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A cost-effective tailings solution to rheology issues while meeting the environmental constraints using inexpensive additives

YK Leong *University of Western Australia, Australia*

SJ Bensley *Rio Tinto Iron Ore, Australia*

J Drewett *Rio Tinto Iron Ore, Australia*

S Burkett *Rio Tinto Iron Ore, Australia*

Abstract

A significant quantity of tailings is produced in the wet beneficiation of iron ore. These tailings are flocculated and thickened in a thickener before being pumped to a tailings storage facility TSF, i.e., a pond, which can be several km away. Occasionally, the thickened tailings acquired a higher yield stress than can be pumped. This material then becomes a bottleneck reducing the plant output. This study demonstrates how to reduce these problematic tailings' yield stress or viscosity with a cheap additive. NaOH costing ~ US 400 per tonne resulted in a 50-60% reduction in the yield stress at pH 10 and ~ 90% reduction in the viscosity at 100s^{-1}. The legislated environmental constraints are i) the pH of the disposed of tailings must be less than 10 and ii) any chemical leachate of heavy metal ions must be less than stock drinking water guidelines or water table water. Leaching results showed this was the case for all leachate chemicals evaluated up to pH 11.2. Some leachate chemicals evaluated were As, B, Cr, Cu, Mo, Pb, Se, Th, Ti, U and V. However, not all tailings (from different mines) respond to NaOH treatment.

Keywords: *rheology control, composite additives, leachate, heavy metal, dry stacking, filtration*

1 Introduction

The recent disastrous iron ore tailings dam failures in Brazil in 2015 and 2019, resulting in significant fatalities, drew attention to the safety of tailings dams worldwide. Australia is the world's largest producer and exporter of iron ore, so the integrity of its tailings dams concerns the owning companies. The design adopted for the tailings dams and the storage of low-viscosity and low-density tailings are of concern. Technical analysis by Williams (2021) has found inherent weak points in the 2019 failed dam in Brazil. These weaknesses were further compromised by storing low-density and low-viscosity tailings along with rain and runoff directed by the topography behind the dam.

In a Rio Tinto iron ore plant located in the Pilbara region of Western Australia, tailings rheological problems are sometimes encountered. Occasionally the thickened tailings developed an enhanced yield stress that exceeds the capacity of the pump to deliver it to the tailing dams. This bottleneck adversely affects the daily iron ore throughput, a very undesirable problem. A standard solution is to dilute the tailings with water to reduce the yield stress and viscosity. This method is also undesirable from the viewpoint of safe tailings storage. Therefore, a study was conducted to determine a cost-effective resolution to the problem. The use of chemical additives was identified as a possible answer. Indeed, a cheap chemical additive, NaOH, was found to reduce the yield stress and viscosity, particularly at high pH 12.

However, there are environmental requirements that need to be addressed. These constraints are the pH of the discharged tailings must be less than 10, and the heavy metal ions leachate concentration must be below that in the stock or bore water. The cheap NaOH additive can reduce the viscosity and yield stress of tailings to a significant extent at pH 10, but this may not always be the case, especially when there is an abrupt change in the properties of the incoming tailings, such as minerals composition, water chemistry, etc. Therefore, more robust additives that are not sensitive to these property changes are needed. This conclusion led to the development of a set composite additive comprising a mixture of phosphate-based compounds and NaOH. This study demonstrates the performance of these additives in reducing the viscosity and yield stress at pH below 10 on three iron ore tailings. A previous study also showed that one of these tailings can be converted back to paste-like consistency with a neutralising additive (Leong 2018, 2020, 2021; Leong et al. 2019).

