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Influencing factors on the efficiency of tailings slurry thickening with sodium polyacrylate superabsorbent polymers

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Abstract

This study proposes an alternative method for dewatering mine tailings slurries using superabsorbent polymers (SAPs), leveraging their exceptional water absorption and retention properties. The factors influencing the efficiency of this dewatering process are systematically evaluated and discussed. Experimental investigations were conducted using two types of SAPs (SAP1 and SAP2, differentiated by varying concentrations of the same adsorbed Na cation) to assess their dewatering potential on four distinct mine tailings slurries under two addition modes (direct and indirect). The initial solid mass concentrations ($C_{w\_initial}$) tested were 40% and 50%, with SAP dosages (D_{vSAP}) ranging from 6 to 29 kg dry SAP per cubic meter of tailings slurry.

The findings indicate a negligible difference in absorbency between SAP1 and SAP2. Furthermore, final solid mass concentrations (C_{w_final}) of 70–82% were achieved with SAP dosages between 10 and 29 kg/m³. However, the efficiency of the SAP-mediated dewatering process was influenced by several factors, including D_{vSAP}, the mineralogical and physical characteristics of the tailings' slurry, the initial solid mass concentration ($C_{w\_initial}$), the porewater chemistry and geochemistry, the SAP residence time (RT), and the addition mode (direct or indirect).

Keywords: *tailings management, superabsorbent polymers, dewatering of mine tailing slurries, tailings storage facility, surface deposition*

1 Introduction

In Canada, the mining industry generates over 800 million metric tonnes of solid waste annually, comprising tailings and waste rock (2016 data; Lapointe 2020). In the United States, this figure approaches 2 billion metric tonnes annually. Globally, the cumulative volume of tailings produced over recent decades is estimated to exceed 200 billion metric tonnes (Twardowska & Allen 2004). Tailings are the finely ground (1–800 µm) residual rocks left after extracting economically valuable minerals and process water (e.g. Edraki et al. 2014). In the United States, mineral processing waste constitutes nearly half of all solid waste generated annually. Mining operations can produce a volume of tailings nearly equivalent to the raw ore processed (Adiansyah et al. 2015). For instance, it was reported that the global mining industry generated approximately 14 billion metric tonnes of tailings in 2010 alone (Jones & Boger 2012).

Tailings are typically stored on the surface as a slurry in tailings storage facilities (TSFs), with solid mass concentrations (C_w) at deposition ranging between 20–50% (Bussière 2007; KCB 2017) for conventional deposition methods. Although conventional deposition methods are considered simple and cost-effective, they are associated with substantial financial and environmental risks, as well as catastrophic failures (Hatje et al. 2017; Owen et al. 2020). Such failures are often attributed to inadequate tailings and mine water management practices. Given the severe socioeconomic and environmental consequences of poor tailings management, exploring alternative approaches to conventional deposition is imperative. Densifying tailings

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before deposition, through methods such as thickened, paste, or filtered tailings, offers a viable alternative for improving tailings management practices (e.g. Bussière 2007; Moreno et al. 2018; Yin et al. 2020).

The primary equipment currently employed for densifying tailings slurries and enhancing water recovery includes hydrocyclones, conventional/high-rate thickeners, high-density/paste thickeners, vacuum belt/disc filters, and filter presses. These methods significantly reduce the environmental footprint of tailings management by increasing slurry density, thereby improving both chemical and mechanical stability. However, these technologies are expensive to operate (Carneiro & Fourie 2018) and often fail to achieve the desired solid mass concentration targets (e.g. Fourie 2009; Sahi et al. 2019). This shortfall is partly due to the increased fine grinding of ores, necessitated by favourable conditions in the base and precious metals markets to maximise recovery rates. While this practice enhances metal extraction, it can compromise the stability of TSFs. Consequently, there is an urgent need for research into more efficient and cost-effective methods of tailings dewatering and densification, addressing the fundamental sustainability pillars of environmental, economic, social, and regulatory considerations (Adiansyah et al. 2015).

Superabsorbent polymers (SAPs), which possess exceptional water absorption and retention capacities, offer a promising alternative for non-mechanised thickening processes. SAPs are hydrophilic materials capable of absorbing and retaining significant amounts of water relative to their mass by trapping water molecules in their macro-porous structures via capillary and osmotic forces (Zohuriaan-Mehr 2008). The water absorption capacity of SAPs is influenced by the degree of crosslinking within the polymer chains; higher crosslinking reduces polymer chain expansion, thereby lowering absorbency (Masuda & Iwata 1986; Omidian 1998; Bajpai et al. 2006; Ismi et al. 2015; Radwan et al. 2017). The potential of SAPs for dewatering applications was first demonstrated by Masuda and Iwata (1990) in fine coal dewatering. Subsequent studies confirmed the efficacy of SAPs in reducing the moisture content of fine coal (Peer & Venter 2003; Roshani et al. 2017). The water absorption behaviour of SAPs depends on the properties of the suspension medium, SAP characteristics, and the concentration and composition of the aqueous solution (Kazanskii & Dubrovskii 1992; Huettermann et al. 2009; Bhardwaj et al. 2007; Yu et al. 2011; Roshani et al. 2017; Joseph-Soly et al. 2019). These findings suggest that SAP-based dewatering represents a promising innovation for a variety of mining industry applications. Encouraging results have been reported for the thickening and densification of mine tailings using SAPs (Sahi et al. 2017; 2019; Kabamba et al. 2019), underscoring the potential of this technology to address critical challenges in tailings management.

The primary objective of this study is to develop and execute an experimental program aimed at enhancing the dewatering of four distinct types of tailings slurries by leveraging the properties of SAPs. The investigation evaluates the parameters influencing the absorption capacity of SAPs, including mine water ionic strength, SAP dosage, initial solid mass concentration, the types of SAPs and tailings, residence time (RT), and the mode of SAP addition (direct or indirect). This research aims to improve the understanding of SAP behaviour within tailings pulp, enabling an assessment of the feasibility and efficiency of this dewatering process for applications in the metal mining industry.

2 Materials and methods

2.1 Mine tailings

In this study, gold tailings were collected from four distinct mining sites in the Abitibi-Témiscamingue region of Quebec, Canada, and designated as tailings A, B, C, and D. The samples were stored separately in plastic barrels. The tailings were manually homogenised in the laboratory, and sub-samples were extracted for physical, mineralogical, and chemical characterisation. The relative density (D_R, formerly referred to as specific gravity, G_s) of the tailings was determined using a helium pycnometer following ASTM D4892-24 (ASTM International 2024). The relative density values are 2.77 for tailings A, 2.90 for tailings B, 3.10 for tailings C, and 2.74 for tailings D.

The particle size distribution (PSD) of the tailings was analysed using a Malvern Mastersizer S3000 laser particle size analyser, following ASTM C1070-01. The PSDs of the four tailings samples are shown in Figure 1, from which the ultrafine content (particles with *d* < 20 µm, $P_{20µm}$) and fine content (particles with *d* < 80 µm, $P_{80µm}$) were determined. Additionally, key physical parameters derived from the PSD curves include the coefficient of curvature (C_C), the coefficient of uniformity (C_U), and D_x (the particle diameter corresponding to x% passing). These parameters are summarised in Table 1.

