145 Ann Street, Level 9
Brisbane, Queensland 4000
Australia
ghd.com

Investigation on the efficient selection of flocculants for dewatering of coal tailings

A Khazaie[1], B Samali[2] and S Gilmour[3]

1. Tailings and Dams Engineer, GHD Pty Ltd, Sydney NSW 2065. Email: atousa.khazaie@ghd.com
2. Professor, Centre for Infrastructure Engineering, Western Sydney University, Sydney NSW 2753. Email: B.Samali@westernsydney.edu.au
3. Geochemist, GHD Pty Ltd, Hobart Tas 7000. Email: sarah.gilmour@ghd.com

ABSTRACT

Coal processing plants generate a large volume of tailings containing fine and colloidal particles. The most conventional method for coal waste disposal is using tailing storage facilities (TSFs) (Khazaie et al, 2022). Tailings dam failures have always been a serious environmental threat to the contamination of surface and groundwater due to seepage, blockages, and insufficient capacity of spillway systems which leads to overtopping (Fourie, 2009; Spain and Tibbett, 2012). Moreover, mine tailings disposal imposes additional cost to mining companies. According to NSW Environment Protection Authority (EPA), the waste levy rate for Coal Washery Reject (CWR) in 2019–2020 is $15 per ton (NSW Environmental Protection Authority (NSW EPA), 2020). Sustainable alternative proposals for coal tailings disposal in tailings dams include mechanical dewatering methods such as coagulation, flocculation, and sedimentation, followed by filtration. Efficient selection of flocculants is an important factor in this process.

In this study, mono flocculation experiments were conducted using various polyacrylamide (PAM) based flocculants with different molecular weight and charge type to evaluate the effect of molecular weight on settling rate and turbidity removal of coal tailings. Microstructural analysis of coal tailings including the X-Ray Diffraction (XRD) and Scanning Electron Microscopy and Energy Dispersive X-ray Spectroscopy (SEM-EDS) results, demonstrated that coal tailings were mostly composed of quartz, magnesium calcite, dawsonite, muscovite, and different clay minerals, including kaolinite, illite, and montmorillonite.

Introduction

Coal processing plants produce large volumes of tailings annually. Tailing storage facilities (TSFs) are the most commonly used method for tailings disposal. Tailing dams have always been a serious threat to the surrounding environment (Fourie, 2009; Spain and Tibbett, 2012). Moreover, they impose additional risk and cost to mining industry. According to NSW Environment Protection Authority (EPA), the waste levy rate for coal tailings disposal in 2019–2020 is $15 per ton (NSW EPA, 2020).

Sustainable alternative proposals for TSFs include mechanical dewatering through coagulation, flocculation, and sedimentation processes, followed by filtration or centrifugation. Polymeric flocculants are normally used in solid-liquid separation of tailings before disposal which can result in saving huge volumes of fresh water consumed in mineral processing plants (Ahmari, Chen and Zhang, 2012; Ahmari and Zhang, 2012).

Polyacrylamide (PAM) flocculants are the most commonly used in coal processing plants that can be classified based on charge type into four categories including cationic, anionic, non-ionic and amphoteric.

The polymers can vary in charge density, molecular weight and polymeric structure. The performance of flocculation is evaluated by two different parameters, ie the turbidity rate of supernatant water and the settling rate of flocculated particles (Sabah and Cengiz, 2004). Various factors involved in the flocculation process such as mineral composition, polymer type and dosage, mixing speed, pH etc (Hogg, 2000; Hogg, Bunnaul and Suharyono, 1993).

This research studies the effect of molecular weight on the flocculation efficiency of cationic PAM (CPAM), anionic PAM (APAM), and non-ionic PAM (NPAM) for dewatering of coal tailings collected from a coalmine in New South Wales (NSW), Australia. The settling rate and turbidity removal have been considered as criteria for optimisation of the flocculation conditions.

