Mining, Metallurgy & Exploration
https://doi.org/10.1007/s42461-022-00679-w

Dewatering of Mine Waste Using Geotextile Tubes

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Received: 8 May 2021 / Accepted: 15 September 2022

Abstract
This study proposes a methodology for dewatering of mine waste using a multistage process, combining geotextile tubes and anionic polyacrylamide (PAM), which accelerates the recycling process of water for aggregate mine waste facilities. For this purpose, waste from a rock quarry located in Istanbul was investigated. Flocculation tests revealed that the use of anionic PAM at an optimum dosage reduced sedimentation time and decreased turbidity. The compatibility of geotextiles and mine waste conditioned with different dosages of the effective PAM was evaluated by rapid dewatering tests, considering the water content of the filter cake, amount of infiltrated solid content, and rate of filtration. Geotextile dewatering tests were also performed on PAM-free and conditioned suspensions. The dewatering process was optimized by the use of a geotextile tube in two stages: (i) on the unconditioned suspension and (ii) on recovered PAM-conditioned leachate. Directing PAM-free non-hazardous soil-based material obtained in stage i to alternative beneficial uses is suggested, to minimize the volume of waste. Furthermore, recycling of the effluent obtained at the second stage of the proposed method will ensure more efficient water reuse

Keywords Mine Waste · Dewatering · Geotextile Tubes · Polyacrylamide

1 Introduction

Mining, alongside agriculture, is one of the most important economic activities undertaken to meet basic human needs. Most mining activities, the driving force of the Industrial Revolution, continue to expand in order to meet increased needs. Mining is an important industrial activity which produces substantial amounts of waste material in the region where it occurs. Therefore, this waste is considered the second worst global pollutant today [1]. Ore minerals found in different layers of the crust constitute only a small part of the total excavation volume in mining activities. The soil material excavated during the acquisition of the desired mineral or element undergoes physical and/or chemical procedures, producing various waste and stripping materials [2]. This may lead to pollution in the mining region and its surroundings by increasing the level of some elements by up to 1000 times their concentrations in nature [3–5].

Urbanization and rapid population growth, caused by technological developments and industrialization, have led to the formation of waste materials that have high levels of water content (*w*), caused by industrial processes in various fields. These industrial wastes are disposed of in high-cost sanitary landfills which require large spaces and long-term monitoring. The problems surrounding the disposal of millions of tons of fly ashes that are produced globally as industrial by products serve as an example [6, 7]. Recycling of these waste materials is possible in different fields. Several studies have examined the production of artificial lightweight aggregates using waste materials such as sediment, waste glass, siliceous soil, waste incinerator fly ashes, waste ceramic powder, metal sludge, sewage sludge, and mine waste [8–13].

Dewatering has become one of the major issues in the environmental geotechnics field, needing solutions involving useful applications for waste materials with high levels of water content (w) and compressibility [14–16]. Such solutions can provide numerous economic and environmental benefits. However, studies about dewatering of waste are limited in the literature. Some of these studies have investigated electroosmotic flow [17], the use of electrokinetic energy [18, 19], and the use of geotextiles [20].

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The use of soluble polyacrylamide (PAM) in geotextile tube dewatering applications is regarded as an efficient method for treating waste materials that have high levels of w [21–27]. In this method, geotextile tubes, which are constructed with high-strength seaming and have high levels of permeability, act as a filter for waste suspensions placed within them. PAM solution, added into the suspension before filling the geotextile tube, produces bigger flocs by combining smaller ones. Therefore, the filtration rate of wastewater is increased while the quantity of initial solid content (ISC) in the supernatant phase is decreased. There is a reduction in w of up to 85% during dewatering in geotextile tubes after PAM-conditioning [28]. The anionic and cationic characters of PAMs allow them to be used efficiently in dewatering studies [16, 29, 30]. PAMs can also aid in reduction of pollutant levels. PAMs decreased phosphorus in the sludge of manure lagoons in experiments using geotextile tubes [31].

Some researchers note that the use of synthetic PAM may pose problems for human and environmental health [32–34]. Therefore, determining the proper type and dosage of PAMs that will be used in the field is of the utmost importance.

Previous studies suggest that the use of PAM in dewatering of waste inside a geotextile tube will provide major benefits. In this context, dewatering of waste taken from an aggregate mine was performed using a geotextile tube and PAM, and the results were evaluated in terms of economic costs and benefits as well as environmental health.

2 Materials

2.1 Mine Waste

Mine waste used in the study was taken from an aggregate mine in Istanbul, Kemerburgaz. Figure 1a shows a Google Earth image of the location of the mining facility, and the waste facility where mine waste produced during mining activities are stored can be seen in Figure 1b. Samples were taken from the extraction line in lidded plastic 15-l barrels and preserved in humidity chambers at the Istanbul Technical University Geotechnical Laboratories until experiments were conducted.

The mine waste has no organic content according to SM 2540C. The pH of the mine waste is 6.8 as measured with a Mettler Toledo S220-K SevenCompact™ pH meter. The zeta potential is observed to be −19.7 mV using a Malvern Zetasizer Nano instrument within the deviation of 6.55 mV. The specific gravity (Gs) value is 2.67 according to ASTM D584. The liquid and plastic limit test demonstrates that the mine waste is non-plastic (NP) according to ASTM D4318. The grain size distribution of the mine waste was measured by sieve analysis and hydrometer tests, according to ASTM D6913 and ASTM D7928, respectively, and is shown in Figure 2a. Therefore, the mine waste is consistent with the silty sand "SM" soil type, as defined in the Unified Soil Classification System (ASTM D2487). The scanning electron microscope (SEM) image in Figure 2b shows that the mine waste is mostly composed of discrete grains. Elemental analysis by a Quanta-FEG 250 device shows that O_2, Si, Al, and Fe are the major chemical components of the mine waste (Table 1).