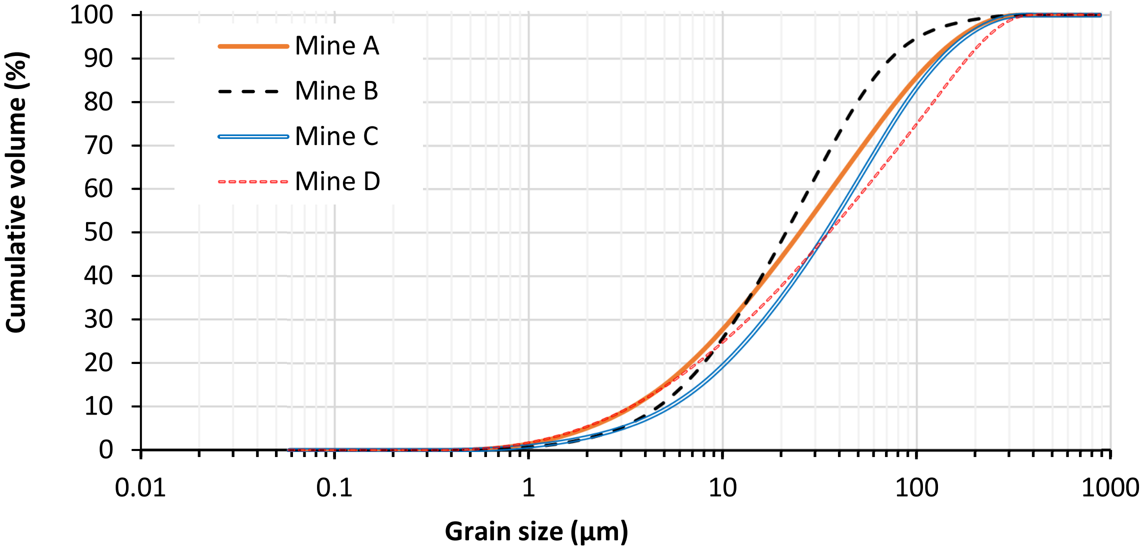

Figure 1 **Laser diffraction particle size distribution curves for the four mine tailings**

As presented in Table 1, the $P_{20µm}$ values for the four tailings range between 35–60%. According to the Golder Paste Technology classification system (e.g. Landriault 2001; Belem & Benzaazoua 2008), these tailings are classified as medium-sized.

Table 1 **Tailings main physical parameters from the particle size distribution curves**

Parameter	Tailings A	Tailings B	Tailings C	Tailings D
D_{10} (µm)	3.4	1.9	5.3	3.4
D_{30} (µm)	11.1	3.8	16.3	13.5
D_{50} (µm)	25.0	5.8	33.9	35.3
D_{60} (µm)	36.3	7.1	46.7	54.2
D_{90} (µm)	123.2	15.2	133.5	182.9
C_U (µm)	10.7	3.8	8.8	16.1
C_C (µm)	1.0	1.1	1.1	1.0
% clay mineral	4.5	2.5	2.5	2.5
$P_{20µm}$ (%)	43.0	48.0	35.0	38.0
$P_{80µm}$ (%)	81.0	92.0	76.0	68.0

The mineralogical composition was determined via X-ray diffraction using a Bruker AXS Advance D8 diffractometer equipped with a cobalt anode, scanning over a diffraction angle range (2θ) from 5° to 70°. Mineral species were identified using the DiffracPlus EVA software, while their abundance was quantified through the Rietveld refinement method using TOPAS software (e.g. Bouzahzah et al. 2008). The results of the mineralogical characterisation reveal that Tailings A are rich in albite (42.3%) and quartz (24.4%). Tailings B predominantly comprise quartz (47.8%) and chlorite (22.1%). Similarly, Tailings C exhibits a high quartz content (72.7%) and significant sulphide mineralisation, primarily pyrite (~20%). Tailings D is characterised by a high abundance of albite (59.6%) and quartz (20.1%).

2.2 Superabsorbent polymers tested

The tailings dewatering tests used two types of synthetic, cross-linked, and negatively charged acrylate-acrylamide copolymers (SAP1 and SAP2). These SAPs were sourced from two different suppliers. The first type, SAP1, is commercially known as SAG-MD6K and was provided by Recyc PHP Inc. (Drummondville, Canada). The second type, SAP2, is identified as APROMUD-G300 and was supplied by APROTEK S.A.R.L. (France). The concentration and type of adsorbed cation on the SAPs were determined using microwave plasma atomic emission spectroscopy (MP-AES). The results showed that the negative charges on both SAPs were neutralised by adsorbed sodium cations (Na^+), though at different concentrations: 172 ppm for SAP1 and 135 ppm for SAP2. The PSD of the SAPs in their dry state was analysed using a Malvern Mastersizer S3000 laser particle size analyser with dry dispersion. The resulting PSD curves are presented in Figure 2.

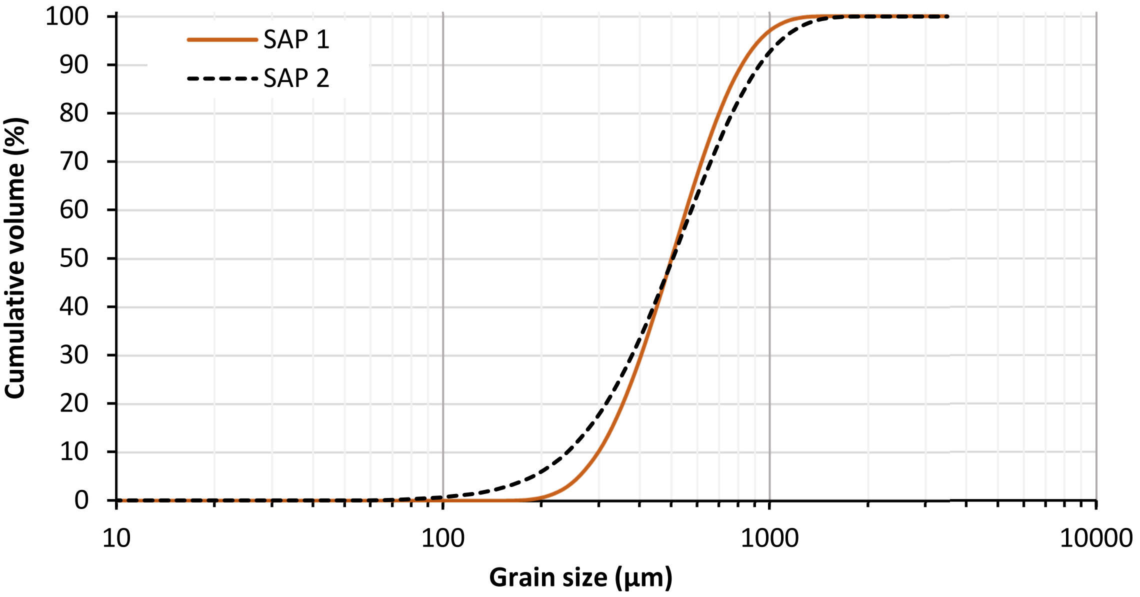

Figure 2 Particle size distribution curves of the two tested superabsorbent polymers

Figure 2 shows that the PSDs of SAP1 (200–1,850 µm) and SAP2 (100–1,850 µm) are nearly identical. Both SAPs exhibit a uniform grading with a narrow PSD, as indicated by their CU of 1.9–2.3 and span values of 1.06–1.4. Based on the specific surface area (S.S.A.) derived from the PSD curves (0.081–0.261), SAP2 can be considered relatively finer than SAP1, which is coarser.

2.3 Methods: physicochemical characterisation of the superabsorbent polymers

2.3.1 Cationic composition of neat superabsorbent polymer

It should be emphasised that this test aims to provide a baseline of the cation exchange state of unreacted (neat) SAP. In this study, 1.5 g of dry SAP (SAP1 and SAP2) was directly mixed with 500 mL of a 1 mol/L ammonium acetate ($CH_3COO.NH_4$) solution in a beaker. The mixture was manually stirred for 5 minutes using a spoon to ensure uniform distribution. After a 2-hour contact period, the superabsorbent hydrogel (also, SAP-gel or swollen SAP) was separated from the solution using a geotextile bag, and 20 mL of the residual water was collected. This process was repeated twice more, and the recovered residual waters were combined. The nature and concentration of the cations adsorbed onto the SAP (specifically Ca, Mg, Na, and K) were determined using MP-AES, with the results provided in Table 2.