Materials and method

Coal tailings were collected from a coalmine in New South Wales, Australia. The electrokinetic potential in coal tailings at its natural pH was measured using a zeta-meter. The pH was also obtained using pH metre. The elemental composition of coal tailings was also obtained using Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) technique. The mineral composition of coal tailings was determined after oven drying by X-ray diffraction (XRD) using a Bruker D8 Advance Powder Diffractometer. Six polyacrylamide-based (PAM) flocculants with different charge type and molecular weight have been used in this study purchased from Henan Runquan Purification Material Co., Ltd, China. The characteristics of these polymers are shown in Table 1

Table 1 Summary of flocculant characteristics.

Name	Charge type	Charge density %	Molecular weight
CPAM-C5	Cationic	40	~5 million
CPAM-C5	Cationic	40	~10 million
APAM-A10	Anionic	40	~10 million
APAM-A14	Anionic	40	~14 million
NPAM-N10	Non-ionic	-	~10 million
NPAM-N14	Non-ionic	-	~14 million

The flocculation experiments were conducted using a Velp JLT6 jar test with speed control. A stock solution of 0.1 g/L of each of the polymers was prepared using tap water. For each flocculation test, 200 ml slurry was added into a 1000 ml glass beaker and stirred for 1 minute at 150 rev/min to obtain a homogeneous suspension. Then, the specified volume of polymer solution was added continuously in a way that the total volume of suspension became 1000 ml and stirred for an additional 1 minute. The water interface and the height of the sediment bed were recorded at selected times for the calculation of the settling rate. The turbidity rate was measured after 15 min of settling using turbidity metre in accordance with ASTM D2035–19 and ASTM D7315–17.

RESULTS AND DISCUSSION

Characterisation of coal tailings

The general characteristics of coal tailings and their elemental composition are presented in Table 2Figure 2 and Table 3 respectively. The Zeta potential value for coal tailings at its natural pH showed that suspended particles carry a negative charge in an aqueous environment. The comparison between the conductivity value of coal tailings and distilled water indicates that the coal tailings are very saline; as a result, they affect the zeta potential significantly. The EDS analysis results specified that coal tailings are mostly composed of Si, Al, and O elements. Mineralogical analysis results show that the coal tailings are mainly composed of quartz, magnesium, calcite, dawsonite, muscovite, and different clay minerals including kaolinite, illite, and montmorillonite.

Table 2 Summary of flocculant characteristics.

Natural pH	Carbon content %	Conductivity (mS/cm)	Zeta potential at natural pH	Original solid content %
8.1	19.75	4.06	– 32	12

Table 3 Elemental composition of coal tailings.

Si	Al	O	Na	Mg	Ca	Fe	K	S	Ti
26.7	14.1	48	0.6	1.2	1.1	3.9	2.5	1.1	0.7

Effect of flocculant type and dosage on sedimentation

Sedimentation of coal tailings using CPAM

The turbidity measurements and settling rate of coal tailings using CPAMs with different molecular weights are plotted as a function of flocculant dosage in Figure 1. Increasing the molecular weight of CPAM significantly improves the settling rate and turbidity removal. The reason can be attributed to the increased micro-ion length, which is in favour of bridge mechanism. The maximum settling rate is obtained by CPAM-C10 at lower dosage compared to the CPAM-C5. In other words, using CPAM-C10 requires less polymer to get the maximum settling rate. In terms of turbidity removal, the optimum dosage is 250 g/t solid for both polymers and after that, increasing the dosage does not have any effect on the turbidity rate while it has an adverse effect on the settling rate. Experimental results show that CPAM-C10 can improve turbidity removal significantly, up to 97.3 per cent, which results in a clear water. The interaction mechanism between CPAM molecules and coal tailing particles is mostly composed of charge neutralisation. Through this mechanism, negatively charged coal tailing particles absorb on positively charged polyacrylamide molecules as a result of electrostatic attraction force (Sabah and Erkan, 2006).