2 Materials and method

Rio Tinto provided two iron ore tailings from their Pilbara mines. They are designated as Pilbara mine A and B tailings. The main components of these tailings were goethite, hematite, kaolin and quartz. AR grade reagents, NaOH, Na phosphate, Na polyphosphate or Na (polyPO_4) and others were used. The yield stress was measured with Brookfield vane viscometers. A Haake VT 550 cone-and-plate viscometer characterised the shear stress-shear rate behaviour. The cone angle is 1°, so the shear rate is constant throughout the tailings in the gap. Orion 3- and 4-star pH and conductivity meters were used to measure the tailings pH and conductivity of the supernatant water of Pilbara mine A and B tailings at 7.25 and 0.56 mS/cm, and 7.2 and 1.39 mS/cm, respectively. A third tailings from the Pilbara not associated with Rio Tinto was used to demonstrate that safer tailings storage practice is possible. This Pilbara mine C tailings have a very high yield stress of 1000 Pa. The composite NaOH:Na (polyPO_4) additives were used to drastically reduce this yield stress and viscosity so it can be handled or pumped and then neutralised using calcium solution, returning it to a paste consistency.

3 Results and discussion

The effect of pH on the yield stress of 48% Pilbara mine A tailings is shown in Figure 1. NaOH was used to change the pH. The tailings have a natural pH of 7.3 and yield stress of 55-60 Pa. The yield stress decreased to about 30 Pa at pH 10, representing a 50% decrease. The yield stress decreased to less than 10 Pa, and the conductivity increased to 1.45 mS/cm at pH 12.

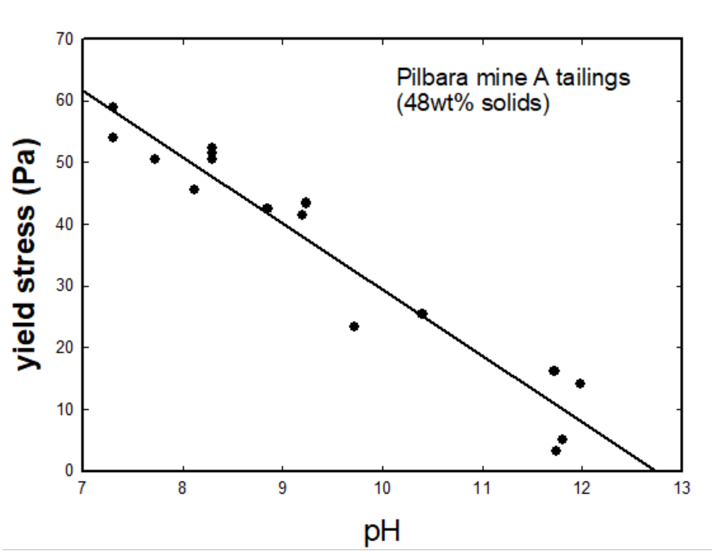


Figure 1 The effect of pH on Pilbara mine A tailings yield stress. NaOH was used as the additive to increase the pH. The concentration of NaOH used to arrive at pH 11.7 was 0.23 g per 100 g tailings solids.

The flow or viscosity-shear rate behaviour of this Pilbara A tailings as a function of pH is shown in Figure 2. The untreated tailings at pH 7.3 displayed shear thinning behaviour characterised by viscosity decreasing with shear rate. The treated tailings at pH 10.4 also displayed a similar behaviour but with a much lower viscosity. At any shear rate, the untreated tailings possessed a much higher viscosity than those at a higher pH. The reduction in viscosity at pH 9.7 was about 70% at the shear rate of 139 s^{-1}. The tailings with a pH of 11.74 displayed Newtonian flow behaviour with constant viscosity. This Newtonian tailings has a viscosity of only 11 mPa.s, ~ 10 times that of water. The tailings treated to a pH of ~ 9 showed only a marginal decrease in the viscosity, less than 20% at 139 s^{-1}.