2.2 Polyacrylamides

PAM, a polymer group, acts as a flocculant that joins fine sediment particles together. Hence, PAMs provide rapid solid-liquid separation when added into a waste material suspension with high water content [29, 30, 35–39]. PAMs demonstrate different types of activity related to the pH level of the environment they are mixed into, and different types of links formed with grains in the suspension (surface absorption and chemical ion exchange). Therefore, various PAMs are tested on the waste suspension in order to choose the most appropriate chemical types, relative charges, bulk densities, and molecular weights. In this study, 11 types of

Fig. 1 The location of mine and waste facility

Fig. 2 **a** Grain size distribution curve. **b** SEM photograph of the mine waste

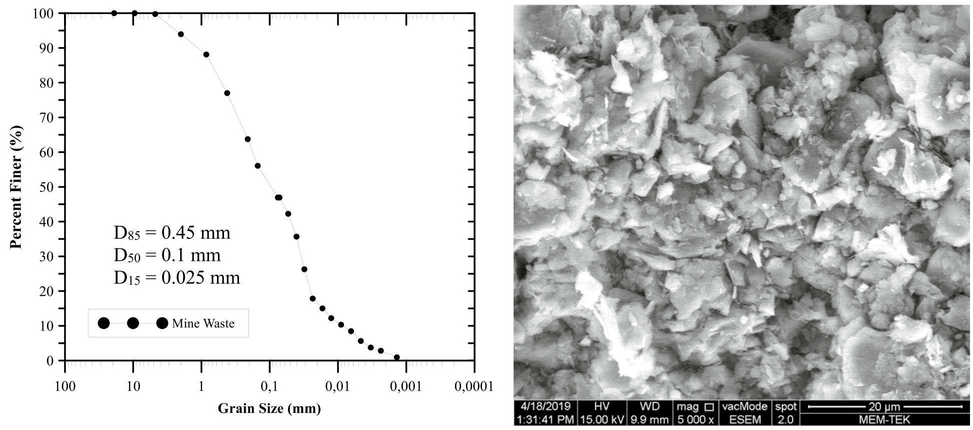


Table 1 The chemical components in the mine waste

Element	C	O	F	Na	Mg	Al	Si	K	Ca	Fe
Wt %	5.42	36.35	1.07	0.83	4.75	13.21	24.84	1.73	0.68	11.12

Table 2 Properties of PAMs

PAMs	Chemical type	Relative charge	Molecular weight
A1	Anionic	Low	Low-medium
A2	Anionic	Low	Medium
A3	Anionic	Low-medium	Medium
A4	Anionic	Medium	Medium-high
A5	Anionic	Medium	Medium-high
A6	Anionic	Medium	Medium-high
A7	Anionic	Medium	High
A8	Anionic	Medium-high	High
A9	Anionic	High	High
A10	Anionic	High	High
A11	Anionic	Very high	High
C1	Cationic	Medium-high	High
C2	Cationic	High	High

anionic PAMs and 2 types of cationic PAMs obtained from different producers were tested as flocculants (Table 2).

2.3 Geotextiles

As geotextiles have a large number of uses in different fields, their physical and mechanical properties differ depending on their purpose and use. While the hydraulic permittivity is important for geotextiles fabricated in tube form for dewatering applications, tensile strength is also an important attribute and must be adequate, especially when the tube is full or is subjected to additional loading. The gap size distribution (O95) and apparent opening size (AOS) are of the highest importance to determine the largest grain diameter which can be infiltrated through the geotextile. Properties of the woven geotextile material used in the dewatering processes in this study are provided in Table 3.

3 Methods

3.1 Flocculation Test

A Velp JLT6 Jar-Test device, enabling simultaneous analyses in 6 separate beakers, was used during flocculation tests, in which the rotational speed and duration of mixing could be adjusted (Figure 3a). Tests were performed in compliance with the ASTM D2035 standard. Suspensions of 500 ml with a solid mineral waste content of 10% were prepared. The suspensions were mixed at a rate of 150 rpm (revolutions per minute) for 2 min before conditioning with one of the PAMs, with a dosage of 10 ppm. After conditioning, the mixing rate was set to 50 rpm for the flocculation process. Due to rapid precipitation, the sedimentation rate of the flocculated grains was calculated using the measurements of final sedimentation time and height for each test.

Figure 3a and 3b presents examples of the turbidity during flocculation tests of the suspensions before and after conditioning with PAMs A1 to A6, from left to right. The samples for turbidity testing were taken from the mid-height of the supernatant phase using an automatic pipette after 10 min of settling. The turbidity test was conducted in compliance with the ASTM D7725-17 standard, using a HACH 2100P Turbidimeter device, and results were presented in NTU (Nephelometric Turbidity Units).

3.2 Small-Scale Test (Rapid Dewatering Test)

The rapid dewatering test (RDT), a small-scale laboratory test, was performed in order to determine the interaction

Table 3 Woven geotextile properties

Properties	Description	Unit	Value	Test method
Physical	Material		Polypropylene yarns	
	Mass/unit area	g/m^2	585	ASTM D5261
	Thickness	mm	1.8	ASTM D5199
Mechanical	Apparent opening size (AOS)	mm	0.43	ASTM D4751
	Minimum tensile strength	kN/m	78	ASTM D4595
	Minimum seam strength	kN/m	70	ASTM D4884
	Water flow rate	$l/min/m^2$	813	ASTM D4491
Filtration	Pore size distribution (O_{50})	Micron	80	ASTM D6767
	Pore size distribution (O_{95})	Micron	195	ASTM D6767

