Optimization of superabsorbent polymers (SAPs) dosage for dewatering mine tailings slurry

C. N. Kabamba, T. Belem, M. Mbonimpa, A. Maqsoud, Khadija El Mahboub, Lotyé Élisée Poudama, Nor el-hoda Addi,
Research Institute on Mines and Environment (RIME), Université du Québec en Abitibi-Témiscamingue - UQAT, Rouyn-Noranda, Québec, Canada

J.F. Lemay
Centre de transfert de technologie du Collège Shawinigan, Shawinigan, Québec, Canada

ABSTRACT

This paper deals with the experimental use of superabsorbent polymers (SAPs) as a promising alternative for mine tailings slurry dewatering due to their abilities to absorb and immobilize large amounts of water. Six types of SAP with different chemical compositions have been used for this purpose. The initial solid mass concentrations of tailings ($C_{w-initial}$) were 35% and 50%, while 68% was the targeted final solid content ($C_{w-final}$). The tests were performed by varying the SAP dosages (kg SAP/t mine tailings slurry) and its equilibrium time in the tailings slurries. The results show that it is possible to reach and even exceed the targeted $C_{w-final}$ value of 68%. Indeed, to achieve a $C_{w-final}$ = 68% from a tailings slurry of $C_{w-initial}$ of 50 and 35%, the SAP dosages range between 6.5 and 13.0 kg/t and 14.6 and 30 kg/t, respectively.

RÉSUMÉ

Cet article traite de l'utilisation expérimentale des polymères superabsorbants (PSAs) comme alternative prometteuse à la déshydratation des résidus miniers en pulpe en raison de leur capacité à absorber et à immobiliser de grandes quantités d'eau. Six types de PSA de différentes compositions chimiques ont été utilisés à cette fin. Les pourcentages en solide initiaux ($C_{w-initial}$) étaient de 35% et 50%, tandis que 68% correspondait au pourcentage solide final cible ($C_{w-final}$). Les tests ont été effectués en faisant varier les dosages en PSA (kg PSA/t de résidus en pulpe) et leur temps de résidence dans les pulpes de résidus. Les résultats montrent qu'il est possible d'atteindre et même de dépasser la valeur cible $C_{w-final}$ de 68%. En effet, pour obtenir un $C_{w-final}$ de 68% à partir d'une pulpe de résidus ayant un $C_{w-initial}$ de 50% et 35%, des plages de dosage de PSA entre 6,5 et 13,0 kg/t et 14,6 et 30 kg/t ont été respectivement utilisés.

1 INTRODUCTION

Ore deposits are exploited by the mining industry because of the valuable minerals they contain. To move from hard rock to metal concentrate, ores are finely ground to extract valuable metals. These operations generate millions of tonnes of mine tailings slurries. This trend is expected to intensify due to a growing demand for mineral resources and technological advances that allow the exploitation of the poor deposits by hydrometallurgy and the finer ore grinding in order to release as much as possible of metals contained in mineral rocks, respectively (Simms, 2016). The mine tailings slurry is produced in the form of pulp (mixture of crushed rock and water) having a solid mass content (C_w) usually between 25 and 45% (Aubertin et al., 2002) with very high corresponding gravimetric water content (*w*) (between 300 and 122%).

The mine tailings slurries are generally pumped into storage areas circumscribed by dykes (McMullen et Aubertin, 2005). This relatively simple and inexpensive disposal method sometimes entails huge operating costs and substantial environmental responsibility related to the long-term geotechnical stability of the dykes and the restoration of these storage sites, respectively (Wang et al., 2014; Aubertin et al., 2013a, b). Several physical problems may compromise the geotechnical stability of these dykes (Simms, 2016; Aubertin et al., 2013a, b; Azam et Li, 2010). The mine tailings slurry spill can have serious short and long-term environmental and socio-economic impacts, especially when tailings contain reactive minerals that may generate acid mine drainage or contaminated mine drainage.

Faced with the tightening of constraints, both in terms of legislation, social pressures and the environmental responsibility of the mining industry, emerging disposal strategies alternative to the conventional method have been proposed. These include the surface disposal of mine tailings slurry in thickened form obtained using various machinery such as conventional thickeners, high-rate and high-density thickeners (Bussiere, 2007; Jewell et Fourie, 2006; Crowder, 2003;; Robinsky, 1975) and in filtered form (disc filters, filters press). These emerging disposal strategies make it possible to improve the mechanical and hydrogeotechnical properties of fine tailings slurry (Simms, 2016; Fourie, 2012; Bussière 2007; Martin et al., 2005), and consequently, to ensure the geotechnical stability of dikes. However, despite these numerous benefits, the conventional mine tailings slurry disposal approach remains the most widely used method in the mining industry around the world (Simms, 2016) because of their low costs. In fact, the efficiency of tailings densification techniques depends on i) the tailings slurry properties, and ii) the operating conditions. The operating conditions are those of the crusher (size of the ore particles in the feed), and the concentrator. The tailings properties are the initial solid content ($C_{w\text{-}initial}$) of the thickener feed and the mineralogical composition of the ore (Martin et al., 2005; Robinsky, 1975). The variation of these parameters sometimes makes the densification approaches more complex and very expensive for the mining industry. However, to be attractive, these processes should be inexpensive while allowing to get the expected mechanical and hydrogeotechnical properties (Bussiere, 2007). But because of the frequency of conventional tailings dam failures observed in recent years, the mining industry is increasingly inclined to consider these new methods of surface storage of densified tailings (e.g. KCB, 2017; Li et al., 2016).

The safe, sustainable and affordable mine tailings slurry management remains a field open to research and technological development. It is in this context that the experimental use of polymers for the dehydration of mine tailings slurry is a promising approach for the mining industry because of its capacity for water absorption and retention (Wang et al., 2014).