2.3.2 Cationic composition of superabsorbent polymer in mine water

For this analysis, 1.5 g of dry SAP was manually mixed with 500 mL of supernatant mine water in a beaker for 5 minutes. After reaching equilibrium between the SAP and the supernatant (after 24 hours), the SAP hydrogel was removed from the mine water and placed into 250 mL of a 1 mol/L $CH_3COO.NH_4$ solution. The cationic composition was determined as described previously for the neat SAP, with the results presented in Table 2. This table shows the composition of the cation exchange complex for both the neat SAP and the SAP soaked in mine water (supernatant).

The data indicate that cation exchange between the SAP and the solution (either distilled water or supernatant) led to an increase in the concentrations of Ca^{2+} and Mg^{2+} in the SAP, at the expense of Na^+ and K^+. For instance, for SAP1, the initial concentrations of Na^+ and Ca^{2+} in the polymer were 172 ppm and 1.48 ppm, respectively. After mixing with the Tailings A supernatant, the Na concentration in SAP1 decreased to 111 ppm, while the Ca concentration increased to 59.9 ppm. The degree of cation exchange appears to be influenced by the specific nature of the supernatant (i.e. Tailings A, B, C, or D).

Table 2 Composition of the cation exchange complex of the neat superabsorbent polymer and superabsorbent polymer in mine water

SAP	**Analysis**	**Cation concentration (ppm)**			
		Na^+	**K^+**	**Ca^{2+}**	**Mg^{2+}**
SAP1	Neat SAP1	172	0.40	1.48	0.28
	S-Tailings C	125	0.53	5.85	0.77
	S-Tailings B	158	0.72	6.60	0.86
	S-Tailings D	127	3.59	121.00	0.86
	S-Tailings A	111	19.20	59.90	1.32
SAP2	Neat SAP2	135	0.24	1.84	0.31
	S-Tailings C	124	0.52	6.61	0.95
	S- Tailings B	109	0.37	3.79	0.66
	S-Tailings D	144	3.76	103.00	0.68
	S-Tailings A	105	18.70	72.20	1.50

2.3.3 Measurements of deswelling of the swollen superabsorbent polymer

The SAP hydrogel samples, which had reached their equilibrium absorption capacity in distilled water, were placed in open dishes at ambient temperature (22 ± 2°C) for 20 days. The mass change of each SAP hydrogel sample was monitored by weighing at regular intervals. The deflation behaviour of the swollen SAP hydrogels was characterised by their water retention capacity, which refers to the residual water content in the SAP hydrogel after the spontaneous release of water. The water retention capacity (WR) was calculated as per Equation 1 (Adair et al. 2017):

$$WR(\%) = 100 \times \frac{M_{\text{SAP-deflated}}(t)}{M_{\text{SAP-swollen}}(t_0)} \tag{1}$$

where:

t = a given time

t_0 = the initial time.

2.4 Methods: superabsorbent polymer water absorption and tailings dewatering mode (direct and indirect)

The dewatering mode aims to determine the optimal SAP dosages required to enhance the dewatering of tailings slurries, achieving a final solid mass concentration (%$C_{\text{w-final}}$) ranging from 70–90%, while also assessing the factors that influence the dehydration process of the tailings.

2.4.1 Absorption rate test in supernatant waters

The purpose of this test was to evaluate the mine water absorption capacity of the SAPs. A weighed dry sample of SAP was added to two beakers, one containing 500 mL of distilled water and the other containing mine water. The beakers were sealed with plastic film to prevent water evaporation. At regular intervals, the polymer-water mixture was transferred into a wet geotextile bag (saturated), which was then suspended for 20 minutes to allow the free water to drain from the hydrogel by gravity. The sample was then weighed. The SAP absorbency (Q_{SAP}) was calculated (in g water/g dry SAP) in duplicate using Equation 2:

$$Q_{\text{SAP}} = \frac{m_3 - \left(m_1 + m_2\right)}{m_1} \tag{2}$$

where:

m_1 = the mass of the dry SAP (in g)

m_2 = the wet geotextile bag (in g)

m_3 = the wet geotextile bag containing the SAP hydrogel.

2.4.2 SAP dosages

In this study, the SAP dosage (D_{vSAP}, in kg/m^3) is defined as the ratio of the dry mass of SAP ($m_{\text{SAP-dry}}$, in kg) to the volume of the slurry tailings (V_{slurry}, in m^3), as shown in Equation 3 (Sahi et al. 2017, 2019):

$$D_{\text{vSAP}} = \frac{m_{\text{SAP-dry}}}{V_{\text{slurry}}} = m_{\text{SAP-dry}}\left(\frac{\rho_{\text{slurry}}}{m_{\text{slurry}}}\right) \tag{3}$$

The corresponding mass dosage, D_{mSAP} (in kg SAP/t of dry tailings), which would be easily usable by the mining industry, is given by the relation in Equation 4:

$$D_{\text{mSAP}} = \frac{m_{\text{SAP-dry}}}{m_{\text{tailings-dry}}} = \frac{D_{\text{vSAP}}}{C_{\text{w0}}\rho_{\text{slurry}}} \tag{4}$$

where:

ρ_{slurry} = is the wet density of the tailings slurry (in t/m^3)

m_{slurry} = is the mass of the slurry tailings (in t)

C_{w0} = is the initial solids mass concentration of the tailings slurry (decimal).

2.4.3 Tailings slurry dewatering using the indirect addition mode of superabsorbent polymer

In this experiment, a known mass of SAP is placed into a wet geotextile bag and submerged into rectangular bins containing tailings slurries with two different initial solid mass concentrations ($C_{\text{w-initial}}$) of 40% and 50%. Additionally, varying RT ranging from 5 minutes to 72 hours were tested. The bins were sealed with lids to prevent evaporation. After the specified RT, the geotextile bags containing the swollen SAPs were removed and suspended for 20 minutes above the bins to allow excess free water to return to the dewatered tailings (e.g. Kabamba et al. 2019). The thin layer of mine tailings covering the swollen SAP hydrogel was removed and placed back into the bins using a spatula. The resulting thickened/dewatered tailings were then weighed and oven-dried at 60°C. After three days of drying, the samples were reweighed to calculate the gravimetric water content (*w*) and the corresponding solid mass concentration (%C_w).

2.4.4 Tailings slurry dewatering using the direct addition method of superabsorbent polymer

The first step in this experiment involved preparing known masses of tailings slurry at two initial solid mass concentrations ($C_{w\text{-initial}}$) of 40% and 50%. A fixed mass of SAP was then added to a KitchenAid mixer bowl containing the tailings slurry. The SAP-tailings mixture was kneaded at low speed (speed 1) for 7 minutes and subsequently stored in sealed plastic containers. Preliminary tests revealed that separating the SAP hydrogel from the dewatered fine tailings using sieve screening was not feasible due to the sticking and agglomeration of fine tailings particles on the swollen SAP. This made it impossible to measure the water absorbed by the SAP or determine the resulting solid mass concentration of the thickened tailings. Therefore, a novel approach was devised to overcome this separation issue.

It is assumed that the SAP powder, which constitutes only 1.2–1.6% of the total tailings slurry mass, could absorb a significant amount of water, forming a gel-like substance. This gel would lock the water firmly within, preventing it from interacting with the surrounding tailings matrix and the residual free water. Consequently, it is hypothesised that the SAP hydrogel would not substantially affect the workability and water content of the thickened tailings, which are primarily influenced by the residual free water. It can be concluded that the workability and final water content of the SAP-based thickened tailings mixture are primarily controlled by the amount of free water (not absorbed by the SAP-gel) and the properties of the tailings. Based on this assumption, the solid mass concentration of the SAP-based thickened tailings, corresponding to a given slump value, can be predicted empirically by comparing it to the slump value of a reference mine tailings mixture without SAP. The slump of the SAP-based thickened tailings mixture was measured using a small Abrams cone (150 mm in height). Subsequently, the solid mass concentration (C_w) of the SAP-based thickened tailings was calculated using a statistical regression model that relates the solid mass concentration of the reference mine tailings (C_{w0}) to the corresponding slump (s) value (Table 3).