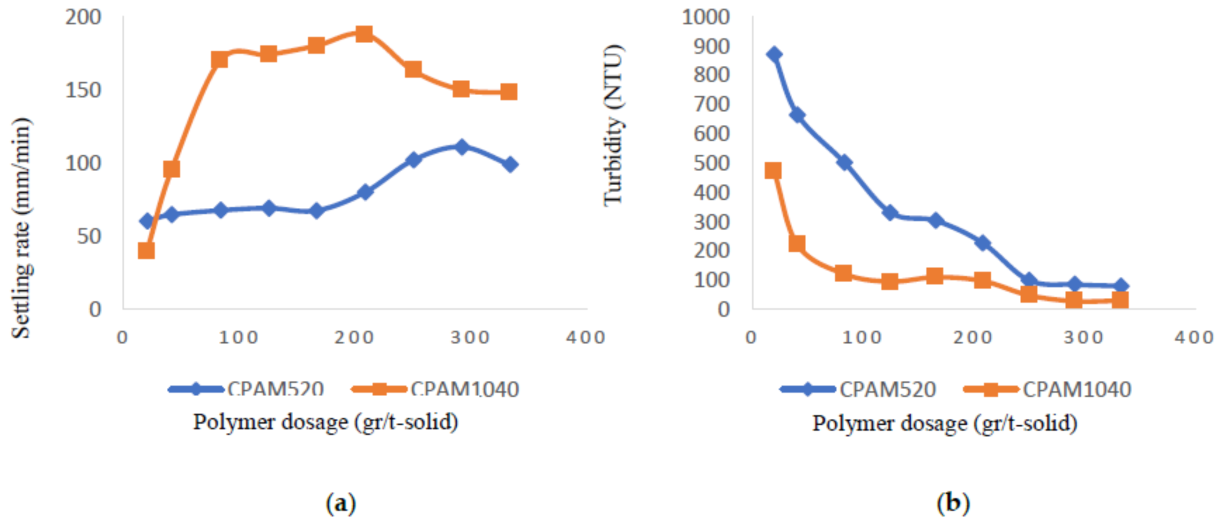
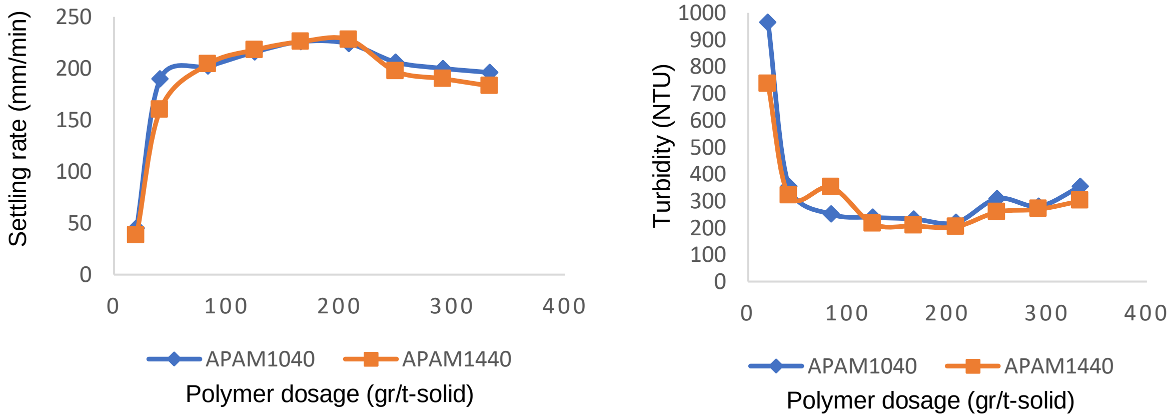


Figure 1 Effect of CPAM on settling rate (a) and turbidity removal (b).