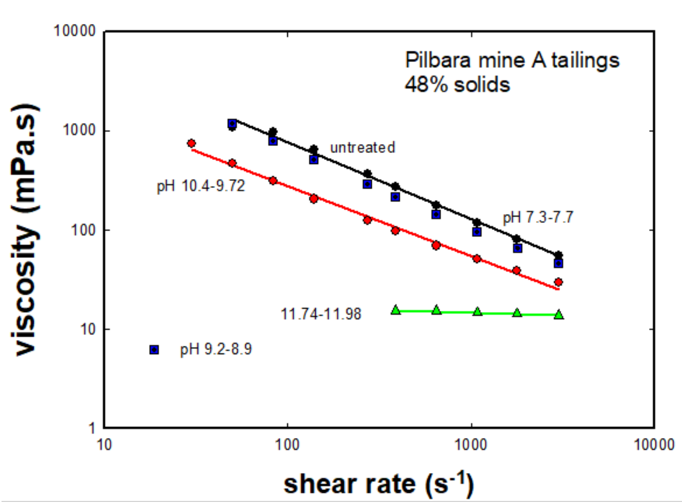
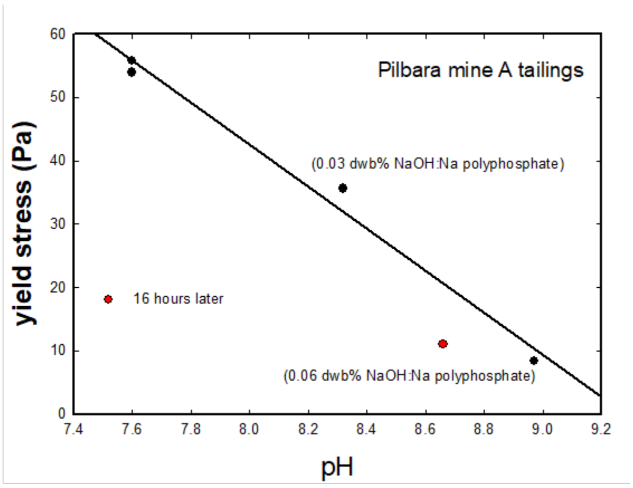
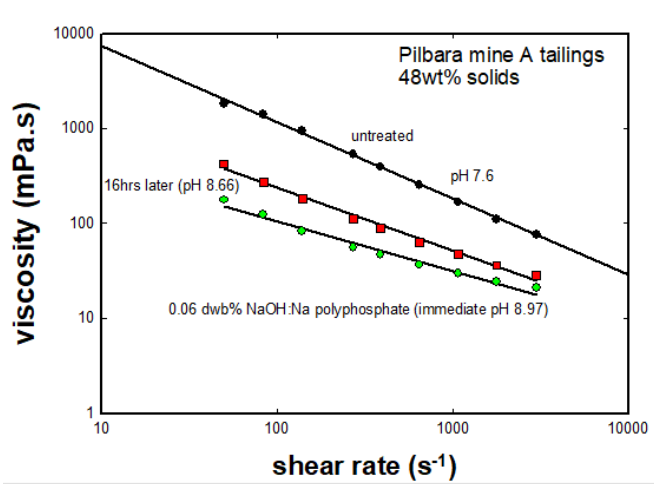


Figure 2 The effect of pH on the viscosity-shear rate behaviour of Pilbara tailings A. NaOH was used to increase the pH.

In addition to NaOH, more effective additives have been developed to reduce iron ore tailings slurries' viscosity and yield stress at a pH well below 10. These composite additives contain NaOH and phosphate-based compounds (Leong 2018, 2021). Figure 3(a) shows the effect of NaOH:Na polyphosphate on the yield stress-pH behaviour of Pilbara mine A tailings. The yield stress was reduced from ~ 60 Pa to less than 10 Pa with 0.06 dwb% (g additives/100 g tailings solids) of the additives while keeping the pH less than nine. The cost of additives was estimated to be USD 0.48 per tonne of tailings solids based on USD 400 per tonne for NaOH and USD 1000 per tonne for polyphosphate. Figure 3(b) shows the viscosity-shear rate behaviour of the slurry treated with 0.06 dwb% composite additives at pH 8.97. It indicates more than a 90% reduction in viscosity at 139 s^{-1} compared to the untreated sample. Upon standing for 16 hrs, the pH was decreased to 8.66, accompanied by an increase in viscosity. The decrease at 139 s^{-1} compared to the untreated sample remained significant, more than 80%.



(a)



(b)

Figure 3 (a) The yield stress-pH behaviour of Pilbara A tailings under the influence of composite additives; (b) The corresponding viscosity-shear rate behaviour.

