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Research paper

Studies on flocculation characteristics of chromite's ore process tailing: Effect of flocculants ionicity and molecular mass

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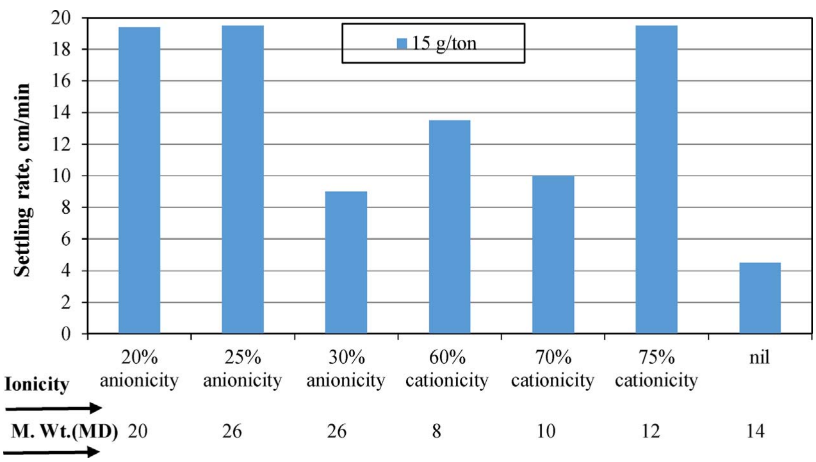
GRAPHICAL ABSTRACT



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ABSTRACT

At the moment, it is vital for mineral industries to abide environmental regulation to dispose of the wastes generated in the beneficiation process. The redesign of dewatering process is required to meet the present demand. This paper reports the results of systematic investigations on the flocculation, sedimentation and consolidation characteristics of the chromite ore process tailings using different polyacrylamide flocculants. Laboratory batch sedimentation tests were performed to assess the performance of flocculants. Different categories of flocculants such as anionic, cationic, non-ionic with varying ionicity and molecular mass were used to improve the settling rate. The influence of flocculants on the settling rate, solid consolidation, and supernatant liquid clarity was recorded. Ionicity and molecular weight of the flocculants have a significant effect on the tailings settling properties. Anionic flocculants with low ionic strength and molecular weight show higher settling efficiency, whereas, cationic flocculants bearing high ionic strength and molecular weight also display the similar settling behaviour. The opaqueness of consolidated solids is greater with cationic than the anionic polyacrylamide. The anionic Alstafloc 40, 60 and cationic Alstafloc 155XX have exhibited excellent turbidity removal efficiency with 19.5 cm/min settling rate at 15 g polymer/tonne solid dosage. The non-ionic polyacrylamide was not found efficient for the tailings flocculation.

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1. Introduction

Dewatering and consolidation of mineral tailings by flocculation and filtration is one of the primary mineral processing activities. The polyacrylamide (PAM) flocculant is used extensively in the thickening process [1–4]. Typically, the chromites ore process tailing contains a heterogeneous mixture of iron and chromium oxides, silicates, and aluminum silicate minerals [5].

The Indian chromite ores are characterized as a ferruginous and siliceous type of ores. The Major resources are concentrated at Sukinda Valley, Odisha. The chromite ore beneficiation plants are present in this region. The beneficiation plants majorly consist of comminution to physically liberate the minerals followed by physical separation to generate the concentrate. During the comminution process, large quantities of fines generated. The fines commonly de-slimed using hydro-cyclone and cyclone underflow processed using gravity concentrator like spirals and tables. During the process, approximately 50% (w/w) of the total feed is discarded as tailings [5]. The particles below 75 μm reported in the tailing contain about 9–20% Cr_2O_3 [6]. Preserving these mineral values is paramount. Different unit operations such as thickening, filtration are included in the process flowsheet to dewater the tailings. The fine particles less than 10 μm causes a serious problem in dewatering process [7]. The process tailings consist of 5–10% solid (w/w). The dewatered product contains high moisture, which creates technical and economic difficulties in handling, disposal, and water removal.

The design and optimization of dewatering system require a thorough analysis of the solid-liquid system and slimes stability behaviour. The pH, ionic strength, addition of the coagulant and polymeric flocculant can change the stability of particles [7–13]. In flocculation, the fine particulates suspended in liquid, interact with the flocculating agent and consequently aggregate to form flocs which settle rapidly under the influence of gravity. The characteristics of floc decide the rate of settling as well as the moisture content of the consolidated tailings [14]. The floc characteristics depend on several factors such as particle size distribution, particle shape, density; surface chemistry, viscosity and dielectric constant of suspension; chemical nature, molecular mass, charge and charge density of flocculant [15,16]. Polymeric flocculent flocculates ultrafine particles through various mechanisms such as bridging, charge neutralization, electrostatic patch and depletion flocculation [17]. High molecular weight polymer forms a link between particles through bridging by reducing the electrostatic repulsion [15]. The flocs formed by charge neutralization or electrostatic patch mechanism are weaker than those formed by bridging [18,19]. It is also reported that the flocs formed by bridging mechanism have weak structure [16]. Yu et al. [20] showed that kaolinite aggregates made by addition of polyelectrolyte have stout and compact structures compared to flocs formed by the charge neutralization. Strong flocs are formed with electrostatic patch mechanisms in a situation where the polymers and particles have high and low charge density respectively [21].