Table 3 Predictive empirical equations of solid mass concentration of mine tailings according to slump

Mine tailings	Empirical equations	Correlation
Tailings A	$\%C_w = 0.816793 - 0.005397(\text{slump}) - 0.00015(\text{slump})^2$	$R^2 = 0.98$
Tailings B	$\%C_w = 0.816300 - 0.014749(\text{slump}) + 0.000171(\text{slump})^2$	$R^2 = 0.99$
Tailings C	$\%C_w = 0.835965 - 0.008358(\text{slump}) + 0.000038(\text{slump})^2$	$R^2 = 0.99$
Tailings D	$\%C_w = 0.791295 + 0.002289(\text{slump}) - 0.000439(\text{slump})^2$	$R^2 = 0.98$

3 Results

3.1 Water retention capacity of the superabsorbent polymers

Figure 3 illustrates the variation in the *WR* capacity of the SAP, as defined by Equation 1, over time. As shown in the Figure, the residual water content in SAP1 and SAP2 decreases progressively with time, eventually reaching a completely dry state after approximately 17 days of drying under ambient conditions. During the initial two days of drying, SAP1 (coarser), which exhibits a higher water absorbency (277 g/g) in distilled water, demonstrated a slightly slower deswelling rate of 2% compared to SAP2 (finer), which has a lower absorbency (257 g/g). This suggests that the higher water absorption capacity associated with coarser SAP correlates with a reduced water-holding capacity. This phenomenon can be attributed to the reduced crosslinking degree and increased mesh size of the SAP network, which enhances the swelling capacity and facilitates higher water absorption. However, this increased swelling reduces the mechanical strength of the swollen polymer chains, thereby accelerating the deswelling process over time (e.g. Li et al. 2004; Dogu &

Okay 2006; Sadeghi et al. 2013). From the third day of drying onward, the rates of water loss for both SAP1 and SAP2 became nearly identical.

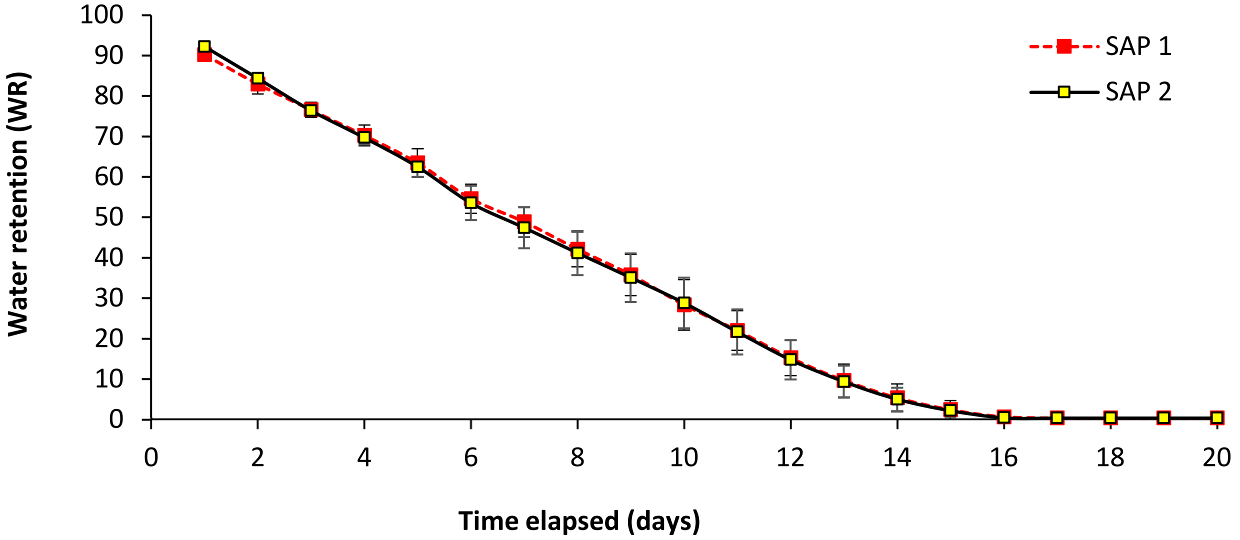

Figure 3 Variation in water retention capacity of the superabsorbent polymers after equilibrium absorption of distilled water over time, at ambient temperature

3.2 Rate of mine water absorption by the superabsorbent polymers

The chemical composition of the surrounding water medium is recognised as a critical factor influencing the water absorption capacity of SAPs (Flory 1953; Castel et al. 1990; Li et al. 2004; Ismi et al. 2015). To investigate and quantify this phenomenon, SAP1 (coarse) was selected for use with mine tailings slurries A, B, and C. The water absorption kinetics of SAP1 were evaluated in three distinct supernatants: the supernatant from Tailing A (S-Tailings A), the supernatant from Tailings B (S-Tailings B), and the supernatant from Tailings C (S-Tailings C).

The ionic strength (I_s) of each supernatant, which represents the intensity of the electric field due to ionic activity, was calculated based on the chemical composition of the supernatants and is presented in Table 4. Ionic strength depends on both the concentration and valence of ions in the solution and is defined by Equation 5 (Tsobanoglous & Schroeder 1985):

$$I_s = \frac{1}{2}\sum C_i z_i^2 \tag{5}$$

where:

C_i = is the concentration of the i^{th} element in the solution (in mol/l or mol/kg)

z_i = is the valence.

Table 4 Chemical composition of mine water supernatants and their ionic strength (I_s)

Parameter	S-Tailing A (mg/l)	S-Tailing B (mg/l)	S-Tailing C (mg/l)
Al	0.185	0.188	0.359
Ca	214	535	793
Fe	0.349	0.348	0.2
K	126	80.4	89.2
Mg	10.2	5.91	18.3
Na	291	498	954
S	558	976	1,510
Si	1.57	2.06	7.66
Sr	3.61	1.77	1.97
Zn	0.147	0.156	0.236
Si	21.34	20.19	21.32
I_s (mol/kg)	4.4×10^{-2}	7.4×10^{-2}	1.1×10^{-1}
pH	8.1	7.9	7.5

As Table 4 illustrates, the trend of the ionic strength (I_s) of these three supernatant media is as follows:

$$I_{s\_(\text{Tailings C})} > I_{s\_(\text{Tailings B})} > I_{s\_(\text{Tailings A})}$$

The results presented in Figure 4 indicate that the water absorption capacity (Q_{SAP}) of the SAP decreases as the ionic strength of the surrounding water medium increases. After an *RT* of 24 hours (1,440 minutes), the lowest absorbency, 29.4 g of water per gram of SAP, was observed in the Tailings C supernatant, which had the highest ionic strength (1.1×10^{-1} mol/kg). In contrast, the highest absorbency, 53.1 g of water per gram of SAP, was achieved in the Tailings A supernatant, which exhibited the lowest ionic strength I_s (4.4×10^{-2} mol/kg).