The polymer in question is a macromolecular network of hydrophilic polymer chains constituted by the identical repetition of an atomic pattern (monomers), linear from each other and regularly interconnected from one another by crosslinking nodes. The crosslinking may be of a physical or chemical nature thus forming a network of crosslinking agents (Macron, 2014; Snoeck et al., 2014; Hoffmann, 2002). This gives polymers the ability to absorb and store large quantities of liquid between their macromolecular chains in comparison with their own mass without degrading and dissolving in the solvent (Sahi et al., 2017; Farkish et Fall, 2013; Patel et Mequanint, 2011; Wang et al., 2010; Zohuriaan-Mehr et Kabiri, 2008; Lee et Yang, 2004; Hoffmann, 2002; Staples et Chatterjee, 2002). Because of these characteristics, polymers are materials commonly referred to as superabsorbent polymers (SAPs) (Kabiri et al., 2005). Hydrogel is the state of a swollen polymer of liquid that it has absorbed.

Since the first synthesis of hydrogel in 1960 for biological use (Wichterle et Lim, 1960), the technology and use of SAPs has grown steadily to the point of interest in several other sectors such as food industry (Chen et al., 1995), agriculture (Lentz et al., 1992), tissue engineering (Lee et Mooney, 2001), biosolids dewatering (Murthy et al., 2000), etc.

Because of their ability to absorb and retain water, SAPs have been tested in the mining sector, particularly for the dewatering of coal fine particles or mature fine tailings from bituminous sand ores (Wang et al., 2010; Dzinomwa et al., 1997). SAPs also find applications in civil engineering (Hasholt et al., 2012) and in the field of environmental protection, etc.

The classification of the polymers can be made according to various criteria, which are in particular, the source of the materials used in the synthesis (synthetic, natural and hybrid polymers), the nature of the crosslinking nodes (physical or chemical polymers), the methods of preparation or polymerization synthesis (homopolymer, copolymer), the ionic charges (non-ionic, cationic, anionic, and amphoteric polymers), etc. (Patel et Mequanint, 2011; Zohuriaan-Mehr et Kabiri, 2008; Ratner et al., 2006).

The main objective of this research project is to experimentally investigate the use of SAPs for the densification of mine tailings slurries that must be stored on the surface in tailings storage facility (TSF). This will include optimizing the SAPs dosage in order to achieve a targeted storage solid content ($C_{w\text{-}final}$) that corresponds to the chosen technique (thickened, paste or filtered tailings).

2 EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Tailings sample

To carry out this study, mine tailings slurries were collected in three 200-liter plastic barrels at the mine M site. Each barrel of mine tailings slurry was homogenized, then samples of supernatant water and slurry were taken with care from the barrels in order to have representative samples on which different physicochemical characterizations were carried out. In particular, the initial water content (w_i) and the corresponding solid content ($C_{w\text{-}initial}$), the mineralogical composition of the tailings (by X-Ray Diffraction, XRD), and the chemical composition of the tailings supernatant water (by Inductively Coupled Plasma-Atomic Emission Spectroscopy, ICP-AES) were determined. The values of w_i and $C_{w\text{-}initial}$ obtained for the different barrels are shown in Table 1. The w_i varies between 26.0 and 31.6% while the $C_{w\text{-}initial}$ varies between 76.0 and 78.4%.

Table 1. Water and solids contents of mine tailings sampled

%	Barrel 1	Barrel 2	Barrel 3
w_i	30.1	31.6	26.0
$C_{w\text{-}initial}$	76.9	76.0	78.4

The results of the mineralogical analysis of mine tailings presented in Table 2 show that the tailings are mainly composed of albite (42%), quartz (24%), and orthoclase (~11%). The mine tailings also contain a low percentage of sulphides, ~2% of pyrite and a few neutralizing minerals such as dolomite (2.5%) and calcite (~3%).

Table 2. Mineralogical composition of mine tailings

Mineral	Grade (%)
Albite	42.32
Biotite	7.51
Calcite	2.97
Chlorite	7.62
Dolomie	2.33
Orthoclase	10.86
Pyrite	1.87
Quartz	24.42
Rutile	0.10

Table 3. Elemental composition of mine tailings water

Element	DLM*	Concentration (mg/L)
Al	0.010	0.063
As	0.060	0.115
Ba	0.001	0.082
Ca	0.030	482
Co	0.004	0.166
Cu	0.003	2.87
Fe	0.006	0.78
K	n/a	260
Mg	0.001	6.71
Mo	0.009	0.445
Na	n/a	550
Ni	0.004	0.14
S	0.090	921
Si	0.040	4.1
Zn	0.005	0.036

*Detection limit of the method

The results of the ICP-AES analyses are presented in Table 3 and show the chemical composition of the mine tailings water. They reveal a high concentration of sulfur (921 mg/L), followed by sodium (550 mg/L), calcium (482 mg/L), and potassium (260 mg/L). There are also low concentrations of other metals.

2.1.2 Superabsorbent polymers (SAPs)

Six types of commercial SAPs of different chemical composition were considered in this study. The six SAPs were subjected to Fourier Transform Infrared Spectroscopy (FTIR) analysis to identify their chemical compositions (Table 4). The results reveal that the six SAPs are synthetic in nature, and that SAP 5 (APROTEK P2) was coated with bentonite. The results also show similarity in the chemical composition between SAP 3 (PHP SAG M85F) and SAP 6 (APROTEK P150).