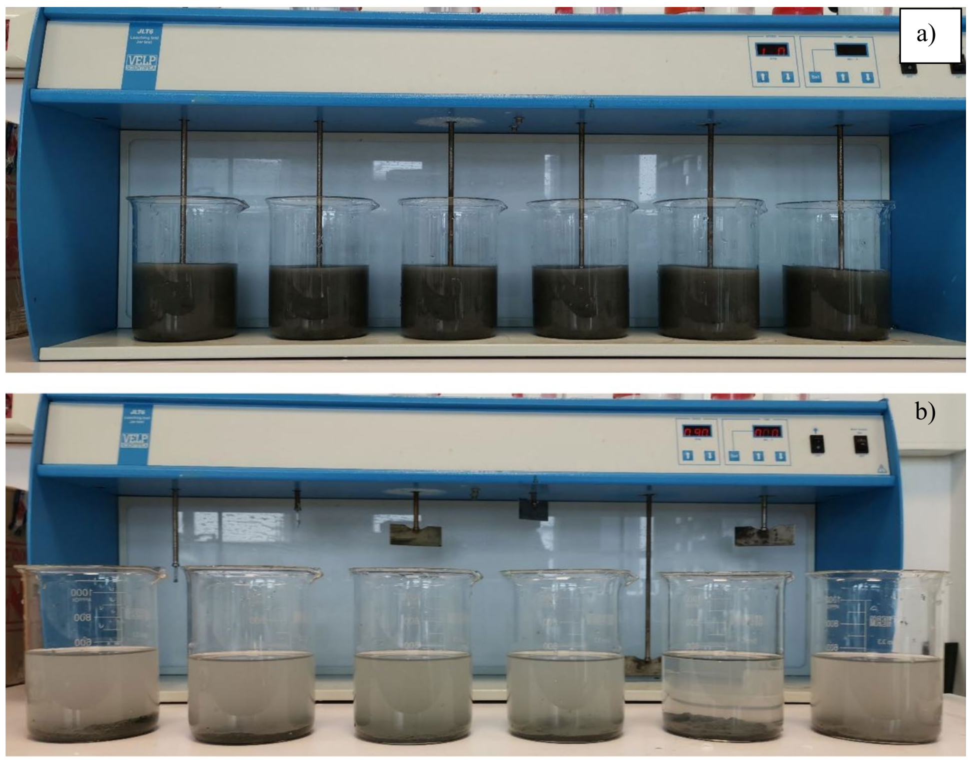


Fig. 3 Flocculation (JAR) test **a** before and **b** after

between the geotextile to be used as the filtration material and the flocs formed using PAMs. The tests were conducted on unconditioned and conditioned 500-ml suspensions of mine waste with 10% solid content. Conditioning with the most effective PAM was studied at dosages of 10, 20, 30, 40, and 50 ppm. A modified version of the rapid dewatering test setup was developed following the method of TenCate [40] and more sensitive data were achieved accordingly. The main body of the setup, consisting of a filling chamber and pedestal, with scales connected to the data collection system, is shown in Figure 4. Before the test, the geotextile material to be used for filtration is placed between the lower and upper segments of the filling chamber. The suspension prepared by a magnetic stirrer is poured on the geotextile in the chamber. The leachate which infiltrates through the geotextile accumulates in the lower measuring cylinder. The weight of the leachate was logged four times per second throughout the test. The thickness of filter cake was measured (Figure 4b). ISC and w of the filter cake (Figure 4c) were measured after oven drying at 105 °C.

3.3 Full-Scale Test (Geotextile Dewatering Test)

Geotextile tubes perform dewatering by acting as a filter for the material they are filled with. The geotextile dewatering test (GDT) is a model of the system used in field applications. In this study, the 3-dimensional dewatering behavior of polymer-free and conditioned suspensions

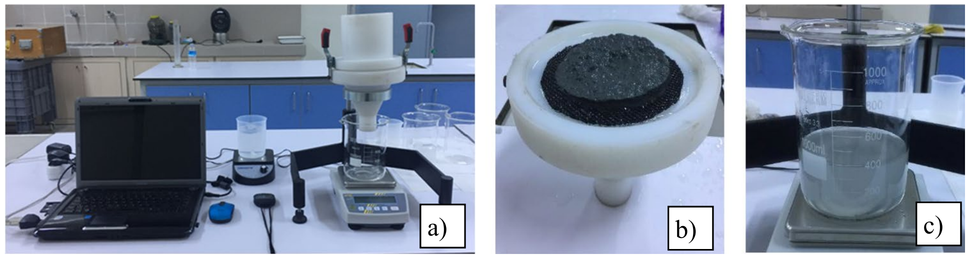


Fig. 4 RDT setup: **a** general view, **b** filter cake, **c** leachate

containing 10% solid mineral waste was modeled by GDT. Pillow-shaped geotextile bags (53 cm × 53 cm) were filled with polymer-free suspensions and with suspensions conditioned by the most efficient PAM used at the optimum dosage. The geotextile pillow bag, which is closed with stitches on all sides, has a capacity of approximately 28000 cm^3. Material is added through an opening left on one side which allows the filling of material to dewater [41, 42]. The GDT setup, consisting of a geotextile pillow connected to a filling pipe on the pedestal and placed in a large container for leachate, can be seen in Figure 5a. After the filling process, the volume of effluent accumulating inside the container shown in Figure 5b was measured at regular time intervals.

3.4 Effluent Analysis

Effluent quality parameters were analyzed after the GDT. pH was measured by a Mettler Toledo S220-K SevenCompact™ pH meter. Dionex ICS-3000 ion chromatography was used in ion specification, while heavy metal and other elemental analyses were performed using a PerkinElmer inductively coupled plasma-optical emission spectrometry (ICP-OES) device. Using these results, the effluent quality was compared with both national and international drinking water standards (TS 266, EPA, WHO).

4 Results

4.1 Flocculation Test (Jar Test)

The turbidity value for a mine waste suspension with 10% solid content was measured as approximately 39800 NTU. After the flocculation tests of the suspensions conditioned with the PAMs given in Table 2 at a dosage of 10 ppm, the sedimentation rate and turbidity values were measured, and the results are shown in Figure 6. The efficiency of cationic PAMs as flocculants was very limited on the unconditioned suspension, such that the rate of sedimentation observed for the suspensions conditioned with anionic PAMs was at least three times higher. Most of the suspensions conditioned with anionic PAMs gave lower values for turbidity than those conditioned with cationic PAMs. The A5 PAM decreased the turbidity value significantly compared to others (5th beaker on the left side, Figure 3b). Additionally, Figure 6 shows that A5 PAM provided the most efficient results in terms of sedimentation rate and turbidity.