Not all iron ore tailings from the Pilbara region in Western Australia responded to the NaOH treatment similarly. Figure 4 showed (a) the yield stress-pH and (b) the viscosity-pH behaviour of Pilbara mine B tailings in response to NaOH and some composite additives treatments. There is no significant reduction in the yield stress or viscosity at 139 s^{-1} at pH 10 for the NaOH-treated tailings. Contrary to expectation, both the yield stress and viscosity displayed quite a marked increase. The maximum yield stress and viscosity were located at pH ~ 10.5. It's thus clear with these tailings that the NaOH additive alone cannot mitigate the bottleneck problem of high viscosity and yield stress. A solution was found quickly by the use of appropriate composite additives.

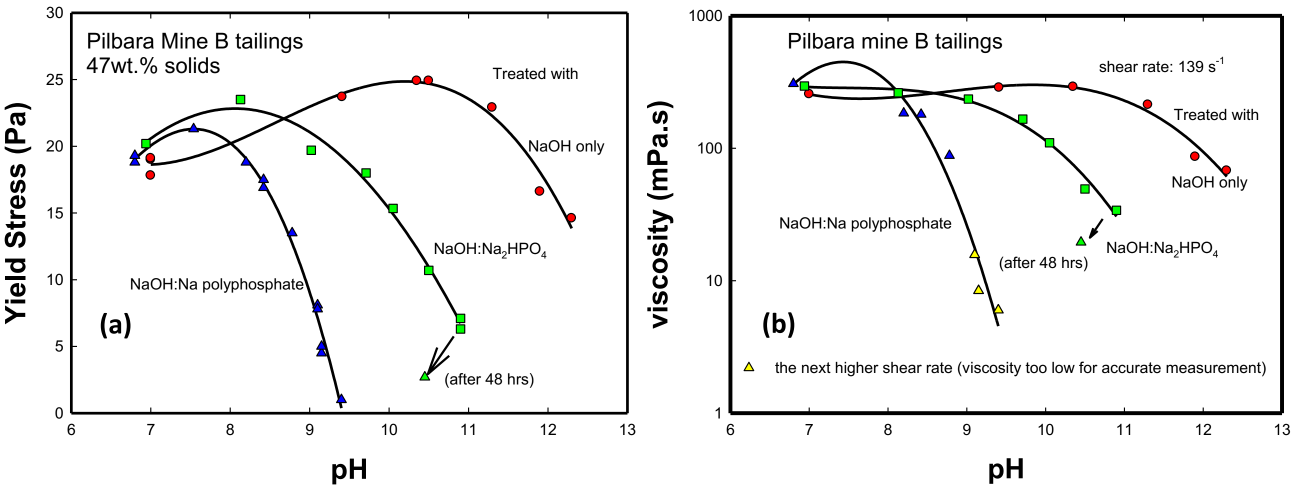


Figure 4 (a) The yield stress-pH behaviour of Pilbara B tailings under the influence of NaOH and composite additives; (b) The corresponding viscosity-pH behaviour

Figures 4(a) and (b) showed the effect of NaOH:Na_2HPO_4 and NaOH:Na poly(phosphate) additives on the yield stress-pH and viscosity-pH behaviour. The yield stress and viscosity decreased sharply at the high pH region. Both the yield stress and viscosity remained relatively high at pH 10 for the first composite additive. In contrast, the composite of NaOH:Na poly(phosphate) reduced the yield stress and viscosity by more than 90% at pH ~9.5, meeting the imposed pH constraint. However, the additive dosage needed was 5 to 10 times more than that required for the mine A tailings. It may be possible to significantly reduce the dosage with changes in the management of the process conditions. (This knowledge is proprietary and cannot be revealed at this stage).