Table 4. Chemical composition of the SAPs derived from FTIR analyses

Name	Commercial name	Chemical composition	Formula
SAP 1	PHP SAG MD6K	Cobalt thiocyanate	$C_2CoN_2S_2$ or $Co(SCN)_2$
		Tosylmethyl isocyanides	$CH_3C_6H_4SO_2CH_2NC$
		Nitrous oxide gas	N_2O
SAP 2	APROTEK G300	Poly(acrylonitrile)	$(C_3H_3N)_x$
		1,6-Dicyanohexane	$NC(CH_2)_8CN$
		Cyclohexane	C_6H_{12}
SAP 3	PHP SAG M85F	Poly (acrylamide), carboxyl modified	$C_9H_{12}NNaO_5$
		Methyl alcohol	CH_3OH
		5,8,11,14,17-Eicosapentaenoic Acid	$C_{20}H_{30}O_2$
SAP 4	APROTEK P6	Monoelaidin	$C_{21}H_{40}O_4$
		Poly(ethylene:Propylene:Diene	-
		5a-androstane	$C_{19}H_{32}$
SAP 5	APROTEK P2	Bentonite (Brown)	$(M.nH_2O)(Al_2-Mg_x)Si_4O_{10}(OH)_2$
		Methyl alcohol	CH_3OH
		Cellophane (hydrate de cellulose)	$(C_6H_{10}O_5)_n$
SAP 6	APROTEK P150	5,8,11,14,17-Eicosapentaenoic Acid	$C_{20}H_{30}O_2$
		Poly(acrylamide), carboxyl modified	$C_9H_{12}NNaO_5$
		Clorazepate dipotassium	$C_{16}H_{11}ClK_2N_2O_4$

Particle size analysis of the SAPs was performed using the Mastersizer 3000 laser granulometer from Malvern using a dry dispersion. Figure 1 shows the volume-based grain size distribution (GSD) curves of the six types of SAP.

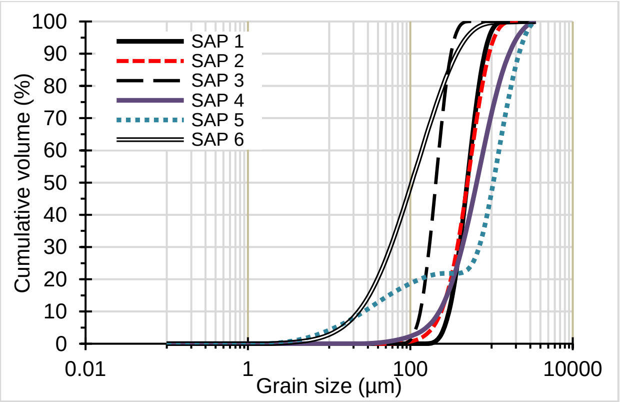

Figure 1. Grain-size distributions of the six types of SAP

The main parameters of the particle size distribution of the SAPs are presented in the Table 4. In this table, Dv_x is the size of particle for which x% of the sample is below this size.

With the exception of the GSD of SAP 5 which is a gap-grading (discontinuous) distribution, the GSD of SAP 1-4 and SAP 6 is uniform. This is confirmed by the value of the coefficient of uniformity $C_U = (Dv_{60}/Dv_{10}) < 6$. In addition, the GSDs of SAP 1 and 2 are almost identical.

Table 5. SAPs grain size distribution parameters

	SAP 1	SAP 2	SAP 3	SAP 4	SAP 5	SAP 6
Dv_{10} (µm)	297	240	132	227	26.9	22.8
Dv_{50} (µm)	501	505	206	656	1050	104
Dv_{60} (µm)	550	550	226	800	1300	149
C_U	1.9	2.3	1.7	3.5	48.3	6.5
Span	1.06	1.4	0.90	2.16	2.05	3.34

The Span is the measurement of the width of the distribution: the smaller the value the narrower the distribution (e.g. SAP 1 to 3). The Dv_{10} value corresponds to the effective diameter, the Dv_{50} value is also known as the Mass median diameter (MMD). The effective diameter (Dv_{10}) varies as follows: SAP 1 > SAP 2 > SAP 4 > SAP 3 > SAP 5 > SAP 6 (see Table 5).

2.2 Method

For the dewatering testing on mine tailings slurry, plastic containers of 0.25 m^3 capacity each were used. Two different tailings initial solid content $C_{w\text{-}initial}$ were investigated: 35% (lower limit), and 50% (upper limit). From the initial solid contents, the goal is to achieve the targeted solid content $C_{w\text{-}final}$ of 68% by varying the SAP dosage and their equilibrium time in the tailings slurry. Hence, the SAPs were added to the tailings slurry according to the indirect addition mode. This mode consists in placing the SAPs in a geotextile bag having the same porosity than filter paper. Then the bags containing the SAPs are immersed in the tailings slurry samples covered to avoid any evaporation. After 72 hours of equilibrium time, the bags are removed from the tailings slurry samples. The bags are then suspended by gravity until the free water is completely removed from the hydrogels. The bags are then weighed to determine the absorption (swelling) rate Q_{eq} as a function of the SAP dosage, as well as the final total mass M_t and/or the final water content w of the samples. This allows to determine $C_{w\text{-}final}$ as a function of the SAP dosage. The optimal equilibrium time of the SAPs in the tailings slurry of 72 hours was determined from preliminary tests.

The swelling equilibrium absorption rate Q_{eq} corresponds to the amount of water absorbed by the SAP during the equilibrium time (72 h) in the tailings slurry. It can be expressed by the following equation (Ismi et al., 2015; Lee and Yang, 2004; Sadeghi, 2012; Zhang et al., 2006) :

$$Q_{eq-SAP} = \frac{M_2 - M_1}{M_1} \qquad [1]$$

Where M_1 and M_2 are the mass of the dry and swollen SAP, respectively.

