewatering process and water recovery and hasten water reuse, part of the underflow was submitted to a filtration step instead of pumping the slurry to the tailings pond. The results of water recovery due to filtration are presented in Figure 6.

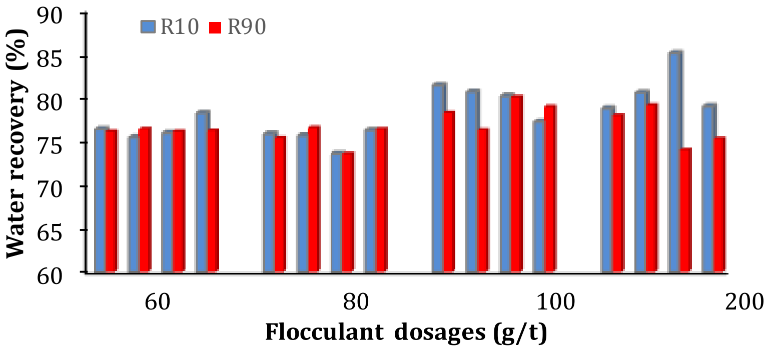

Figure 6 *Water recovery by pressure filtration for different flocculant dosages*

The results show that it possible to proceed with the immediate reuse 68-85% of process water, thus improving the dewatering plant with the filtration operation. Besides the water recovery, filters can produce cakes with 10 to 15% moisture, allowing dry stacking of the low moisture tailings, as also reported by Davies (2011). Flocculant polymers with higher molecular weight (R90) can entrap more water in the floc structure and reduce the water recovery by filtration. Parsapour et al. (2014) observed the same dewatering behavior. Polymer R10 performed better in water release under extra shear and pressure drop.

Conclusions

Natural polymers such as chitosan and humic acid can be used for red mud tailings treatment, to remove color and suspended particles, reaching turbidity reduction of up to 95% and satisfying the limits of Brazilian environmental legislation for water reuse or discharge. For nickel tailings, the use of high molecular weight polymers improved dewatering operations by increasing settling velocity up to 60%, allowing faster water reuse. The insertion of a filtration step for dewatering of thickened material allowed the production of low moisture cake, suitable for dry stacking, besides an extra 65% water recovery.

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