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Improved dewatering of nickel laterite ore slurries using superabsorbent polymers

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ABSTRACT

High sedimentation rates, good supernatant clarity and compact consolidation of valuable mineral slurries and waste tailings are the main requirements for effective dewatering. The current conventional flocculant-mediated and gravity-assisted thickening processes used in industry are far from being efficient in terms of maximising pulp water recovery. The present work investigates an unconventional approach using anionic, highly cross-linked polyacrylate, superabsorbent polymer to dewater slurries of three, unflocculated and flocculated, low-grade nickel (Ni) laterites ores (goethitic, siliceous goethite and saprolitic). The superabsorbent (SAB) sealed in a water permeable polyester bag was applied over 24 h contact time at 1–5 wt.% dosage to dilute (2–8 wt.% solid) and 20–25 wt.% solid, self-settled and polyacrylamide (PAM, 0–400 g/t solid) flocculated sediments generated at 10^{-3} – 2 M solution ionic strength, pH 2.5–10.5 and 25 °C. The results showed that SAB water absorption of 80–90 wt.% occurred within 8 h, reflecting sediment consolidation to 40–55 wt.% solid. SAB water recovery capacity was maximum at dosages of 3 and 2 wt.%, respectively, for dilute and concentrated slurries and at pH 6.0–7.0. The SAB-mediated pulp dewaterability, however, decreased markedly with increasing ionic strength and smectite clay mineral content. Slurries' pre-flocculation at up to 400 g PAM/t solid had a noticeable impact on SAB's dewatering efficacy which decreased appreciably with increasing flocculant dosage. The regeneration and recycle trials of the superabsorbent showed that there is unique opportunity for multiple use and greater pulp water recovery with a given sample. Both the water absorption and release capacities, however, decreased steadily with increasing number of superabsorbent recycles.

1. Introduction

As high grade ore deposits are rapidly exhausted, the mineral industry is forced to increasingly exploit lower grade ores, the processing of which is achieved through extractive hydrometallurgical processes. The voluminous amounts of the ore and water processed result in equivalently large quantities of dilute waste tailings [5,30]. Lateritic ores containing clay minerals, such as kaolinite and smectite, in tailings pose significant technical, socio-economic and environmental problems associated with the treatment and disposal [1,16,19,20,29,31]. The presence of clays even as a minor component in mineral ores, can cause serious dewatering and handling problems in terms of gelation or swelling and space-filling "card house" structures. The resulting high yield stress accompanied by high flocculant demand, low settling rates and poor supernatant clarity are some of the typical challenges [1]. Polyacrylamide-chemistry based flocculants and gravity thickening and pressure filtration processes are currently used by the minerals industry for dewatering. Such processes are however, far from being efficient in terms of compact consolidation of the sediments despite the numerous studies performed and significant advances in thickener technology and flocculant structure and chemistry design [2]. Thus to date compact consolidation still remains a major persistent challenge in dewatering.

The capital and operational costs associated with tailings disposal are significant in terms impoundment dam construction, management and remediation and the loss of several millions of tonnes of entrapped processed water and valuable reagents. Reagent loss and seepage also pose important environmental risk and concern. Therefore, the sustainability of the mining industry is becoming more dependent on improved dewatering methods for waste tailings treatment and some upstream value mineral slurries.

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Usually, flocculation and primary dewatering processes are optimized for fast settling rates with limited attention of the subsequent consolidation. Various studies [12,17,19,21,31] reported that some novel dewatering methods that provide a strategy for improving pulp consolidation efficiency subsequent to fast settling using stimulus responsive polymeric flocculants. Several studies involving high molecular weight polyethylene oxide (PEO) flocculant have shown that sedimented pulps exhibit significant compaction upon the application of moderate shear rates (10–42 s^{-1}) [17–19,31], in contrast to conventional PAM-based sediments. As thickener operations involve a range of shear rates (0.1–50 s^{-1}) in the consolidation zone [18,28], shear-enhanced consolidation is clearly a desirable sediment characteristic.

Other recent studies [8,12,21,26,32] reported consolidation improvement using temperature-responsive flocculant (pNIPAM) and its associated hydrophobic interaction mechanism. Temperature is used as stimulus to change the inter-particle forces from repulsion to attraction to form aggregates at above the LCST (lower critical solution temperature). Upon cooling the sediment below the LCST, the polymer molecules desorb and go back into solution. This results in reduced inter-particle and inter-floc attractions within the sediment, inducing further consolidation. Furthermore, pH sensitive polymers such as chitosan can also be used as flocculants [7,9,13,24]. Through pH modifications, alternating attractive and repulsive chitosan-mediated pulp particle interactions may be invoked judiciously, fostering both fast settling and compact consolidation of the sediment.

SAB polymers can absorb and retain huge amounts of water relative to their own masses [33]. They are hygroscopic materials which entrap water via capillary forces in their macro-porous structure and through the hydration of functional groups [33]. One of the most important characteristics of SAB is their particles shape preservation upon swelling, which is a significant advantage over other hydrogels. This characteristic allows SAB to resist internal pressure that will force the release of water from the hydrogel. Unlike SAB, other materials such as tissue papers and polyurethane foams will lose most of their absorbed water when squeezed [33]. The swelling behaviour of SAB depends on its type and the solvent. The number of crosslinks in a polymer chain will affect the expansion of the polymer so that more crosslinks result in less swelling. The other factor is the amount of ions and organic components present in the solvent, which affect the electrical stability of the polymer chain, thus reducing the swelling capacity [27].