The SAP dosages can be defined either in terms of the mass (D_{mSAP}) or the volume (D_{vSAP}) of the tailings slurry. This corresponds to the ratios of the dry mass of SAP (M_{SAP}) to either the mass (M_{slurry}) or the volume (V_{slurry}) of the tailings slurry. These ratios are given as follows (Sahi et al., 2017):

$$D_{mSAP} = \frac{M_{SAP}}{M_{slurry}} \qquad [2]$$

$$D_{vSAP} = \frac{M_{SAP}}{V_{slurry}} = \rho_{slurry}\left(\frac{M_{SAP}}{M_{slurry}}\right) = \rho_{slurry} D_{mSAP} \qquad [3]$$

where ρ_{slurry} = tailings slurry density in g/cm^3, kg/m^3 or t/m^3. D_{mSAP} can be expressed in kg/t and in g/kg (or in g/g, kg/kg, t/t) whereas D_{vSAP} can be expressed in kg/m^3 (or in g/L and in t/m^3 (or in g/mL). D_{mSAP} is used in this work to express the SAP dosage.

The final solid content $C_{w\text{-}final}$ can be calculated as follows:

$$C_{w-final} = \frac{M_{slurry} C_{w-initial}}{M_{slurry} - M_{water-SAP}} \qquad [4]$$

Where $C_{w-initial}$ = the initial solid mass concentration of the tailings slurry; S_{lurry} = the total mass of the slurry; $M_{water\text{-}SAP}$ = the mass of water absorbed by the SAP which is calculated as follows:

$$M_{water-SAP} = M_{swollen-SAP} - M_{SAP} = M_2 - M_1 \qquad [5]$$

Hence, Eq. 5 becomes:

$$C_{w-final} = \frac{C_{w-initial}}{1 - \left(\frac{M_{swollen-SAP} - M_{SAP}}{M_{slurry}}\right)} \qquad [6]$$

3 RESULTS

3.1 Achieving the target final solid content $C_{w\text{-}final}$

Figure 2 presents the SAP dosages required for the six types of SAPs to dewater the tailings slurry (with an initial $C_{w\text{-}initial}$ of 35%) until reaching the target final solid content $C_{w\text{-}final}$, set at 68%. The results reveal that the dosage for the first three SAP is almost the same and varies between 14.6 and 15.2 kg SAP/t tailings slurry although their kinetics of absorption are different.

The SAP 6 dosage is the highest (30 kg SAP/t tailings slurry), almost double the dosage of SAP 1 to 3. SAP 4 and SAP 5 have dosages respectively of 15.9 and 17.6 kg SAP/t tailings slurry which are close to the dosages required for SAP 1 to 3. It appears from this figure that the finest SAP (SAP 6) requires the highest dosage (30.0 kg SAP/t tailings slurry).

It should be noted that by increasing the solid mass concentration from 35% ($C_{w\text{-}initial}$) to 68% ($C_{w\text{-}final}$), these SAP dosages resulted in a 94% increase in the solid content. This corresponds to about 75% of the initial water from the tailings slurry that has been absorbed:

$= 100 \times [C_{w\text{-}final} – C_{w\text{-}initial}] / (C_{w\text{-}final} * [1 – C_{w\text{-}initial}])$

or more simply:

$100 \times M_{water\text{-}SAP} / M_{water\text{-}slurry}$

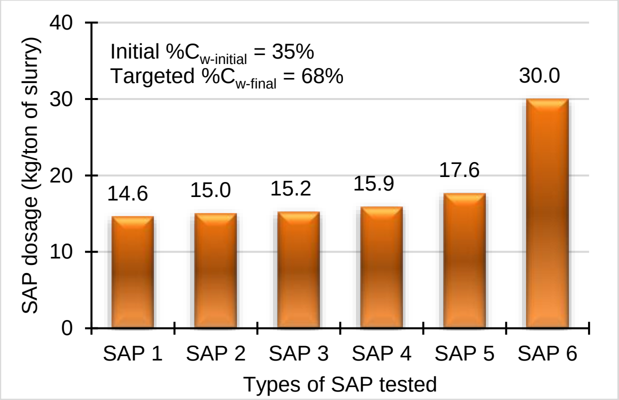

Figure 2. SAP dosages to reach the target $C_{w\text{-final}}$ from an initial $C_{w\text{-initial}}$ of 35%

Figure 3 presents the SAP dosages required for the six types of SAPs to dewater the tailings slurry (with an initial $C_{w\text{-initial}}$ of 50%) until reaching the target final solid content $C_{w\text{-final}}$, set at 68%. This figure shows an expected decrease in the SAP dosages compared to the results presented in Figure 2. Indeed, this decrease in the SAP dosages is proportional to the amount of free water within the tailings slurry and, therefore, to the initial $C_{w\text{-initial}}$ (35% or 50%). It can be observed that SAP 1 to 3 require a lower dosage while being the best performers for reaching the target value. Their dosage is almost identical and in the range of 6.5 – 7.4 kg SAP/t tailings slurry. The SAP 5 and SAP 6 require just under twice (12.4 and 13 kg SAP/t tailings slurry) the dosage of SAP 1 to 3 for reaching the same target $C_{w\text{-final}}$ of 68% (see Figure 3). As in the case of Figure 2, it can be seen in Figure 3 that the SAP 1 and SAP 2 dosages are very close. This is probably due to their particle size which is very similar. The increase in the solid mass concentration from a $C_{w\text{-initial}}$ of 50% to a $C_{w\text{-final}}$ of 68% using these SAP dosages resulted in a 36% increase in the solid content. This corresponds to about 53% of the initial water from the tailings slurry that has been absorbed.