After the pre-assessment of conditioning with 13 PAMs at 10 ppm dosage, and confirmation of the suitability of A5 PAM, the optimum dosage of A5 PAM was analyzed with repeated flocculation tests at different dosages. The sedimentation rate and turbidity observations for the tests with dosages of 10, 20, 30, 40, and 50 ppm conditioning

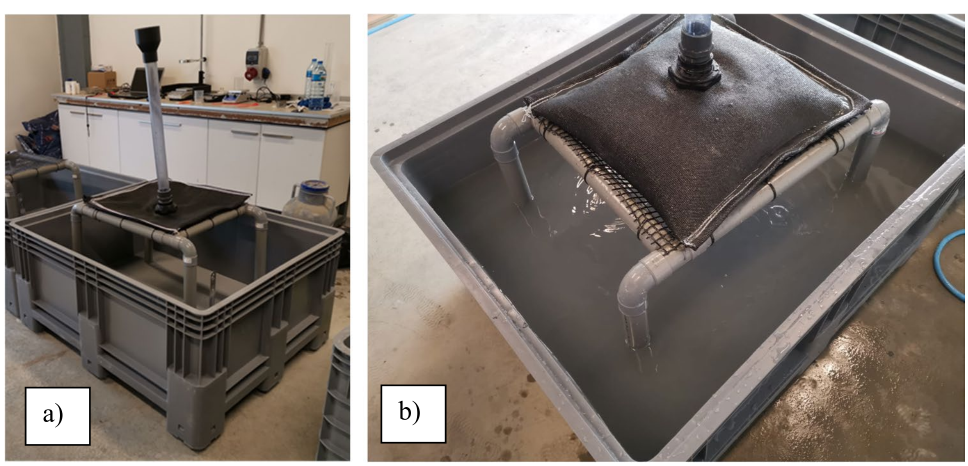


Fig. 5 General view of the GDT setup **a** before and **b** after the mine waste filling process

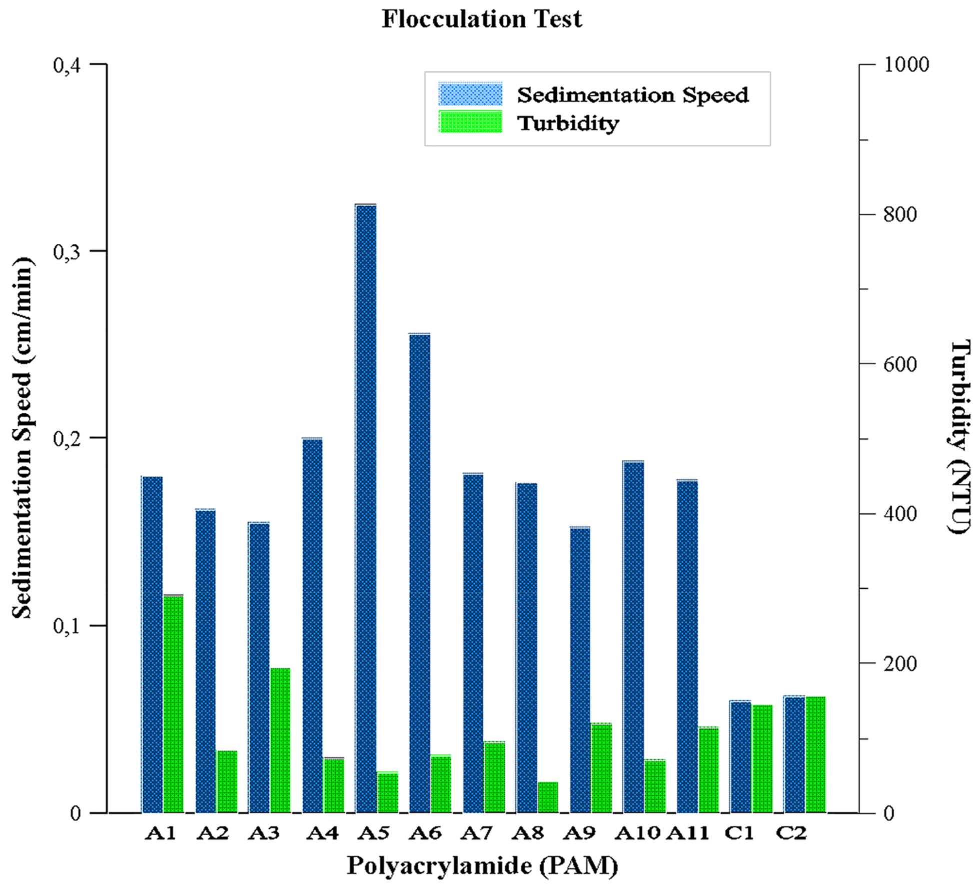


Fig. 6 Sedimentation speed and turbidity values of conditioned suspensions

are presented in Figure 7. The turbidity values decreased initially with increasing dosage, and then increased above an optimum. As a result, 30 ppm has been determined as the most suitable dosage, which exhibits the lowest turbidity and highest sedimentation rate when the mine waste suspension is conditioned with A5 PAM.

4.2 Small-Scale Test (RDT)

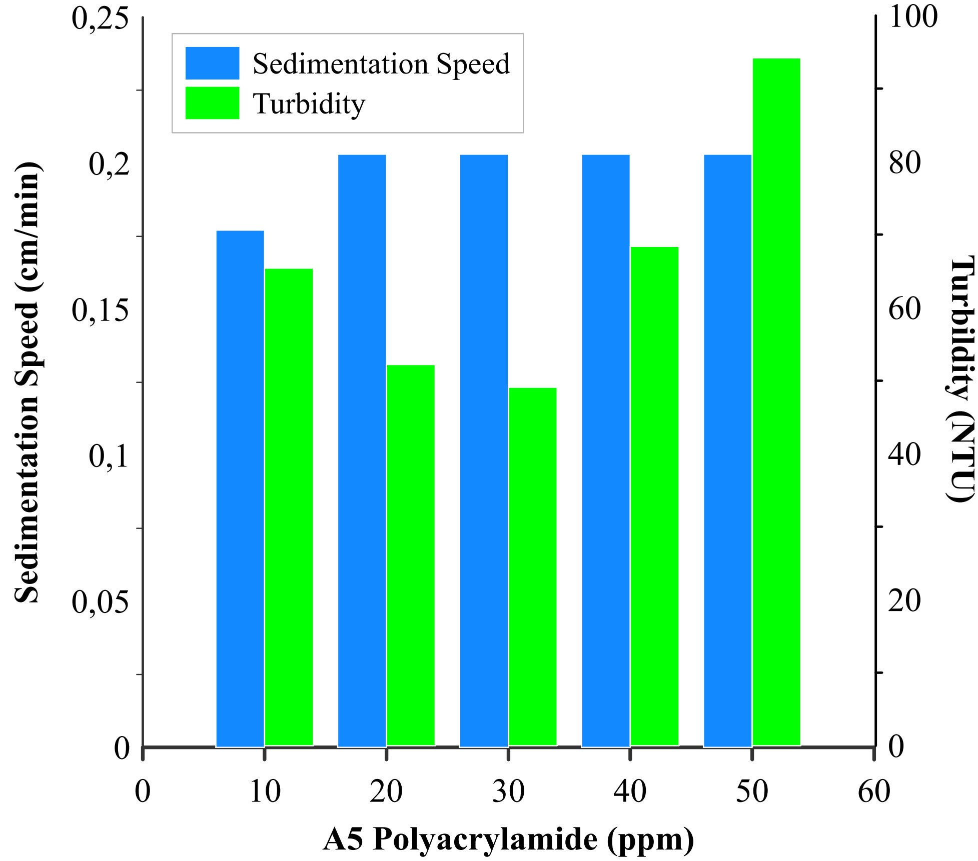
The changes in leak/suspension ratio by weight, called the filtration ratio (R_f), for PAM-free and A5-conditioned suspensions at dosages of 10, 20, 30, 40, and 50 ppm, are plotted against the logarithm of time in Figure 8a. The rate of filtration for the PAM-free suspension infiltrating through the geotextile reached a maximum around R_f = 30% at 2 s. After the formation of filter cake, the filtration rate was observed to decrease. Similarly, the plots of filtration rates versus time given in Figure 8a show peak values that then decrease, as well as delays in time, with increasing dosage. However, it is obvious that the filtration process was extended up to 9 min by conditioning, and the final value of R_f was equal to 80% for all suspensions. Meanwhile, the times required for R_f to reach values of 25, 50, and 75% are also compared in Figure 8b, showing an increase in time with increasing dosage.