The ability of SAB to specifically absorb water and release it upon modification offers new possibilities for effective dewatering. Dzinomwa et al. [10] exploited this concept for fine coal dewatering using pH and temperature sensitive superabsorbent polymers. They showed that it was possible to dewater fine coal from a moisture content of 29.4% to 12–14% using pH-sensitive superabsorbent polymer (2 wt.%) within 4 h contact time. Peer and Venter [22] also reported that it is possible to decrease moisture content in fine coal by ~70% using SAB at 2 wt.% dosage. Farkish and Fall [11] demonstrated the potential of a SAB polymer in the consolidation of mature fine tailings (MFT) to produce a spadeable slurry of ~80 wt.% solid with close to 9 kPa of undrained shear strength gained by using a dosage of 3 wt.% SAB. The SAB recycling can be obtained by temperature- and pH-induced regeneration [10]. Along with the regeneration, hydrogel released water can also be recycled. As water is pervasive in mineral tailings, obviously opportunities exist in the development and application of high-capacity and regenerative water SAB as a feasible dewatering method.

Efficient dewaterability of complex laterite ore slurries is not straight forward. Sedimentation rates are affected by the fineness of the grind, the clay fraction, non-clay fine materials and the chemistry of the pore water [4]. In a study with pre-reduced nickeliferous laterite suspension, Anastassakis [3] reported that the cationic flocculants are more effective among anionic, cationic and non-ionic flocculants probably due to the negative charge of the minerals particularly at high pH. The settling rate increased with increasing polymer dosage reflecting increase polymer bridging forces. However the resulting sediment consolidation was mediocre. For the recovery of valuable metals (Ni, Co) from fine gained laterite mineral slurries, it is crucial to dewater the dilute slurries from milling and beneficiation process prior to subsequent processing such as high and atmospheric pressure acid leaching and agglomeration for heap leaching [23]. The main aim of this study is to investigate the pivotal role of the key primary variables on the dewatering behaviour of three complex, low grade laterite mineral dispersions for significant water recovery and concomitant sediment consolidation enhancement using superabsorbent as a dewatering agent. Specifically, primary variables affecting the absorption capacity of superabsorbent comprising pH, solution ionic strength, superabsorbent dosage, solid loading, feed mineralogy and time, were investigated. Furthermore, pH-induced SAB regeneration was tested for SAB and released water recycling from the absorbed water.

2. Materials and methods

2.1. Materials

Three types of complex low grade Ni laterite ores (Siliceous Goethite (SG), Goethitic (G) and Saprolitic (SAP)) from the same Western Australia deposit were used in this study. The −38 μm fractions obtained from rod milling the −15 mm run of mine (ROM) ores were used. The 10th, 50th and 90th percentile particle sizes, D_{10}, D_{50} and D_{90} respectively, determined by laser diffraction (Malvern Mastersizer X, Malvern UK), were 2, 10, and 52 μm, respectively (Fig. 1A). A summary of chemical and mineralogical characteristics for −38 μm ore samples are given in Tables 1 and 2, respectively [23]. The mineralogical characteristics revealed that goethite, hematite, smectite, kaolinite and quartz are the major minerals present in the samples.

Feed slurries at solid loadings 2, 4 and 8 wt.% were prepared by mixing known amount of the laterite ore sample with known amount of 10^{-3} M KNO_3 solution as a background electrolyte. An anionic SAB polymer (Superabsorbent Polyacrylate, BASF Ltd.) was used in this work. It is sodium polyacrylate, made from sodium salt cross-linked with polyacrylic acid. Its particle size distribution is shown in Fig. 1B and was determined by sieving using a mechanical shaker (AS/NZS3760 Shaker). The SAB particles are in 100–600 μm size range, making the markedly coarser than laterite particles. Dzinomwa et al. [10] reported that for granules size >8 mm, the rate of water absorption is too slow and for those smaller than 2 mm, the rate of absorption is fast.

High molecular wt. (~3–4 × 10^6 Da), anionic polyacrylamide copolymer (Rheomax 1010, BASF Australia) was used to produce flocculated sediment for secondary dewatering tests. The flocculant solution was prepared as stated by the supplier's instructions. Precisely 0.25 vol.% of flocculant was mixed with 5 vol.% of acetone and 94.75 vol.% of Milli-Q water (surface tension 72.8 mN m^{-1}, specific conductivity 0.5 μS cm^{-1} and pH 5.6 at 20 °C) using a suspension mixer (Ratek, Rowe Scientific Pty Ltd) for 90 min to ensure homogeneity. All slurries were prepared using 10^{-3} M KNO_3 solution, unless stated otherwise. All test were replicated at least, 3 times and the arithmetic mean values of measurements and their cognate 95% CI standard errors reported.