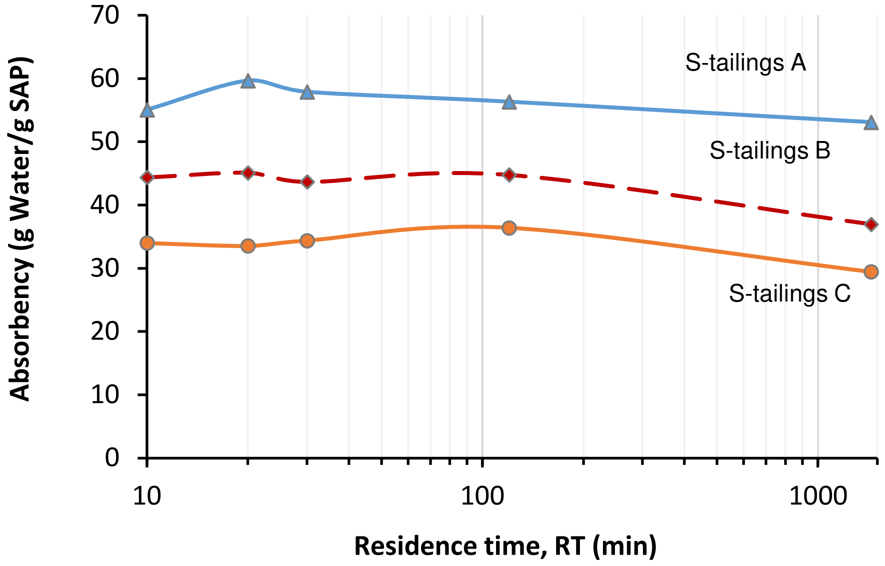

Figure 4 **Variation in water absorption capacity (Q_{SAP}) of SAP 1 as a function of RT: (a) in mine water or supernatant (dosage used is 5 g SAP/500 ml of water)**

3.3 Tailings slurry thickening using superabsorbent polymers in geotextile bags (indirect mode)

Figure 5 illustrates the variation in the final solid mass concentration (%C$_{\text{w-final}}$) of Tailings A slurry with an initial solid mass concentration (%C$_{\text{w-initial}}$) of 50% over time. The study evaluated three different dosages of SAP1 (9, 10, and 12 kg/m^3) using an indirect addition mode. For a 9 kg SAP/m^3 dosage, %C$_{\text{w-final}}$ reached 61.7% within approximately 20 minutes, with rapid dewatering occurring – 95% of which was completed in the first 5 minutes. Increasing the SAP1 dosage from 9 to 12 kg/m^3 led to a %C$_{\text{w-final}}$ of 71.7%, representing an increase of over 16% in the final solid content. As shown in Figure 5, a target %C$_{\text{w-final}}$ of 70% can be achieved with a dosage (D$_{\text{vSAP}}$) of ≥12 kg SAP/m^3 within a short RT (~10 minutes).

Figure 6 provides additional insights into the dewatering behaviour of Tailings A slurry at initial solid mass concentrations (%C$_{\text{w-initial}}$) of 40% and 50%, with SAP dosages ranging from 6–18 kg/m^3 applied via the indirect addition mode for an *RT* of 72 hours. The results indicate that the primary factors influencing the dewatering process include %C$_{\text{w-initial}}$, the SAP type, and the SAP dosage. For a %C$_{\text{w-initial}}$ of 40%, SAP1 at low dosages (8– kg/m^3) resulted in %C$_{\text{w-final}}$ values of 57–68%, which fall below the target solid content of 70%. However, using the same dosage range with %C$_{\text{w-initial}}$of 50%, %C$_{\text{w-final}}$ values in the range of 70–75% were achieved, surpassing the target.

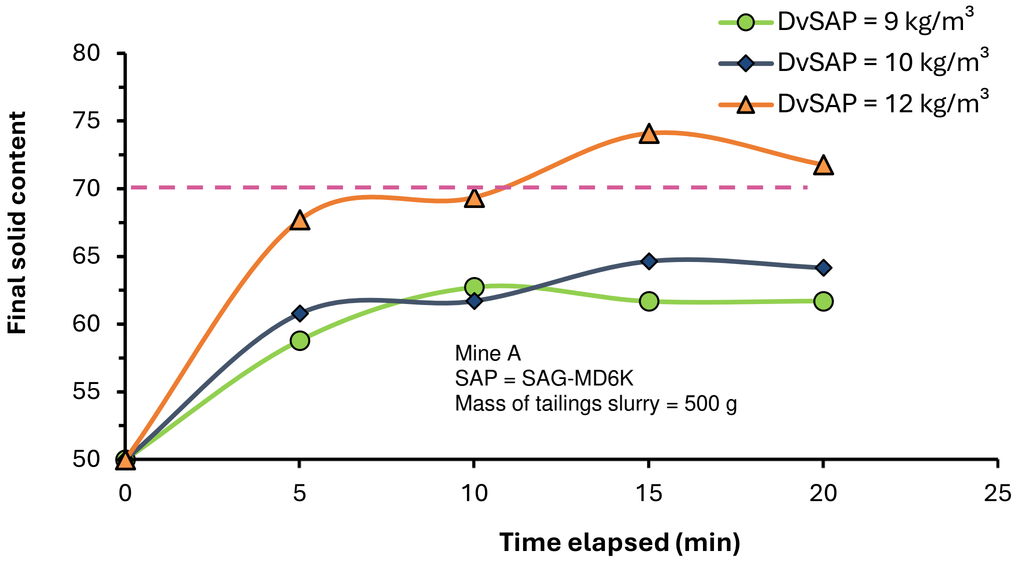

Figure 5 **Variation in final solid mass concentration as a function of RT in Tailings A slurry (%C$_{\text{w-initial}}$ = 50%) using the indirect addition mode of SAP1 (coarser)**

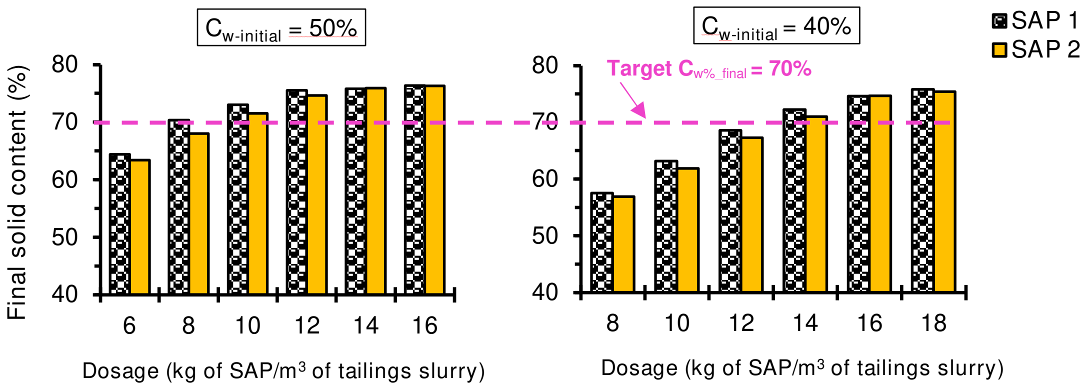

Figure 6 **Variation in final solid mass concentration as a function of SAP1 and SAP2 dosages in Tailings A slurry (%C$_{\text{w-initial}}$ = 40 and 50%) using the indirect addition method (RT = 72 h)**

SAP2 demonstrated a similar dewatering performance at higher dosages. At D_{vSAP} = 12 kg/m^3, it produced thickened tailings with a %$C_{w-final}$ of 74.6% for a slurry with a %$C_{w-initial}$ of 50%. For %$C_{w-initial}$ of 40%, a dosage of 16 kg/m^3 was required to achieve a comparable %$C_{w-final}$. These results suggest that dewatering efficiency increases with a higher %$C_{w-initial}$, as lower SAP dosages are needed to achieve higher final solid concentrations.