A leaching study was undertaken by SRK Consulting (Australasia) in 2018. The leaching of a range of metal ions was conducted on tailings A at four pHs of 7.58, 7.48, 9.09 and 11.22. The range of metal ions evaluated was extensive, including Li, Na, K, Cs, Mg, Ca, Ag, Al, As, B, Bi, Cd, Ce, Cr, Cs, Cu Fe, Ga, Hf, Hg, La, Li, Mn, Mo, Nb, Ni, Pb, Re, Sb, Se, Si, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Zn and Zr. Many were below the measuring device's detection limit, such as Ag, Ne, Bi, Ce, Cs, Hf, La, Ni, Nb, Re, Sn Ta, Te, Tl, W and Zr. Anions concentrations of Cl^- and SO_4^{2-} were also evaluated. The study concluded that no metal ions exceeded the stock or underground water value. The leached concentrations of some selected metal ions are highlighted here. The leached ions concentration of lead (Pb), selenium (Se), antimony (Sb) and molybdenum (Mo) is shown in Figure 5(a) and that of arsenic and strontium in Figure 5(b). Except for molybdenum, the other metal ions concentrations were very low or below the detectable limit in Figure 5(a).

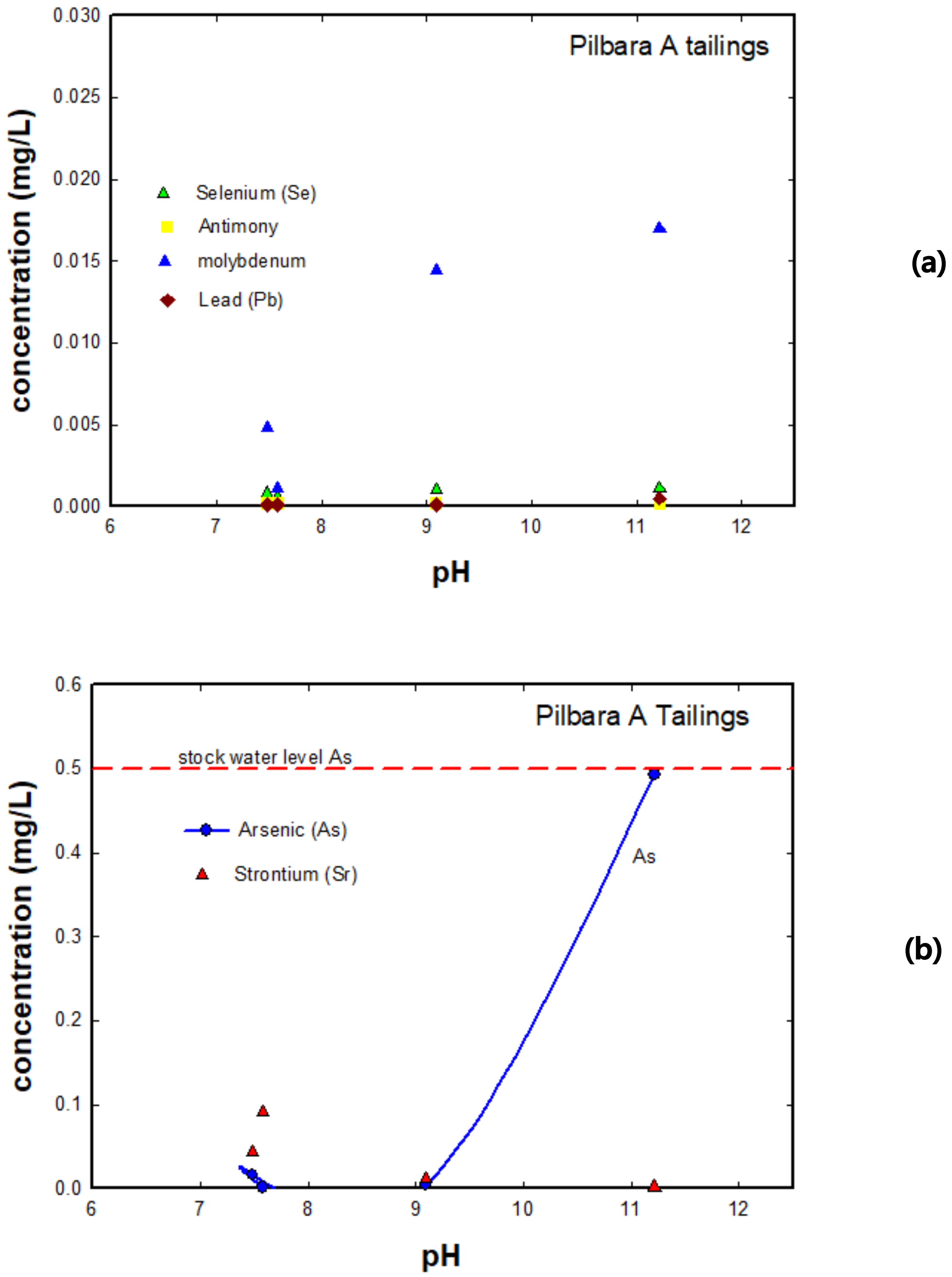
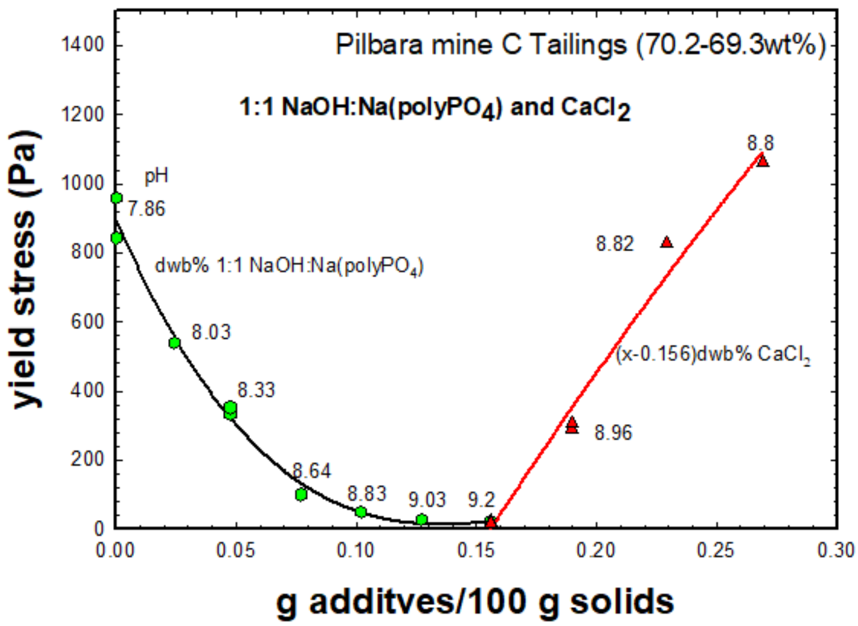
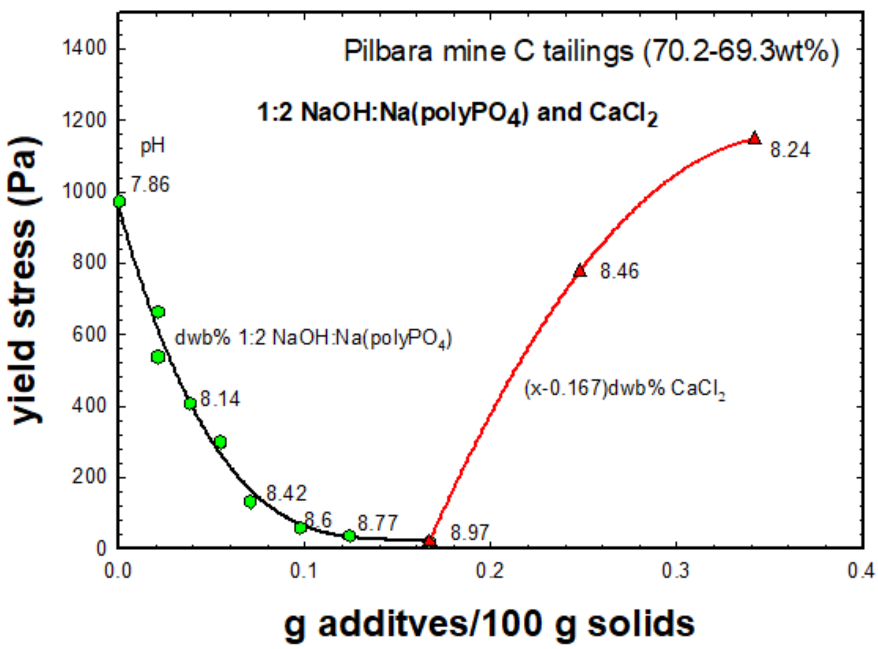