The dry weight ratio of ISC to mineral wastes, which was determined to be 18.5% in the RDT experiment of PAM-free suspension, did not exceed 1% for all doses of A5-conditioned suspensions (Figure 9), and was reduced up to 0.7% in the suspension with the 30 ppm dosage. However, *w* of the fraction retained on the geotextile after RDT was calculated to be higher for A5-conditioned mine waste than the 26% observed for the PAM-free suspension. For A5-conditioned suspensions with 30 ppm dosage, the lowest *w* found was 57%. An increase in dosage of soluble PAM used for conditioning may lead to more water remaining between retained particles. Also, fine-grained materials retained on the geotextile by conditioning could increase *w* for conditioned samples compared to PAM-free suspensions.

4.3 Full-Scale Test (GDT)

The results of RDT on A5-conditioned suspensions support the findings of flocculation tests that the optimum dosage is 30 ppm. Therefore, PAM-free suspensions and suspensions conditioned with 30 ppm A5 PAM are evaluated in GDT. As suggested by the grain size distribution, shown in Figure 2a, the mine waste is highly permeable. Filling of the suspensions into a geotextile pillow bag was

Fig. 7 Sedimentation rate and turbidity at flocculation tests by the use of PAM (A5)



completed in a single attempt, using a volume of 570 l for PAM-free and 300 l for A5-conditioned mine waste. The volume of infiltration was measured over time after filling. The ratios of filtrate volume to total filling volume in the first 15 and 1440 min were 86.7% and 86.8% for PAM-free mine waste, and 74.1% and 76.8% for A5-conditioned mine waste, respectively, and the ratio changed very little in the following days.

A Malvern Mastersizer 2000 device was used to determine the particle size distribution of ISC in the GDT of PAM-free mine waste. Figure 10 shows that the particle sizes of solids in leachate are consistent with the AOS value of the geotextile (Table 3) and are smaller than 0.43 mm. However, in sieve analysis of mine waste (Figure 2a), 77% of the total dry weight passes through a No. 40 sieve with an aperture of 0.43 mm, while in the GDT this ratio is limited to 13.4% of the ISC. This indicates that the main parameter controlling the ISC after the formation of filter cake is not AOS value [43].

The reductions in *w* of mine waste kept inside the pillow bag on day 1, 2, 3, and 7 after filling were measured to be 15%, 14.5%, 14%, and 10.5% for PAM-free mine waste, and 29%, 27%, 24%, and 20% for A5-conditioned mine waste, respectively. GDT shows lower values of *w* than RDT for both of the suspensions after dewatering (Table 4). This is to be expected, as the drainage conditions are unidirectional in RDT and three-dimensional in GDT. As in RDT, for all time periods analyzed in GDT, *w* of A5-conditioned mine waste was found to be higher than *w* of PAM-free mine waste due to fine granular materials and PAM in pores. The ratio of ISC to the initial solid content was 13% for PAM-free mine waste, and 0.6% for A5-conditioned mine waste 7 days after filling. These results are compatible with the measured values from the RDT.

4.4 Effluent Analysis

The water quality of the effluents was analyzed in order to determine environmental risks that may arise with the use of geotextile tubes and PAM during the dewatering process for mine waste. Water quality parameters used in the study are summarized in Table 5, and compared to values provided in Turkish Standards TS266 [44], World Health Organization (WHO) [45], and United States Environmental Protection Agency (US EPA) [46] guidelines for water quality standards. These results show that the effluent values meet national and international water quality standards and that discharging of geotextile tube effluent into a receiving environment or recycling effluent for mining operations are appropriate options.