For %$C_{w-initial}$ of 50%, the range of %$C_{w-final}$ achieved was 64.4–75.5% with SAP1 and 63.4–74.6% with SAP2 at dosages of 6–12 kg/m^3. SAP1 exhibited slightly superior water absorption at lower dosages, attributed to its higher negative surface charge (due to increased Na^+ adsorption) and coarser grain size compared to SAP2. The higher negative charge promotes electrostatic repulsion among negatively charged groups, increasing osmotic pressure and enhancing water uptake (Bhardwaj et al. 2007; Li et al. 2004; Yu et al. 2011). Coarser grain size also facilitates higher water absorption. At higher dosages (D_{vSAP} ≥ 14 kg/m^3 for %$C_{w-initial}$ of 50% and ≥16 kg/m^3 for %$C_{w-initial}$ of 40%), the dewatering efficiency of SAP1 and SAP2 became nearly identical. The maximum %$C_{w-final}$ achieved was approximately 76%, corresponding to increases of 52% and 90% from %$C_{w-initial}$ values of 50% and 40%, respectively, at dosages of 16 kg/m^3 for %$C_{w-initial}$ of 50% and 18 kg/m^3 for %$C_{w-initial}$ of 40%.

3.4 Tailings thickening by mixing superabsorbent polymer with tailings slurry (direct addition mode)

Figure 7 illustrates the variation in the final solid mass concentration (%$C_{w-final}$) of Tailings A slurry (%$C_{w-initial}$ = 50%) over time when directly mixed with SAP1. The results indicate that within the investigated dosage range of 12–15 kg SAP/m^3, the %$C_{w-final}$ of the Tailings A–SAP1 mixture reached its maximum value after 15 minutes of contact time, followed by a slight decrease up to a RT of 30 minutes. The most significant reduction in solid mass concentration occurred between 30 minutes and 2 hours of contact time.

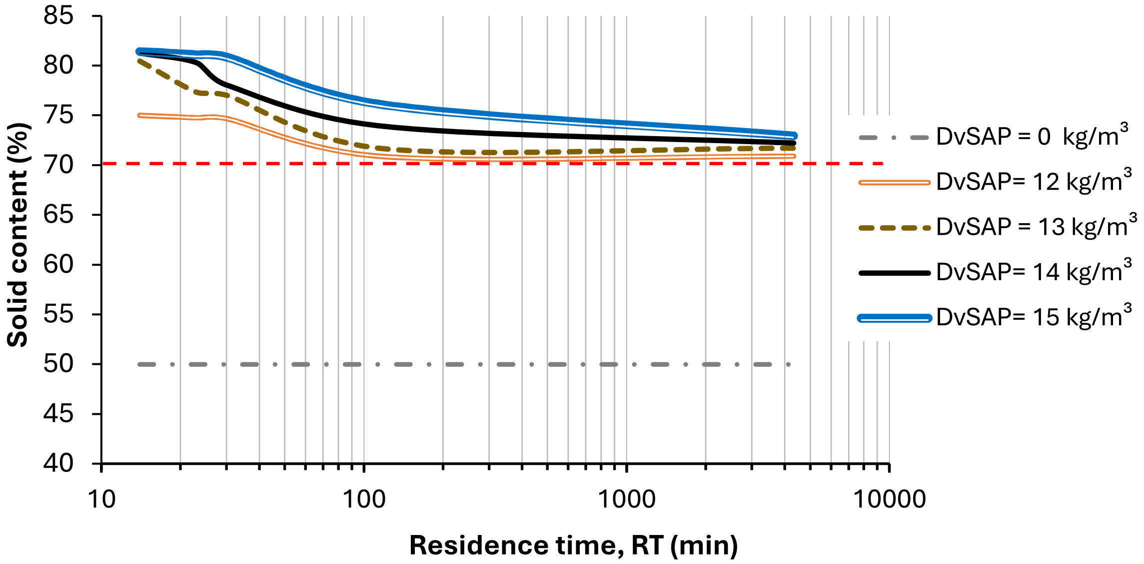

Figure 7 **Variation in solid mass concentration as a function of contact time in Tailings A slurry (%$C_{w-initial}$ = 50%) using the direct addition mode of SAP1**

The observed reduction in %$C_{w-final}$ at short RTs (15–120 minutes) can be attributed to the adhesion of fine tailings particles onto the swollen SAP grains, which imposes a localised 'confining pressure' in the direct addition mode (Masuda & Iwata 1990; Bhardwaj et al. 2007). This pressure causes the release of a portion of the absorbed water from the SAP hydrogel, thereby reducing their water absorption capacity. The impact of this phenomenon was most pronounced between 30 minutes and 120 minutes of contact time, becoming less significant after 120 minutes. Despite the observed decrease in %$C_{w-final}$ over time when using the direct addition mode, effective dewatering was achieved. The tailings slurry was dewatered from an initial solids mass concentration (%$C_{w\text{-initial}}$) of 50% to a %$C_{w\text{-final}}$ exceeding 70%, even after an extended equilibrium time of 72 hours (4,320 minutes) for all SAP1 dosages investigated.

Figure 8 presents the results of dewatering experiments conducted on Tailing A slurry with initial solid mass concentrations (%$C_{w\text{-initial}}$) of 40% and 50%. The study evaluated SAP dosages ranging from 12–22 kg/m^3 using the direct addition mode for a contact time of 72 hours. The findings demonstrate that significant thickening (%$C_{w\text{-final}} \geq 70\%$) can be achieved at SAP dosages (D_{vSAP}) between 12 and 17 kg/m^3 for slurries with a %$C_{w\text{-initial}}$ of 50%, whereas higher dosages of 18–22 kg/m^3 were required for slurries with a %$C_{w\text{-initial}}$ of 40%. Specifically, a dosage of 13 kg/m^3 resulted in a %$C_{w\text{-final}}$ of 71.6% for %$C_{w\text{-initial}}$ of 50%, compared to 18.5 kg/m^3 required to achieve a similar level of thickening for %$C_{w\text{-initial}}$ of 40%. These findings confirm, as previously observed in the indirect addition mode, that higher initial solid content facilitates more efficient thickening and reduces the required SAP dosage, even in the direct addition mode.

As shown in Figure 8, for SAP dosages in the range of 12–16 kg/m^3, the final solids mass concentration (%$C_{w\text{-final}}$) of the thickened Tailings A-SAP1 mixtures ranged from 70.7–77.9% for %$C_{w\text{-initial}}$ of 50%, compared to 70.6–75.1% using SAP2. These results suggest that, within this dosage range, SAP1 (coarser) exhibited superior water absorption compared to SAP2 (finer). This difference can be attributed to the lower negative charge of SAP2, resulting from a lower concentration of adsorbed Na^+ ions on its surface, as well as its higher content of fine grains (diameter < 240 µm). The finer grain size of SAP2 increases its S.S.A. values, rendering it more susceptible to confinement by surrounding particles, as reported by Bhardwaj et al. (2007) and Yu et al. (2011).

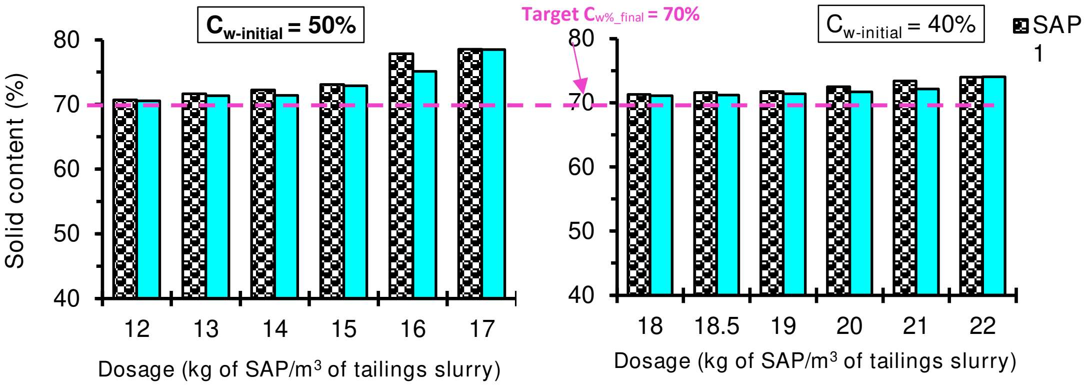

Figure 8 Variation in solid mass concentration as a function of SAP1 and SAP2 dosages in Tailings A slurry (%$C_{w\text{-initial}}$ of 40 and 50%) using the direct addition mode (contact time = 72 h)

At higher dosages ($D_{vSAP} \geq 17$ kg/m^3 for %$C_{w\text{-initial}}$ = 50% and $D_{vSAP} \geq 22$ kg/m^3 for %$C_{w\text{-initial}}$ = 40%), the differences in %$C_{w\text{-final}}$ between SAP1 and SAP2 were negligible. The maximum %$C_{w\text{-final}}$ values achieved were 78.5% for %$C_{w\text{-initial}}$ of 50% at a dosage of 17 kg/m^3 and 74% for a %$C_{w\text{-initial}}$ of 40% at a dosage of 22 kg/m^3. These represent increases of approximately 75% and 85%, respectively, relative to the initial solid content of the slurries.