Sedimentation of coal tailings using APAM

The effect of APAMs on settling rate and turbidity removal of coal tailings is presented in Figure 2. Increasing the molecular weight of APAM does not have a specific effect on settling rate and turbidity removal as follows similar trends. In the flocculation of coal tailings using APAM, the bridging mechanism is the main mechanism for the formation of flocs. In this circumstance, the electrostatic repulsion force between functional groups of PAMs and negatively charged coal particles leads to stretching the hydrocarbon chain of polymers. As a result, suspended particles are adsorbed on the polymer chain through the hydrogen and/or chemical bonding (Sabah and Erkan, 2006; Duong et al, 2000). For both polymers, increasing the polymer dosage positively contributes to increasing the settling rate up to a particular dosage. After the optimum dosage, increasing the polymer dosage adversely affects the flocculation rate due to the increased electrostatic repulsion force between functional groups of PAMs and the negatively charges coal particles which compress the electrical double layer (Sabah, Yüzer and Celik, 2004).



(a) (b)

Figure 2 ***Effect of APAM on settling rate (a) and turbidity removal (b).***

Comparing the maximum settling rate and turbidity removal obtained by the APAM and the CPAM, anionic polymers shows a better performance in terms of settling rate, while cationic polymers are more favourable for turbidity removal purposes. Increasing the polymer dosage provides more surfaces for the adsorption of suspended particles and improves the settling rate.

Sedimentation of coal tailings using NPAM

The flocculation results of coal tailings using NPAM are presented in Figure 3. Experimental results using NPAMs shows that increasing the molecular weight as expected has positive effects on the settling rate but negative impact on decreasing the turbidity values. The effect of increasing the polymer dosage on settling rate and turbidity removal followed similar trends to APAMs. However, NPAMs exhibit less restabilisation effect at high dosages. The interaction mechanism between mineral particles and NPAMs is via hydrophobic interactions or hydrogen bonding (Littlefair and Lowe, 1986). The formation of hydrogen bonds occurs between hydroxyl or carboxyl groups of suspended particles in CWR and carboxyl or amide groups or the polymer (Laskowski, 2001). Comparing the maximum settling rate provided by APAMs and NPAMs, flocculation of coal tailings using NPAMs require less polymer dosage than APAMs in order to obtain the optimum settling rate. Moreover, NPAMs provide better performance in terms of turbidity removal compared to APAMs.