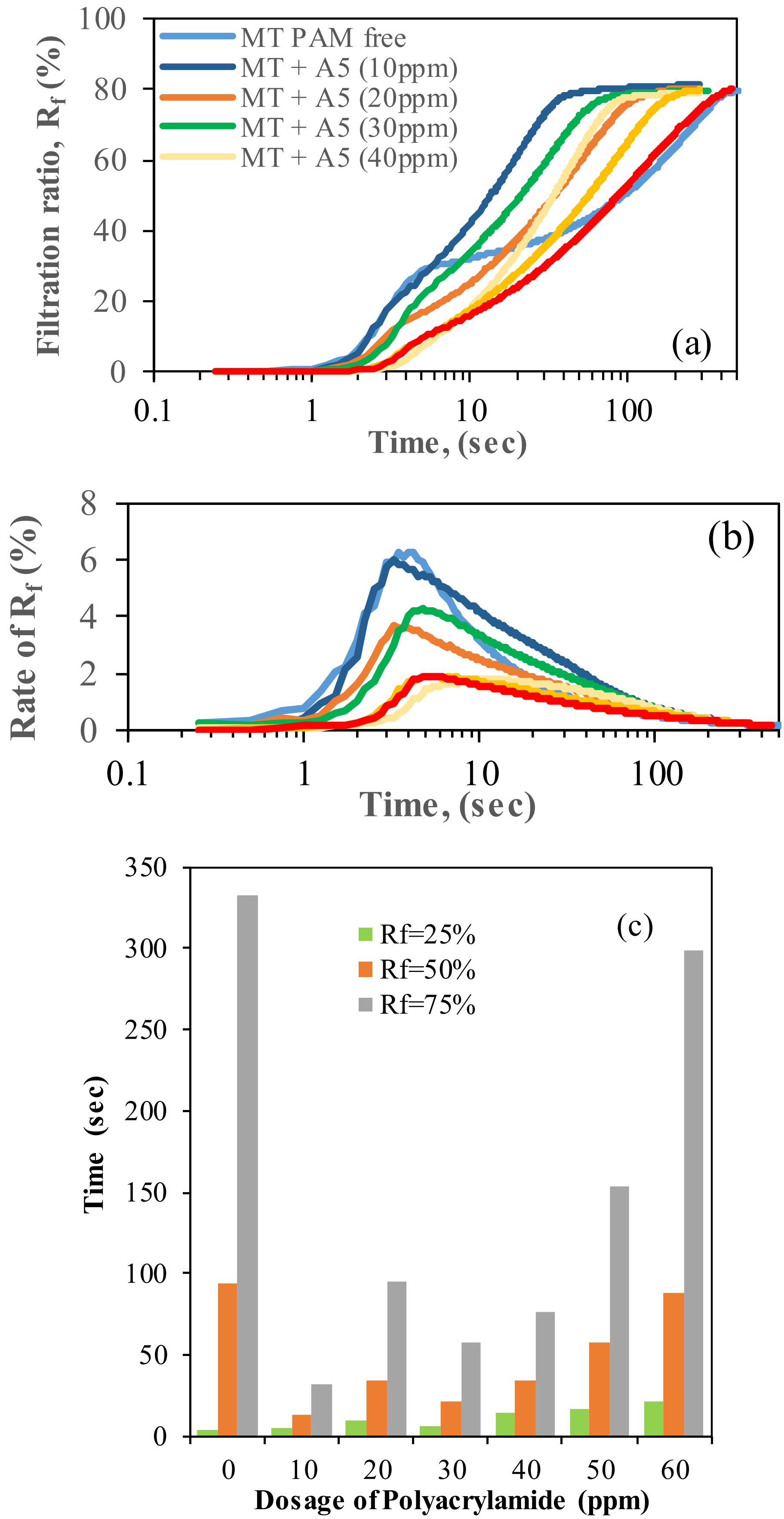


Fig. 8 The ratio and rate of the filtration versus time plots for PAM-free and A5-conditioned suspensions of mine waste in RDT

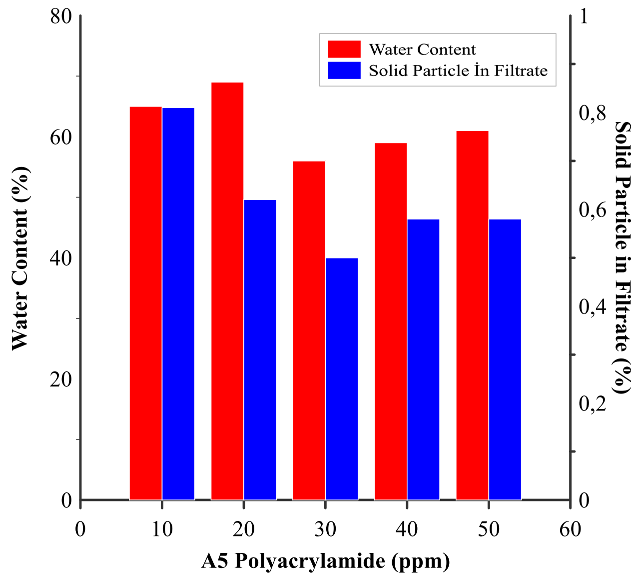


Fig. 9 The *w* of retained fraction and ISC in RDT after A5-conditioning

5 Discussion

Suspensions of mine waste with 10% solid content were analyzed. According to literature review, the mechanism underlying the impact of polymer flocculants is still an incredibly complex physical and chemical process [47–49]. Although researchers have attempted to propose several qualitative explanations, adsorption bridging action has been the most frequently accepted explanation. In the literature, it has been determined that anionic polyacrylamide (APAM) is a suitable flocculant type for rapid flocculation and settling of mine wastes, as it reduces the negative charge by bridging the flock particles [50, 51]. In a similar way, the negatively charged mine waste, with an observed zeta potential of −19.7 mV, exhibits better flocculation behavior with anionic PAM than with cationic PAM. Besides, this may be due to the intramolecular electrostatic repulsion forces between polymer segments, which extend the conformation of polymer chains, leading to more efficient bridging flocculation with minerals [52]. Porous and large aggregates are formed by the absorbance of the PAM only on the neutral sites of many fine particles (i.e., edges of clay particles). Therefore, in the flocculation tests, an anionic PAM (A5) yielded the most efficient results (at the dosage of 30 ppm) such that the turbidity value decreased to 43 NTU (99.9% efficiency) in a very short period of time (10 min).