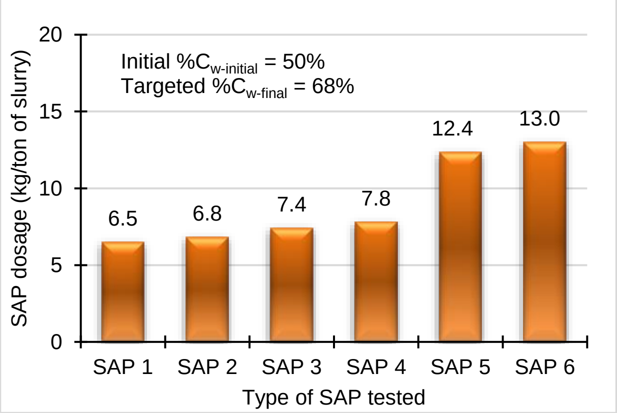

Figure 3. SAP dosages to reach the target $C_{w\text{-final}}$ from an initial $C_{w\text{-initial}}$ of 50%

3.2 Achieving the optimal final solid content $C_{w\text{-optimal}}$

Since the initial solid mass concentrations were 35 and 50% and by setting the targeted solid content to 68% (for the TSF design need), the dewatered tailings samples still hold free water. Therefore, the SAP dosages were increased to reach the respective optimal $C_{w\text{-optimal}}$ for each type of SAP. Figure 4 presents the optimal SAP dosages obtained from tailings slurry samples having an initial $C_{w\text{-initial}}$ of 35%.

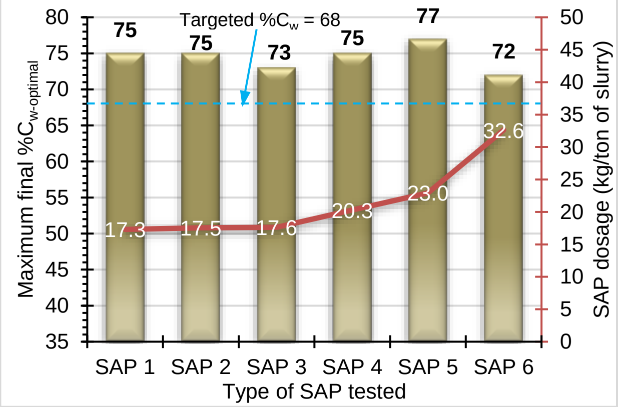

Figure 4. SAP dosages to reach the optimal $C_{w\text{-optimal}}$ from an initial $C_{w\text{-initial}}$ of 35%

The results obtained show that it is possible to achieve an average optimal solid mass concentration $C_{w\text{-optimal}}$ of about 75% (Figure 4). The SAP dosages were almost identical for the SAP 1 and SAP 2 (17.3 and 17.5 kg/t tailings slurry, respectively). Almost the same SAP dosage (17.6) was obtained for SAP 3 but for a lower $C_{w\text{-optimal}}$, that is 73% for the same equilibrium time of 72 h. Figure 4 also shows that a $C_{w\text{-optimal}}$ of 72% was achieved using SAP 6 but with a much higher dosage of 32.6 kg SAP/t tailings slurry. With SAP 5 and for the same equilibrium time, the highest optimal $C_{w\text{-optimal}}$ of 77% was achieved with a dosage of 23.0 kg SAP/t tailings slurry.

Figure 5 presents the optimal SAP dosages obtained from tailings slurry samples having a $C_{w\text{-initial}}$ of 50%. It can be seen that the $C_{w\text{-optimal}}$ was obtained with lower SAP dosages compared to the SAP dosages with $C_{w\text{-initial}}$ of 35%, and that's what's expected. Indeed, a dosage of about 10.5 kg/t tailings slurry was required with the SAP 1 to 3 for achieving $C_{w\text{-optimal}}$ of 75% (SAP 1 and SAP2) and 73% (SAP 3). The highest $C_{w\text{-optimal}}$ of 77% was again obtained with SAP 5 at a dosage of 19.5 kg/t tailings slurry. The highest SAP dosage of 20.8 5 kg/t tailings slurry was observed with SAP 4 for the lowest $C_{w\text{-optimal}}$ of 72%.

4 DISCUSSION

4.1 Effect of SAP equilibrium time on the absorption rate

The equilibrium time of SAPs in the tailings slurry appears to have no major influence on the swelling equilibrium absorption rate ($Q_{eq\text{-}SAP}$) where applicable.

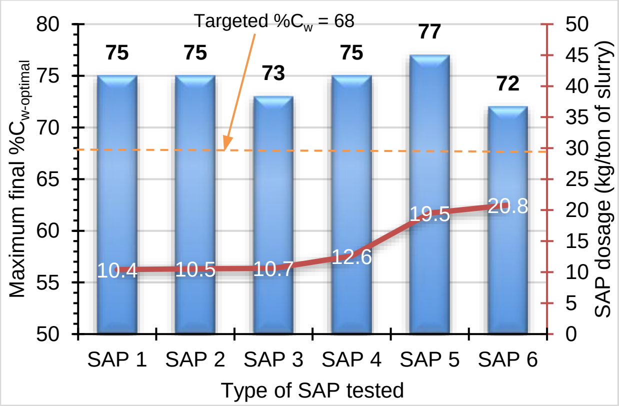

Figure 5. SAP dosages to reach the optimal $C_{w\text{-optimal}}$ from an initial $C_{w\text{-initial}}$ of 50%

Indeed, the results shown in Figures 6 and 7 with M_{SAP} of 1.2 g and 850 ml of three different sources of water (distilled, tap and mine process), revealed that $Q_{eq\text{-}SAP}$ is generally reached between 1 h and 6 h of equilibrium time, depending on the type of SAP used, its grain size distribution, its crosslinking density, and its dosage, as well as the nature and concentration of dissolved cations in the water. However, beyond 6 hours of equilibrium time, insignificant mass variations of hydrogels have been observed for some test samples.