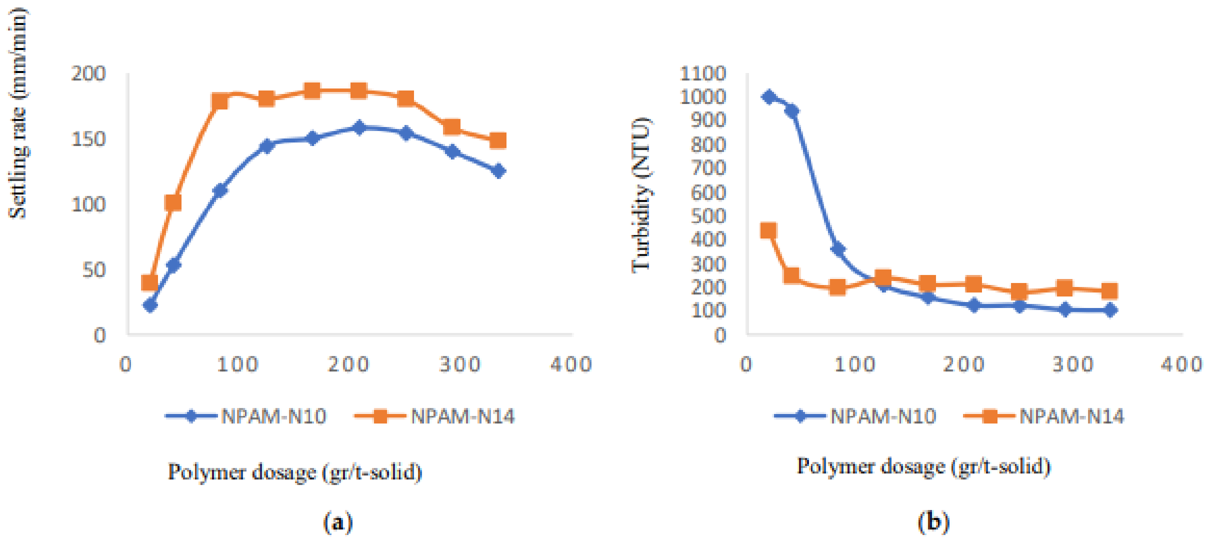


Figure 3 *Effect of NPAM on settling rate (a) and turbidity removal (b).*

Conclusions

XRD and SEM-EDS analysis results demonstrate that coal tailings are mostly composed of quartz, magnesium calcite, dawsonite, muscovite, and different clay minerals, including kaolinite, illite, and montmorillonite. Six commercial polymeric flocculants with different charge type and molecular weight have been tested to identify the effect of molecular weight on flocculation performance at different dosages in terms of settling rate and turbidity value. According to sedimentation results, APAMs provide a high settling rate whereas CPAMs and NPAMs are more effective for turbidity removal. The results also show that increasing the molecular weight of cationic PAM improves the settling rate and turbidity removal while it does not have a significant effect on results obtained from anionic PAM. Although the non-ionic polymer with higher molecular weight achieves a higher settling rate, it is less effective in decreasing the turbidity rate at high dosages.

REFERENCES

Ahmari, S and Zhang, L, 2012. Production of eco-friendly bricks from copper mine tailings through geopolymerization, *Construction and Building Materials,* 29:323–331.

Ahmari, S, Chen, R and Zhang, L, 2012. Utilization of mine tailings as road base material, GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering.

Duong, C, Choung, J, Xu, Z and Szymanski, J, 2000. A novel process for recovering clean coal and water from coal tailings, *Minerals Engineering,* 13(2):173–181.

Fourie, A, 2009. Preventing catastrophic failures and mitigating environmental impacts of tailings storage facilities, *Procedia Earth and Planetary Science,* 1:1067–1071.

Hogg, R, 2000. Flocculation and dewatering, *International Journal of Mineral Processing,* 58:223–236.

Hogg, R, Bunnaul, P and Suharyono, H, 1993. Chemical and physical variables in polymer-induced flocculation, *Mining, Metallurgy & Exploration,* 10:81–85.

Khazaie, A, Mazarji, M, Samali, B, Osborne, D, Minkina, T, Sushkova, S, Mandzhieva, S and Soldatov, A, 2022. A review on coagulation/flocculation in dewatering of coal slurry, *Water,* 14:918.

Laskowski, J, 2001. Coal flotation and fine coal utilization (Elsevier).

Littlefair, M and Lowe, N, 1986. On the selective flocculation of coal using polystyrene latex, *International Journal of Mineral Processing,* 17:187–203.

NSW Environmental Protection Authority (NSW EPA), 2020. Levy regulated area and levy rates [online]. Available: https://www.epa.nsw.gov.au/your-environment/waste/waste-levy/levy-regulated-area-and-levy-rates

Sabah, E and Cengiz, I, 2004. An evaluation procedure for flocculation of coal preparation plant tailings, *Water Res,* 38:1542–9.

Sabah, E and Erkan, Z, 2006. Interaction mechanism of flocculants with coal waste slurry, *Fuel,* 85:350–359.

Sabah, E, Yüzer, H and Celik, M, 2004. Characterization and dewatering of fine coal tailings by dual-flocculant systems, *International Journal of Mineral Processing,* 74:303–315.

Spain, A and Tibbett, M, 2012. Coal mine tailings: development after revegetation with salt-tolerant tree species, in *Mine Closure 2012, Proceedings of the Seventh International Conference on Mine Closure*, pp 583–594 (Australian Centre for Geomechanics: Perth).