Figure 5 **(a) Leached metal ions concentration of selenium, antimony, molybdenum and lead of Pilbara A tailings at different pH levels; (b) The leached metal ions concentration of arsenic and strontium (SRK Consulting 2018).**

The arsenic concentration was just below the value found in the stock water at pH 11.22. See Figure 5(b). With the discharged tailings pH of less than 10, the amount of leached arsenic ions will be much lower and well below the stock water level. The concentration of strontium decreases with pH.



(a)



(b)

Figure 6 (a) The decrease in yield stress of Pilbara C tailings with 1:2 NaOH:Na(polyPO$_4$) and the subsequent increase with CaCl$_2$; (b) A similar result using a cheaper 1:1 NaOH:Na(polyPO$_4$) followed by a subsequent yield stress increase with CaCl$_2$.

The tailings should ideally have a paste-like consistency for safer storage behind a dam. This consistency is easily achievable if the additive used for viscosity reduction to solve the slurry handling problem contains phosphate-based chemicals such as NaOH:Na(polyPO$_4$). The treated low-viscosity tailings can be converted back to a paste-like consistency before discharge using Ca(II) ions such as lime CaO (Leong 2021; Leong et al. 2019). Ca(II) ions bind to the adsorbed phosphate ions neutralising its viscosity reduction effect. Lime, however, can cause a significant increase in the pH to more than 10. Using Ca(II) solution such as CaCl$_2$ will solve this problem. Figures 6(a) and (b) showed the results for two different compositions of NaOH: NaOH:Na(polyPO$_4$) additives. The composite additives caused a dramatic reduction in the yield stress from 1000 to ~10Pa. Adding CaCl$_2$ solution increased the yield stress to more than 1000 Pa. None of the pHs of the treated tailings was more than 10. Indeed, adding soluble Ca(II) decreased the pH slightly. The composite additives with a lower relative polyphosphate content are cheaper, but the operating pH is somewhat higher. It is 30% cheaper than polyphosphate alone.

Various chemical additives were used to beneficiate iron ore in flotation (Filippov et al. 2014) and gravity separation (Kumar & Mandre 2015). Chemical additives, including anionic additives based on lignite and phenolic compounds, were evaluated for alumina removal (Mahiuddin et al. 1989). Guar gum, starch, and hexametaphosphate were used to beneficiate iron ore tailings. Various flocculants are used to thicken the iron ore tailings, but studies on the use of additives to control the thickened tailings rheology and, at the same time, manage the discharged tailings to meet the strict environmental requirements are scarce or non-existent.

There are various approaches for processing iron ore tailings to facilitate safe storage, such as filtration (Gomes et al. 2016; Mamghaderi et al. 2021) and thickening to paste-like consistency for drying and stacking (Gomes et al. 2016). Exploiting the uses of iron ore tailings is another means of removing the threat posed by low-density tailings storage. They have been evaluated as fillers in concrete (Li et al. 2010; Xiong et al. 2017) and feedstocks for ceramic tiles manufacturing (Das et al. 2000; Fontes et al. 2019). Zhao et al. (2021) have comprehensively reviewed the properties and characteristics of iron ore tailings concrete. Turning treated low-viscosity tailings to paste based on this study for drying or storage behind a dam is the next best safe solution if all other approaches are uneconomical or not feasible.

4 Conclusion

This study demonstrates that the rheology of Rio Tinto iron ore tailings A can be controlled effectively using an inexpensive additive, NaOH, and still meet the environmental constraints (leachate composition and content, and pH) imposed by the authority for the tailings discharge in a tailings storage facility. The performance of the NaOH-phosphate-based composite additives is superior in terms of the viscosity and yield stress reduction at a lower discharge pH costing no more than USD 0.50 per tonne of tailings solids. If necessary, another additive based on calcium can be added to neutralise the phosphate-based compound and turn the tailings into a paste for storage.

Tailings B can be treated similarly with the composite additives but is less cost-effective.

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