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A two-step flocculation process on oil sands tailings treatment using oppositely charged polymer flocculants

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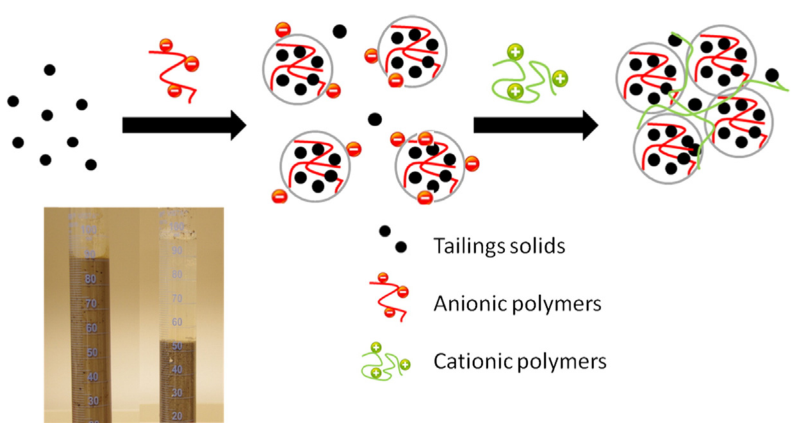
HIGHLIGHTS

- Two-step flocculation was developed for oil sands tailings treatment.
- High settling rate and good effluent clarity were achieved in the two-step process.
- Flocs size, zeta potential and surface forces were measured for mechanism study.
- The flocculation mechanism involves polymer bridging and charge neutralisation.

GRAPHICAL ABSTRACT



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ABSTRACT

Water management and treatment of mineral tailings and oil sands tailings are becoming critical challenges for the sustainable development of natural resources. Polymeric flocculants have been widely employed to facilitate the flocculation and settling of suspended fine solid particles in tailings, resulting in the separation of released water and solid sediments. In this study, a new flocculation process was developed for the treatment of oil sands tailings by using two oppositely charged polymers, i.e. an anionic polyacrylamide and a natural cationic biopolymer, chitosan. The new process was able to not only improve the clarity of supernatant after settling but also achieve a high settling efficiency. Treatment of the oil sands tailings using pure anionic polyacrylamide showed relatively high initial settling rate (ISR) of ~10.3 m/h but with poor supernatant clarity (>1000 NTU); while the treatment using pure cationic polymer resulted in clear supernatant (turbidity as low as 22 NTU) but relatively low ISR of >2 m/h. In the new flocculation process, the addition of anionic polyacrylamide to the tailings was followed by a cationic polymer, which showed both a high ISR (~7.7 m/h) and a low turbidity (71 NTU) of the supernatant. The flocculation mechanism was further investigated via the measurements of floc size, zeta potential and surface forces. The new flocculation process was revealed to include two steps: (1) bridging of fine solids by anionic polyacrylamide, and (2) further aggregation and flocculation mediated by charge neutralisation of the cationic polymer, which significantly eliminated the fine solids in the supernatants as well as increases floc size.

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Our results provide insights into the basic understanding of the interactions between polymer flocculants and solid particles in tailings treatment, as well as the development of novel tailings treatment technologies.

1. Introduction

Canada has the largest oil sands deposits in the world, and bitumen is commonly recovered by oil sands industry using the so-called Clark Hot Water Extraction Process, in which large amounts of hot, caustic water is used to separate bitumen from sands, resulting in the accumulation of fluid wastes referred to as oil sands tailings (Allen, 2008; Giesy et al., 2010). Comprising water, sands, fine clays and bitumen residue, the tailings are discharged into surface tailings ponds (Chalaturnyk et al., 2002; Scott et al., 2008). The accumulated oil sands tailings on site have resulted in over 176 km^2 of tailings ponds in Northern Alberta which will continue to increase with the continuing growth of oil sands exploration (Gosselin et al., 2010; Kelly et al., 2010), causing remarkable land disturbance and posing serious environmental and economic concerns as well as engineering challenges (Mamer, 2010). Therefore, water management is critical to the sustainable development of the Canadian oil sands, and it is highly desirable to develop efficient ways to enhance the settling of the solid particles in the tailings to recycle the water and reclaim the land occupied by tailings ponds (Yergeau et al., 2012).