3.5 SAP compatibility by indirect contact with the four thickened tailings

Figure 9 highlights the significant influence of SAP dosage on the thickening process of tailings slurries through indirect contact with SAP1, specifically for slurries with an initial solid mass concentration (%$C_{w\text{-initial}}$) of 50%. For all four types of tailings examined, the final solid mass concentration (%$C_{w\text{-final}}$) increased with rising SAP dosages, demonstrating a plateau effect at higher dosages depending on the tailings type. This indicates the importance of optimising SAP dosages to achieve final solid mass concentrations exceeding 70% while maintaining the economic feasibility of this non-conventional thickening process.

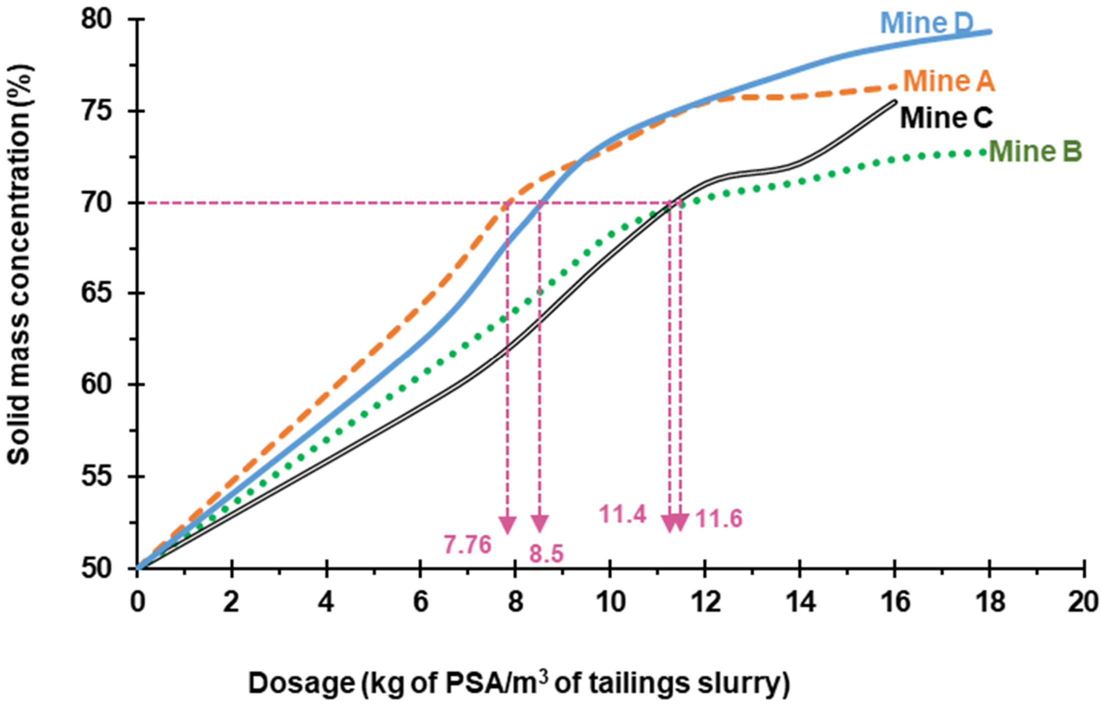

Figure 9 **Superabsorbent polymer dosages required to achieve the target final solid mass concentration (set at 70%) from a %$C_{w\text{-initial}}$ of 50% for the four types of tailings using the indirect addition mode of SAP1 (RT = 72 h)**

4 Conclusion

The conclusions emerging from this study show that the SAP dewatering method should be a promising alternative for the rapid densification of tailings slurries.

- While considering the main parameters affecting the SAP absorbency, it was clear from the results that for all tailings slurries investigated, rapid and significant dewatering can be achieved within 15 minutes.
- Indeed, a final solids mass concentration greater than 70% was obtained by indirect or direct addition modes of SAP at optimum dosages.
- The indirect mode generally shows the best performance, particularly regarding SAP dosages.
- The dewatering rate increases with increasing the initial solid mass concentration of the tailings slurries. Furthermore, the SAP water absorbency and concomitant dewatering rate decrease with an increase in the supernatant water ionic strength.
- The type of SAP, and more specifically its grain size and the concentration of the adsorbed cation (e.g. Na^+), influences the SAP water absorption capacity.
- In addition, the particle surface charge of the tailings to be thickened seems to be the dominant factor controlling the amount of water absorbed by the SAP. However, the direct addition mode does not seem to offer an alternative to the current tailings' management practices, mainly because of water that remains in the SAP-tailings mixtures (entrapped within the polymers), over which there is no control, especially in the long-term behaviour.

Finally, the SAP dewatering process must be then subject to geotechnical and cost-effective assessments, so that it can be applied both in primary (thickening) and secondary (filtering) dewatering systems.

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References

Adair, A, Klinpituksa, P & Kaesaman, A 2017, 'Influences of neutralization of superabsorbent hydrogel from hydroxyethyl cellulose on water swelling capacities', *AIP Conference Proceedings: The 4th International Conference on Research, Implementation, and Education of Mathematics and Science*, AIP Publishing, Melville, vol. 1868, no. 1.

Adiansyah, JS, Rosano, M, Vink, S & Keir, G 2015, 'A framework for a sustainable approach to mine tailings management: disposal strategies', *Journal of Cleaner Production*, vol. 108, pp. 1050–1062.

ASTM International 2024, *Standard Test Method for Density of Solid Pitch (Helium Pycnometer Method (D 4892-24 2024)*, West Conshohocken.

Bajpai, SK & Singh, S 2006, 'Analysis of swelling behavior of poly (methacrylamide-co-methacrylic acid) hydrogels and effect of synthesis conditions on water uptake', *Reactive and Functional Polymers*, vol. 66, no. 4, pp. 431–440.

Belem, T & Benzaazoua, M 2008, 'Design and application of underground mine paste backfill technology', *Geotechnical and Geological Engineering*, vol. 26, pp. 147–175.

Bhardwaj, A, Shainberg, I, Goldstein, D, Warrington, D & Levy, JG 2007, 'Water retention and hydraulic conductivity of cross-linked polyacrylamides in sandy soils', *Soil Science Society of America Journal*, vol. 71, no. 2,pp. 406–412.

Bouzahzah, H, Califice, A, Mermillod-Blondin, R, Benzaazoua, M & Pirard, E 2008, 'Modal analysis of mineralogical blends using optical image analysis versus X-Ray diffraction and ICP', *Proceedings of the 9th International Congress for Applied Mineralogy*, The Australasian Institute of Mining and Metallurgy, Melbourne.

Bussiere, B 2007, 'Colloquium 2004: Hydrogeotechnical properties of hard rock tailings from metal mines and emerging geoenvironmental disposal approaches', *Canadian Geotechnical Journal*, vol. 44, no. 9, pp. 1019–1052.