The suitability of geotextiles and PAM to be used in dewatering was tested in RDT experiments. The maximum grain size of ISC in effluent was equal to 0.43 mm, consistent with the apparent opening size (AOS) value of geotextile in use. The filtration rate of the effluent suddenly decreased with the formation of filter cake during the RDT of PAM-free mine waste. Thereafter, ISC should be limited such that 83% of the particles below 0.43 mm in diameter could be retained on the geotextile. The ratio of retained particles to total particles was improved to 99.5% by A5-conditioning at a dosage of 30 ppm. In the GDT, 3-dimensional filtration of a 28-l internal volume geotextile pillow bag was assessed. GDT showed

Fig. 10 The particle size distribution of ISC in GDT of PAM-free mine waste

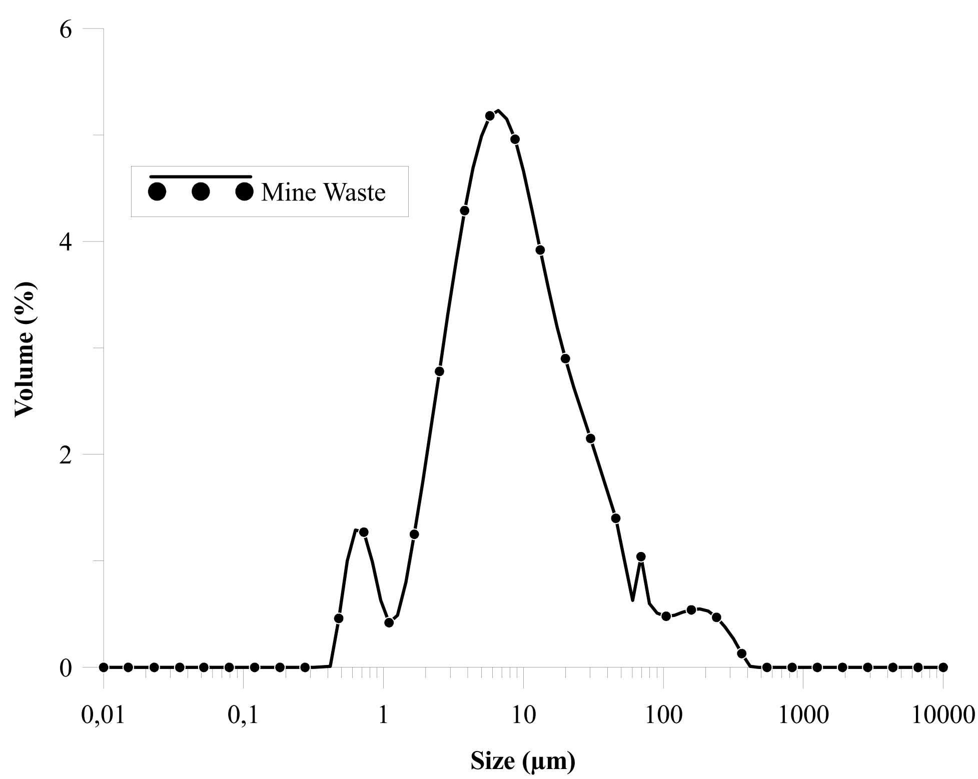


Table 4 The change in the water content of the filter cake in the tube after GDT

Day	PAM-free (%)	PAM-conditioned (%)
1	15	29
2	14.5	27
3	14	24
7	10.5	20

that ISC was decreased by PAM-conditioning, consistent with the results of RDT. However, the measured dewatering capability of 570 l for a PAM-free mineral waste suspension was greater than the 300-l capability observed for a mine waste suspension after A5-conditioning. Additionally, in both RDT and GDT models, the A5-conditioned mine waste exhibited higher w than PAM-free mine waste, due to the water absorbed by PAM and fine-grained particles. GDT showed lower values of w for the retained fraction than RDT, which is consistent with the model of infiltration in three dimensions and one dimension, respectively.

The dewatering process aims to minimize w of the retaining particles on the geotextile and to limit ISC as much as possible. In addition, the use of geotextile tubes in dewatering applications requires maximizing the solid fraction retained in the tube while minimizing infiltration of solids. In this respect, the use of geotextile tubes in two stages was evaluated as an option to optimize the dewatering process in aggregate mine waste. The high dewatering capability for PAM-free mine waste presented in GDT was assessed by the use of a geotextile tube in the first stage. Applying PAM conditioning to the filtered volume will allow the ISC to be stored in a second geotextile tube. Therefore, it will be possible to direct the PAM-free mine waste recovered in the first stage to beneficial alternative uses, and to minimize the chemical dependency and the volume of PAM-conditioned mine waste, before the effluent is recycled or discharged, in order to maximize economic and environmental benefits.

In this context, it was necessary to reassess the optimum dosage of PAM-conditioning for the filtrate volume generated in the first stage, to be dewatered in the second stage. This experiment was performed on the samples of ISC recovered from the GDT of PAM-free mine waste. The suspensions prepared with 10% of the sample were conditioned by PAM (A5) at doses of 5, 10, 15, 20, and 25 ppm. This study was limited to RDT, considering the large amount of dry ISC required for GDT and the consistency of ISC presented between GDT and RDT. Figure 11a presents R_f for the PAM-free and A5-conditioned leachate infiltrated through the geotextile, plotted against time. The 5 ppm PAM dosage was insufficient for flocculation such that the solid content was effectively filtered without being held on the geotextile, producing filtration rates similar to those of PAM-free waste. Flocculation occurred at dosages of 10 ppm and above. The optimum dosage was found to be 15 ppm for the dewatering of leachate by the second geotextile tube, considering w of filter cakes and ISC (Figure 11b). This result demonstrates that PAM could be used more effectively than at the dosage of 30 ppm determined in the previous dewatering experiment involving the use of a single geotextile tube on A5-conditioned suspensions of mine waste.

From this point of view, two different scenarios were considered for dewatering via geotextiles and PAM-conditioning. The first alternative is to take mine waste from

Table 5 Water quality parameters of filter effluent and standards

Parameter	Unit	Influent	Effluent	EPA	TS 266	WHO
pH		6.8	6.8	6.5-8.5	6.5-9.5	6.5-8.0
Fluoride (F)	mg/l	0.125	0.110	2	1.500	1.500
Chloride (Cl)	mg/l	42.856	41.610	250	250	250
Nitrite (NO_2)	mg/l	< 0.050	< 0.050	4.500	-	3
Nitrate (NO_3)	mg/l	2.985	2.790	45	50	50
Sodium (Na)	mg/l	34.050	34.010	-	200	200
Ammonium (NH_4)	mg/l	0.530	0.530	-	0.500	1.500
Iron (Fe)	mg/l	-	-	0.300	0.200	0.300
Manganese (Mn)	mg/l	0.022	0.022	0.050	0.050	0.100
Nickel (Ni)	mg/l	-	0.001	-	0.020	0.020
Copper (Cu)	mg/l	-	-	1	2	2
Zinc (Zn)	mg/l	-	0.002	5	-	3
Antimony (Sb)	mg/l	0.004	-	0.006	0.005	0.020
Cadmium (Cd)	mg/l	0.003	0.003	0.005	0.005	0.003
Chromium (Cr)	mg/l	0.015	0.015	0.100	0.050	0.050
Lead (Pb)	mg/l	0.008	0.007	0.015	0.500	2
Selenium (Se)	mg/l	0.007	0.008	0.050	0.010	0.010
Arsenic (As)	mg/l	0.004	-	0.010	0.010	0.010

waste facilities and to dewater them in a geotextile tube after conditioning with PAM (Figure 12a). The second alternative can be described in two stages. When the PAM-free mine waste taken from the facility are dewatered in the first tube, effluent with 13% ISC will accumulate in a pool. Dewatering of this volume will be performed in a second geotextile tube after PAM-conditioning to minimize turbidity and ISC of the effluent before discharge (Figure 12b).