It is important to note that the SAPs absorption rate in the mineral process water is much lower than that for distilled water and tap water. This is due, among other reasons, to the concentration of dissolved cations in the mine tailings slurry water, in particular sodium (550 mg/L Na^+) and calcium (482 mg/L Ca^{2+}). Indeed, the preliminary results from a parallel study in progress reveal that the absorption rate decreases with the increase in the sulfates concentration in the mine tailings slurry water (Poudama et al., 2019).

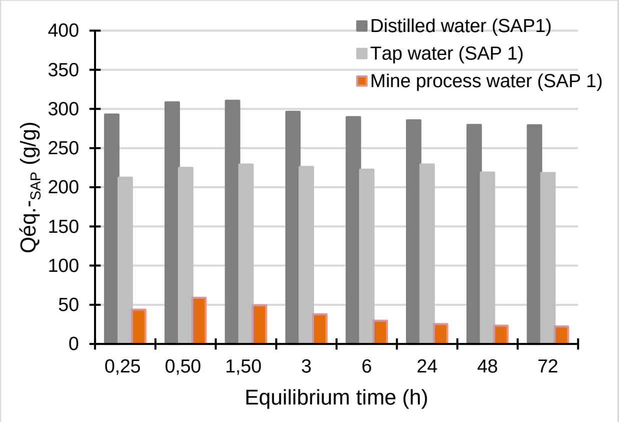

Figure 6. Effect of SAP 1 equilibrium time on the absorption rate $Q_{eq\text{-}SAP}$ (M_{SAP} = 1.2 g)

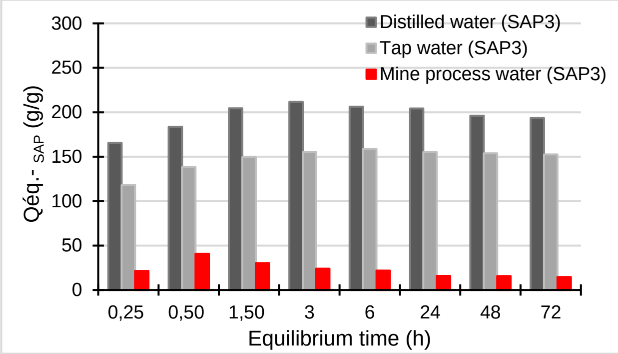

Figure 7. Effect of SAP 3 equilibrium time on the absorption rate $Q_{eq.SAP}$ (M_{SAP} = 1.2 g)

4.2 Optimization of SAP dewatering of mine tailings slurries and gel-blocking effect

Figure 8 presents two cases of mine tailings slurries dewatering test results ($C_{w\text{-initial}}$ = 50%): the ideal dewatering (optimal absorption) and the dewatering affected by hydrogel-blocking (limited absorption). It can be observed that the final solid mass concentration $C_{w\text{-final}}$ increases with the increase in SAP dosages until reaching the optimal solid content $C_{w\text{-optimal}}$ (see plateau in Figure 8). At this point, there is almost no more absorbable free water in the mine tailings slurry.

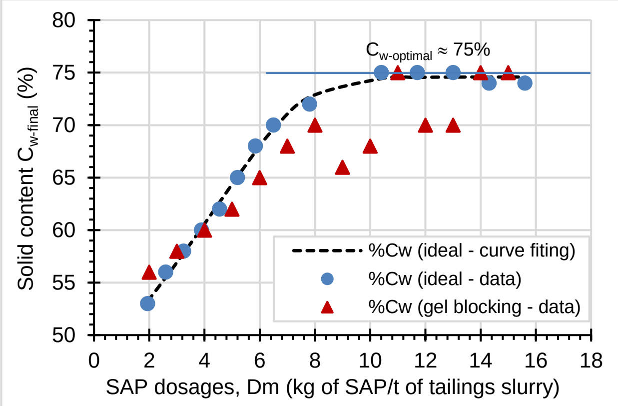

Figure 8. Variation in final solid mass content (after polymers dewatering) as a function of SAP dosage

When a SAP is immersed in water (tailings slurry), the water molecules begin to swell the surface of the sample, then gradually diffuse inwardly until it inflates all the SAP. However, it may be that during the first instants of absorption, a sealed hydrogel layer is formed which prevents diffusion of the liquid to adjacent layers of still dry SAP particles thereby reducing the absorption rate of the hydrogel. This phenomenon, termed gel-blocking effect, depends on the porosity of the layer of the swollen hydrogel. The finer grain size distribution polymers are the most exposed to this phenomenon (e.g. Bao, Ma et Li, 2011; Wack et Ulbricht, 2007; Buchholz, 2006;).

As a first approximation, it is possible to predict the SAP dosage (in particular SAP 1, which seems to be the most efficient and effective of the six types) to be used in order to reach a desired final solid percentage (considering the case of an initial solid content of 50%). This prediction can be done using the proposed empirical Equation 7 that integrate the $C_{w\text{-}initial}$ (see Figure 9). These predictions will be further verified by additional experimental tests

$$\frac{\%C_{w-final}}{\%C_{w-initial}} = a\times\left(1+\exp\left(7.6122-1.0546\times D_{mSAP}\right)\right)^{-0.06063} \qquad [7]$$

$$a = 25.799\left(\%C_{w-initial}\right)^{-0.728}$$

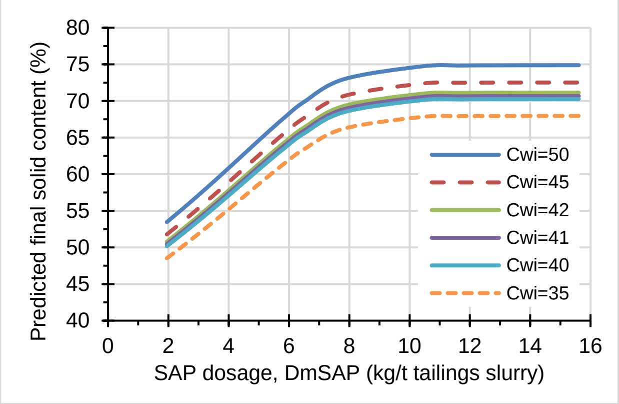

Figure 9. Prediction of the final solid mass content (after polymers dewatering) as a function of SAP dosage using Equation 7 for different initial solid content (C_{wi})