Castel, D, Ricard, A & Audebert, R 1990, 'Swelling of anionic and cationic starch-based superabsorbents in water and saline solution', *Journal of Applied Polymer Science*, vol. 39, no. 1, pp. 11–29.

Carneiro, A & Fourie, AB 2018, 'A conceptual cost comparison of alternative tailings disposal strategies in Western Australia', in RJ Jewell & AB Fourie (eds), *Paste 2018: Proceedings of the 21st International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 439–454, https://doi.org/10.36487/ACG_rep/1805_36_Carneiro

Dogu, Y & Okay, O 2006, 'Swelling–deswelling kinetics of poly (N-isopropylacrylamide) hydrogels formed in PEG solutions', *Journal of Applied Polymer Science*, vol. 99, no. 1, pp. 37–44.

Edraki, M, Baumgartl, T, Manlapig, E, Bradshaw, D, Franks, DM & Moran, CJ 2014, 'Designing mine tailings for better environmental, social and economic outcomes: a review of alternative approaches', *Journal of Cleaner Production*, vol. 84, pp. 411–420.

Flory, PJ 1953, *Principle of polymer chemistry*, Cornell University Press, New York.

Fourie, A 2009, 'Preventing catastrophic failures and mitigating environmental impacts of tailings storage facilities', *Procedia Earth and Planetary Science*, vol. 1, no. 1, pp. 1067–1071.

Hatje, V, Pedreira, RM, de Rezende, CE, Schettini, CAF, de Souza, GC, Marin, DC & Hackspacher, PC 2017, 'The environmental impacts of one of the largest tailing dam failures worldwide', *Scientific reports*, vol. 7, no. 1, pp. 1–13.

Huettermann, A, Orikiriza, LJ & Agaba, H 2009, 'Application of superabsorbent polymers for improving the ecological chemistry of degraded or polluted lands', *CLEAN–Soil, Air, Water*, vol. 37, no. 7, pp. 517–526.

Ismi, I, Elaidi, H, Rifi, E, Lebkiri, A & Skalli, A 2015, 'Behaviour of sodium polyacrylate in contact with aqueous solutions in the absence and the presence of ions metal (Ag, Cu 2, Cr 3)', *Journal of Materials and Environmental Sciences*, vol. 6, no. 4, pp. 1060–1067.

Jones, H, & Boger, DV 2012, 'Sustainability and waste management in the resource industries', *Industrial & Engineering Chemistry Research*, vol. 51, no. 30, pp. 10057–10065.

Joseph-Soly, S, Nosrati, A, Skinner, W & Addai-Mensah, J 2019, 'Superabsorbent-mediated dewaterability of fine hydrophobic sulphide mineral slurries', *Separation Science and Technology*, vol. 54, no. 18.

Kabamba, NC 2019, *Optimisation du dosage des polymères superabsorbants (PSAs) dans le processus de densification des résidus miniers fins en pulpe: application au cas de la mine Canadian Malartic*, Master's thesis, Polytechnique Montréal, Montreal.

Kazanskii, K & Dubrovskii, S 1992, 'Chemistry and physics of "agricultural" hydrogels', *Polyelectrolytes hydrogels chromatographic materials*, Springer, Berlin, pp. 97–133.

Klohn Crippen Berger 2017, 'Study of tailings management technologies', Mine Environment Neutral Drainage Program, The Mining Association of Canada, Ottawa.

Landriault D 2001, 'Backfill in underground mining', in WA Hustrulid & RL Bullock (Eds.), *Underground Mining Methods Engineering Fundamentals and International Case Studies*, Society for Mining, Metallurgy and Exploration, Littleton.

Lapointe U 2020, 'Mine Waste in Canada, A Growing Liability', *MiningWatch Canada*, https://miningwatch.ca/blog/2020/10/5/mine-waste-canada-growing-liability

Li, A, Wang, A & Chen, J 2004, 'Studies on poly (acrylic acid)/attapulgite superabsorbent composites. II. Swelling behaviors of superabsorbent composites in saline solutions and hydrophilic solvent–water mixtures', *Journal of Applied Polymer Science*, vol. 94, no. 5, pp. 1869–1876.

Masuda, K & Iwata, H 1986, 'Dewatering tests of coals using a highly hygroscopic resin', *Nippon Kogyo Kaishi*, vol. 102, no. 1184.

Masuda, K & Iwata, H 1990, 'Dewatering of particulate materials utilizing highly water-absorptive polymer', *Powder Technology*, vol. 63, no. 2, pp. 113–119.

Moreno, JJ, Kendall, S & Ortiz, A 2018, 'Dewatering options for management of fine gold tailings in Western Australian Goldfields', in RJ Jewell & AB Fourie (eds), *Paste 2018: Proceedings of the 21st International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 413–424, https://doi.org/10.36487/ACG_rep/1805_34_Moreno

Omidian, H, Hashemi, S, Sammes, P & Meldrum, I 1998, 'A model for the swelling of superabsorbent polymers', *Polymer*, vol. 39, no. 26, pp. 6697–6704.

Owen, J, Kemp, D, Lèbre, É, Svobodova, K & Murillo, GP 2020, 'Catastrophic tailings dam failures and disaster risk disclosure', *International Journal of Disaster Risk Reduction*, vol. 42.

Peer, F & Venter T 2003, 'Dewatering of coal fines using a super absorbent polymer', *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 103, no. 6, pp. 403–409.

Radwan, MA, Al-Sweasy, OH & Elazab, HA 2017, 'Preparation of Hydrogel Based on Acryl Amide and Investigation of Different Factors Affecting Rate and Amount of Absorbed Water', *Agricultural Sciences*, vol. 8, no. 2.

Roshani, A, Fall, M & Kennedy, K 2017, 'Impact of drying on geo-environmental properties of mature fine tailings pre-dewatered with super absorbent polymer', *International Journal of Environmental Science and Technology*, vol. 14, no.3, pp. 453–462.

Sadeghi, H, Shasavari, S, Mirdarikvande, M & Alahyari, M 2013, 'Investigation Swelling Behavior of a Novel alginate-based Composite Hydrogel in various salinity solutions', Bulletin of Environment, Pharmacology and Life Sciences, vol. 3, no. 1, pp. 54–58.

Sahi A, El Mahboub K, Belem T, Maqsoud A & Mbonimpa, M 2019, 'Dewatering of mine tailings slurries using superabsorbent polymers (saps) reclaimed from industrial reject of baby diapers: a preliminary Study', *Minerals*, vol. 9, no. 12, pp. 785–803.

Sahi, A, Belem, T, Maqsoud, A & Mbonimpa, M 2017, 'Preliminary assessment of tailings pulp thickening using super absorbent polymers', *Proceedings of the 70th Canadian Geotechnical Conference, GeoOttawa2017*, Canadian Geotechnical Society, Richmond.

Tsobanoglous, G & Schroeder, ED 1985, Water Quality: characteristics, modeling and modification, Addison-Wesley Publishing Co, Reading.

Twardowska I & Allen HE 2004, 'Solid waste origins: sources, trends, quality, quantity', in I Twardowska, *Solid Waste: Assessment, Monitoring and Remediation,* Elsevier, Amsterdam.

Yin, S, Shao, Y, Wu, A, Wang, H, Liu, X & Wang, Y 2020, 'A systematic review of paste technology in metal mines for cleaner production in China', *Journal of Cleaner Production*, vol. 247.

Yu, J, Shainberg, I, Yan, Y, Shi, J, Levy, G, & Mamedov, A 2011, 'Superabsorbents and semiarid soil properties affecting water absorption', *Soil Science Society of America Journal*, vol. 75, no. 6, pp. 2305–2313.

Zohuriaan-Mehr, MJ & Kabiri, K 2008, 'Superabsorbent polymer materials: a review', *Iranian Polymer Journal*, vol. 17, no. 6, pp. 451–477.