Over the last two decades, much effort has been devoted to development of technologies for oil sand tailings treatment including composite tailings, flocculation by polymers, fine tailings centrifuge and freeze/thaw method (Jeremy Boswell, 2012; Xu et al., 2008). Flocculation by polymers has been extensively explored and implemented by the oil sands industries due to its high efficiency in dewatering mineral tailings (Farkish and Fall, 2013; Gray et al., 2009). Polymers (as flocculants) are normally employed to overcome the potential energy barrier between negatively charged solid particles in the oil sands tailings, and to bring these particles into the effective range of attractive van der Waals force and polymer bridging attraction, which triggers the destabilization and flocculation of suspended particles to form large sediments, or so-called flocs (Tripathy and De, 2006). Depending on the properties of employed polymer flocculants and composition of tailings samples, different destabilization mechanisms such as bridging, charge patching and charge neutralisation could be involved in the flocculation process (O'Shea et al., 2011). Derivatives of polyacrylamide (Pasetto et al., 2009), particularly hydrolyzed polyacrylamide (HPAM) with 20–30% anionicity (Wang et al., 2014a; Wang, 2014) has been widely used in the industrial flocculation of oil sands tailings. Functional polymers such as hybrid $Al(OH)_3$-polyacrylamide (Al-PAM) (Alagha et al., 2011; Alamgir et al., 2012; Guo, 2012; Wang et al., 2014b) and thermo-sensitive poly(*N*-isopropyl acrylamide) (Li et al., 2015; Long et al., 2011; Wang et al., 2014c) have been developed as alternatives to improve both settling and consolidation performance. However, this widely explored flocculation technology based on a single polymer flocculant usually demonstrates unsatisfactory performances on oil sands tailings treatment (Alamgir et al., 2012; Li et al., 2007; Sworska et al., 2000). The specific and complex properties of oil sands tailings, i.e., alkalinity, residual bitumen and a wide size range of clay colloids, generally complicate the interactions of polymer-particle and particle-particle during flocculation and undermine the performance of the polymer flocculant. Thereby most polymers fail to simultaneously enhance the settling rate of suspended solid particles as well as the clarity of released water during the treatment of oil sands tailings, which are the two major criteria for evaluation of flocculant performance (Sworska et al., 2000). Therefore, it is of both fundamental and practical importance to explore and develop a novel flocculation strategy for oil sands tailings treatment with fast settling rate as well as sufficient dewatering capacity.

Treatment of mining tailings or pulp sludge from food and paper industries generally appears to be a multi-component flocculation procedure. Compared to using a single polymer flocculant, the multi-component flocculation procedure has demonstrated improved flocculation performance on treating these industrial tailings. A major driving interaction might be that the first component could serve as an anchor for the adsorption of the second component through interactions like electrostatic attraction (Glover et al., 2004; Xiao et al., 1999). For example, previous studies by Xiao et al. (Sang and Xiao, 2008; Xiao et al., 1999) revealed that a two-component system consisting of both cationic micro-particles and anionic polymers as retention aids in papermaking process could improve flocculation efficiency and lead to better retention performance than that using either individual component. Similar results were also shown that treating positively charged alumina suspension by two-polymer based flocculation procedure could greatly lower final cake moisture and increase filtration rate (Glover et al., 2004). However, little effort has been devoted to exploring a multi-component flocculation procedure on oil sands tailings treatment. Meanwhile, most polymer flocculants used are synthetic and little attention has been paid to usage of biopolymers as effective flocculants for oil sands tailings treatment. Natural biopolymers such as chitosan are generally non-toxic and biodegradable, non-corrosive and safe to handle, which are considered as eco-friendly alternatives for synthetic flocculants (Renault et al., 2009).

Herein, a new two-step flocculation process was developed for the treatment of extraction tailings directly from oil sands extracting plants in Northern Alberta by using two oppositely charged polymers, i.e. an anionic polyacrylamide and a cationic biopolymer chitosan. The performance (i.e., settling rate and clarity of released water) of the two-step flocculation was compared with that of single polymer flocculation. To explore the underlying flocculation mechanism, focused beam reflectance measurements (FBRM), zeta potential and surface force measurements were conducted. This work provides insights into the development of novel tailings treatment technologies.

2. Materials and methods

2.1. Materials

Extraction tailings (ET) were provided by an oil company from the oil sands extraction operation in Northern Alberta, which consist of water (73.0–74.0 vol%), solids (26.0–27.0 vol%) and bitumen residues (0.10–0.25 vol%) with a pH of 8.6–8.9 at 20 °C. Two oppositely charged polymers, Magnafloc-1011 (Percol 727, Ciba, UK) and chitosan (Sigma, Canada), were employed as polymer flocculants in the two-step flocculation process. Magnafloc-1011 (MF) is a partially hydrolyzed polyacrylamide with an anion charge density of 27 mol% and has a high molecular weight of around 1.75×10^7 g/mol. Chitosan is a natural abundant cationic polymer with a molecular weight of 60,000 to 80,000 g/mol in 1% acetic acid solution.

2.2. Setting tests

Polymer dosages were expressed on the basis of tailings weight. The stock solutions of MF and chitosan were prepared one day earlier at a concentration of 500 ppm in Milli-Q water and 2000 ppm in 1% acetic acid solution, respectively. The settling tests followed a procedure reported previously (Ji et al., 2013). Briefly, 90 mL extraction tailings samples were transferred into a 250 mL standard baffled beaker and homogenized at 600 rpm for 2 min. Then the agitation speed was