5 CONCLUDING REMARKS

The results obtained in this study demonstrate the potential for SAPs used for dewatering, and therefore densifying, of mine tailings slurry (from a gold mine) for surface storage. Indeed, the results obtained show that it was possible to achieve a final solid mass concentration of about 75%. These performances make SAPs an attractive alternative for the mining industry regarding the tailings slurry management for surface storage. However, the following remarks can be made:

- As reported by several other authors, this study also asserts that polymers with coarse grain size distribution (GSD) have a high absorption capacity and therefore will result in a higher final C_w than with the finer GDS polymers. It has also been observed that the SAP 1 and SAP 2 have a similar behavior despite their chemical composition which is completely different. The results of the test carried have allowed to observe that the finer the polymers GSD, the more they are exposed to the gel-blocking effect;
- The occurrence of gel-blocking phenomenon which is reducing the absorption capacity of the polymers is a hypothesis to be deepened;
- The equilibrium time of polymers does not have a major impact on the absorption rate beyond 24 hours of equilibrium time;
- The economic aspect on SAP costs and the technical implementation at a mine site-scale mine tailings slurry dewatering system remains to be investigated.

6 REFERENCES

Aubertin, M., Bussiere, B., James, M., Mbonimpa, M. et Chapuis, R.P. 2013a. Revue de divers aspects liés à la stabilité géotechnique des ouvrages de retenue de résidus miniers. Partie I – Mise en contexte et caractéristiques générales, *Environnement & technique*, 326, 29-38.

Aubertin, M., James, M., Mbonimpa, M., Bussière, B. et Chapuis, R.P. 2013b. Revue de divers aspects liés à la stabilité géotechnique des ouvrages de retenue de résidus miniers. Partie II – Analyse et conception, *Déchets scientifiques et techniques*, 38-50.

Aubertin, M., Mbonimpa, M., Jolette, D., Bussière, B., Chapuis, R.P., James, M., et al. (2002). *Stabilité géotechnique des ouvrages de retenue pour les résidus miniers: problèmes persistants et méthodes de contrôle. Défis et perspectives.* Communications au Symposium Mines et Environnement, Rouyn-Noranda.

Azam, S. and Li, Q. 2010. Tailings dam failures: a review of the last one hundred years, *Geotechnical News, 28*,4, 50-54.

Bao, Y., Ma, J.Z. and Li, N. 2011. Synthesis and swelling behaviors of sodium carboxymethyl cellulose-g-poly (AA-co-AM-co-AMPS)/MMT superabsorbent hydrogel, *Carbohydrate Polymers, 84*,1, 76-82.

Buchholz, F.L. 2006. Model of liquid permeability in swollen composites of superabsorbent polymer and fiber, *Journal of applied polymer science, 102*,4, 4075-4084.

Bussiere, B. 2007. Colloquium 2004: Hydrogeotechnical properties of hard rock tailings from metal mines and emerging geoenvironmental disposal approaches, *Canadian Geotechnical Journal, 44*,9, 1019-1052.

Chen, X., Martin, B.D., Neubauer, T.K., Linhardt, R.J., Dordick, J.S. and Rethwisch, D.G. 1995. Enzymatic and chemoenzymatic approaches to synthesis of sugar-based polymer and hydrogels, *Carbohydrate Polymers, 28*,1, 15-21.

Crowder, J.J. 2004. Deposition, consolidation, and strength of a non-plastic tailings paste for surface disposal. 162p. Thèse de doctorat en génie civil, Université de Toronto, Canada.

Deschamps, T., Benzaazoua, M., Bussière, B., Aubertin, M., Bouzahzah, H. and Martin, V. 2009. Les effets d'amendements alcalins sur des résidus miniers sulfureux entreposés en surface: Cas des dépôts en pâte, *DÉCHE TS*, 19.

Dzinomwa, G.P.T., Wood, C.J. and Hill, D.J.T. 1997. Fine coal dewatering using pH-and temperature-sensitive superabsorbent polymers, *Polymers for Advanced Technologies, 8*,12, 767-772.

Farkish, A. and Fall, M. 2013. Rapid dewatering of oil sand mature fine tailings using super absorbent polymer (SAP), *Minerals Engineering, 50*, 38-47.

Hasholt, M.T., Jensen, O.M., Kovler, K. and Zhutovsky, S. 2012. Can superabsorent polymers mitigate autogenous shrinkage of internally cured concrete without compromising the strength?, *Construction and Building Materials, 31*, 226-230.

Hoffmann, A.S. 2002. Hydrogels for biomedical applications, *Advanced Drug Delivery Reviews, 54*,1, 3-12.