Several kinds of literature are available in which polyacrylamide used as a flocculant for the independent mineral system. Also, there are literature available with hetero flocculation of process tailings such as iron ore [7,18], coal [22–24] etc. However, very few articles are available with hetero flocculation of the complex mineral system like chromite ore process tailings. Das [5] did extensive studies on the characterization of chromite ore beneficiation plant tailings using XRD, XRF, QUEMSCAN, and SEM-EDS. The mineralogical investigation using XRD and QUEMSCAN revealed that majority mineral phases present in chromite ore tailings are chromite, goethite, and gibbsite whereas hematite, kaolinite, and quartz are secondary mineral phases [5]. The SiO_2 and Al_2O_3 contents in process tailings vary between 10 and 12% and 15–17%, respectively [5]. Several reports show that the settling rate of alumina-silicate in the range of 1–10 m/h and low solid loading [20–30% (w/w)] is achievable with the aid of polyelectrolyte [25,26]. The basal faces of 1:1 tetra-octahedral aluminosilicates are consists of tetrahedral siloxane (−Si−O−Si−) species and octahedral, alumina (Al_2O_3) sheet [27]. Van Olphen [27] showed that the basal faces having siloxane structure carry a permanent negative charge due to the isomorphous substitution of Si^{4+} by Al^{3+} groups. Also, aluminol (Al-OH) and silanol (Si−OH) groups occur at the edges. The edge faces are charged by protonation and deprotonation of hydroxyl groups based on pH [27,28]. Therefore, these particles are highly charged at neutral and alkaline pH and shows stable dispersion behaviour. The iron oxide phases present in tailings are hematite (Fe_2O_3), magnetite Fe_3O_4), goethite (FeOOH). In water, anhydrous iron oxide hydrolysed to oxyhydroxide (FeOOH) and hydroxide (Fe $(OH)_3$) [29,30]. The surface hydroxyl groups undergo protonation or deprotonation to $-OH_2^+$ and $-O^-$ species depends on pH, respectively [31]. Therefore, iron oxide shows different charging behaviour in the aqueous medium that influences the slurry interfacial chemistry, particle aggregation and dewatering behaviour of iron oxide [10].

Chromite is a spinel mineral varies widely in chemical composition with the chemical formula (Fe^{+2}, Mg), (Cr, Al, $Fe^{+3})_2O_4$ [5,6]. The substitution of the element occurs in the chromite ore composition. The magnesium is easily filled in with iron, while aluminium and ferric ions typically replace chromium. Therefore, the surface properties of chromite depend on its chemical composition and crystal structure. The extent of bivalent or trivalent ions replacement determines the formation of hydroxyl complexes as a function of pH. Naturally, affect the slurry interfacial chemistry and the chromite stability behaviour [32].

In recent times, stringent environmental policies have imposed legal rules for the disposal of mineral wastes to the environment. Given this, it is essential to re-design our age old dewatering operations to meet the present demand. Minerals industry in the last decades has seen many activities in the area of development of specific reagents and design of new equipment for treating a wide variety of tailings. The present work has been under taken to study the influence of polyacrylamide flocculants with varying ionicity and molecular mass on the settling behaviour of chromite tailings and the flocculation-consolidation characteristics thereof.

2. Experimental

2.1. Materials

The chromite ore tailing sample was received from M/s. Tata steel, Sukinda, Odisha, India for the present study. Representative samples were prepared using standard sampling techniques. M/s. Chemtex Speciality Ltd, Kolkata supplied the flocculants i.e. anionic, cationic and non-ionic for the dewatering studies. Table 1 shows the type, molecular mass, and iconicity of different flocculants used in the experiments. The Alstafloc 40, 60 and 107 are high molecular weight anionic polyacrylamide flocculants with 20, 25 and 30% anionicity, respectively. The molecular mass of Alstafloc 40 is less than Alstafloc 60 and 107. The former molecular weight is 20 Million Dalton whereas the latter two have a molecular weight of 26 Million Dalton each. The Alstafloc 155, 155X and 155XX are medium molecular weight polyacrylamide cationic flocculants with 60, 70 and 75% cationicity, respectively. The molecular weight of Alstafloc 155, 155X and 155XX are 8, 10 and 12

Table 1
Type and properties of polyacrylamide flocculant.

Flocculant name	M. W. (Million Dalton	Charge	Ionicity (%)
Alstafloc 40	20	Anionic	20
Alstafloc 60	26	Anionic	25
Alstafloc 107	26	Anionic	30
Alstafloc 155	8	Cationic	60
Alstafloc 155 X	10	Cationic	70
Alstafloc 155 XX	12	Cationic	75
Alstafloc 50	14	Non ionic	Nil

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