Ismi, I., Elaidi, H., Rifi, E.H., Lebkiri, A. et Skalli, A. 2015. Comportement de polyacrylate de sodium au contact des solutions aqueuses en absence et en presence d'ions métalliques (Ag, Cu2, Cr3)(Behaviour of sodium polyacrylate in contact with aqueous solutions in the absence and the presence of ions metal (Ag, Cu 2, Cr 3)), *J. Mater. Environ.*

Jewell, R.J. and Fourie, A.B. 2006. *Paste and thickened tailings: a guide*, Australian Centre for Geomechanics, The University of Western Australia,

Kabiri, K., Faraji-Dana, S. and Zohuriaan-Mehr, M.J. 2005. Novel sulfobetaine-sulfonic acid-contained superswelling hydrogels, *Polymers for advanced technologies, 16*,9, 659-666.

Klohn Crippen Berger (KCB), 2017. Report 2.50.1, Study of tailings management technologies. Prepared for the Mine Environment Neutral Drainage (MEND) Project, October 31, 164 p.

Lee, K.Y. and Mooney, D.J. 2001. Hydrogels for tissue engineering, *Chemical reviews, 101*,7, 1869-1880.

Lee, W.F. and Yang, L.G. 2004. Superabsorbent polymeric materials. XII. Effect of montmorillonite on water absorbency for poly (sodium acrylate) and montmorillonite nanocomposite superabsorbents, *Journal of Applied Polymer Science, 92*,5, 3422-3429.

Lentz, R.D., Sojka, R.E., Carter, D.L. and Shainberg, I. 1992. Preventing irrigation furrow erosion with small applications of polymers, *Soil Science Society of America Journal, 56*,6, 1926-1932.

Li S., Chen Q., and Wang X. 2016. Superiority of filtered tailings storage facility to conventional tailings impoundment in southern rainy regions of China. Sustainability, 8, 1130; doi:10.3390/su8111130, 12p.

Macron, J. 2014. *Hydrogels en milieux immergés: de l'adhésion macroscopique aux mécanismes moléculaires.*Thèse de Doctorat, Université Pierre et Marie Curie-Paris VI.

Martin, V., McMullen, J. et Aubertin, M. 2005. *Les résidus en pâte et la déposition en surface des rejets de concentrateur.* Communications présentées au Proceedings of the 2nd International Symposium on Mining and the Environment, Rouyn-Noranda, Quebec, Canada.

Murthy, S.N., Novak, J.T. and Holbrook, R.D. 2000. Optimizing dewatering of biosolids from autothermal thermophilic aerobic digesters (ATAD) using inorganic conditioners, *Water Environment Research, 72*,6, 714-721.

Patel, A. and Mequanint, K. 2011. Hydrogel biomaterials. *Biomedical engineering-frontiers and challenges* InTechOpen. Departement of Chemical and Biochemical Engineering, University of Western Ontario, London Ontario, Canada.

Poudama, E.L., Mbonimpa, M., Belem T., Maqsoud, A., El Mahboub K., Kabamba C.N., Addi, N.E., and Lemay, J.F. 2019. Assessment of the influence of aqueous solutions chemistry on the water absorbency of recycled superabsorbent polymer. Géo St-John 2019.

Ratner, B.D., Hoffman, A.S., Schoen, F.J. and Lemons, J.E. 2006. Biomaterials science: an introduction to materials in medicine, *MRS Bull, 31*, 59.

Robinsky, E.I. 1975. Thickened discharge - New approach to tailings disposal, *CIM bulletin, 68*,764, 47-53.

Sadeghi, M. 2012. Synthesis of a biocopolymer carrageenan-g-poly (AAm-co-IA)/montmorilonite superabsorbent hydrogel composite, *Brazilian Journal of Chemical Engineering, 29*,2, 295-305.

Sahi, A., Belem, T., Maqsoud, A. and Mbonimpa M. 2017. Preliminary assessment of tailings pulp thickening using super absorbent polymers, Canadian Geotechnical Conference, GeoOttawa2017, Ottawa, Canada (paper 832), 8 p.

Simms, P. 2016. 2013. Colloquium of the Canadian Geotechnical Society: Geotechnical and geoenvironmental behaviour of high-density tailings, *Canadian Geotechnical Journal, 54*,4, 455-468.

Snoeck, D., Schaubroeck, D., Dubruel, P. and De Belie, N. 2014. Effect of high amounts of superabsorbent polymers and additional water on the workability, microstructure and strength of mortars with a water-to-cement ratio of 0.50, *Construction and Building Materials, 72*, 148-157.

Staples, T.L. and Chatterjee, P.K. 2002. Synthetic superabsorbents. *Textile Science and Technology* (Vol. 13, pp. 283-322) Elsevier, 283-322.

Wack, H. and Ulbricht, M. 2007. *Gel blocking effects during the swelling of polymeric hydrogels.* Communications présentées au Proc. First International Conference on Self Healing Materials, Nordwijk aan Zee, The Netherlands.

Wang, C., Harbottle, D., Liu, Q. and Xu, Z. 2014. Current state of fine mineral tailings treatment: A critical review on theory and practice, *Minerals Engineering, 58*, 113-131.

Wang, X.T., Feng, X., Xu, Z. and Masliyah, J.H. 2010. Polymer aids for settling and filtration of oil sands tailings, *The Canadian Journal of Chemical Engineering, 88*,3, 403-410.

Wichterle, O. and Lim, D. 1960. Hydrophilic gels for biological use, *Nature, 185*,4706, 117.

Zhang, J., Li, A. and Wang, A. 2006. Study on superabsorbent composite. VI. Preparation, characterization and swelling behaviors of starch phosphate-graft-acrylamide/attapulgite superabsorbent composite, *Carbohydrate Polymers, 65*,2, 150-158.

Zohuriaan-Mehr, M.J. and Kabiri, K. 2008. Superabsorbent polymer materials: a review, *Iranian polymer journal, 17*,6, 451.