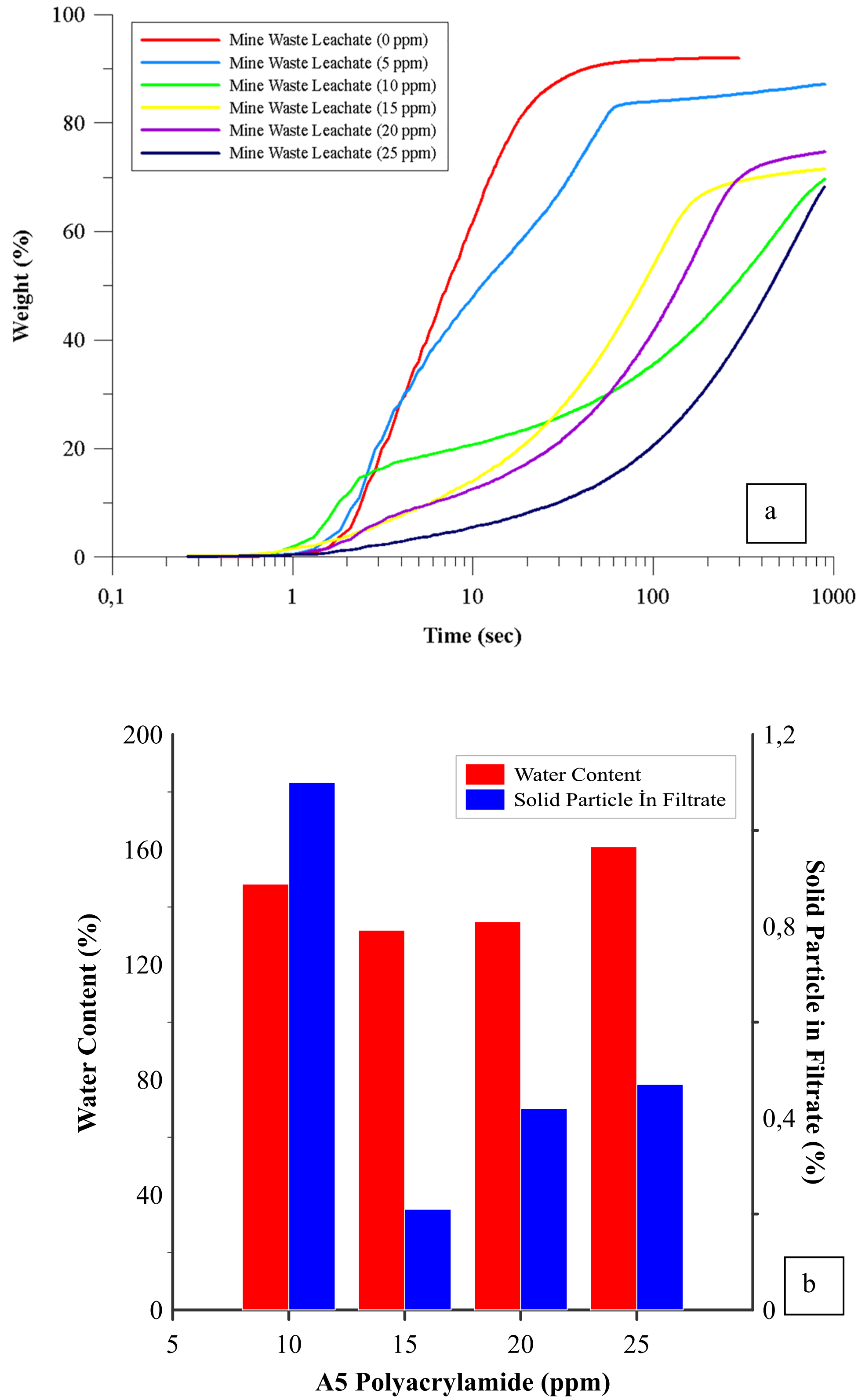
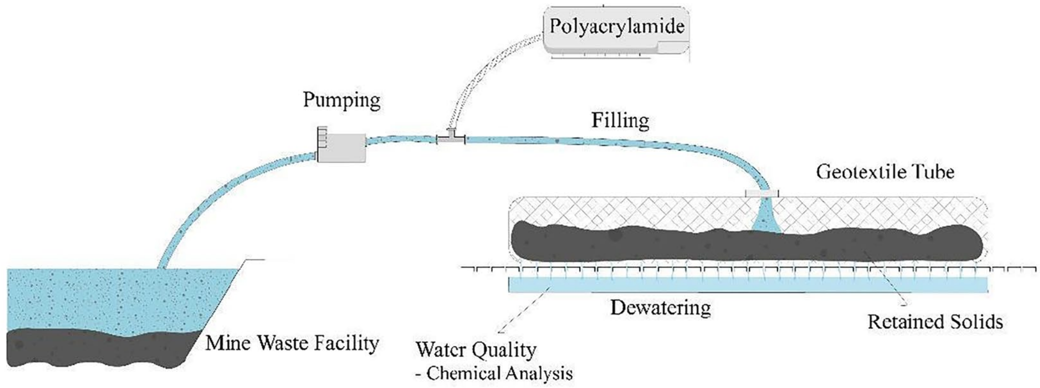


Fig. 11 The result of RDT on PAM-free and A5-conditioned leachate. **a** R_f versus time. **b** The *w* of retained fraction and ISC in RDT after A5-conditioning.



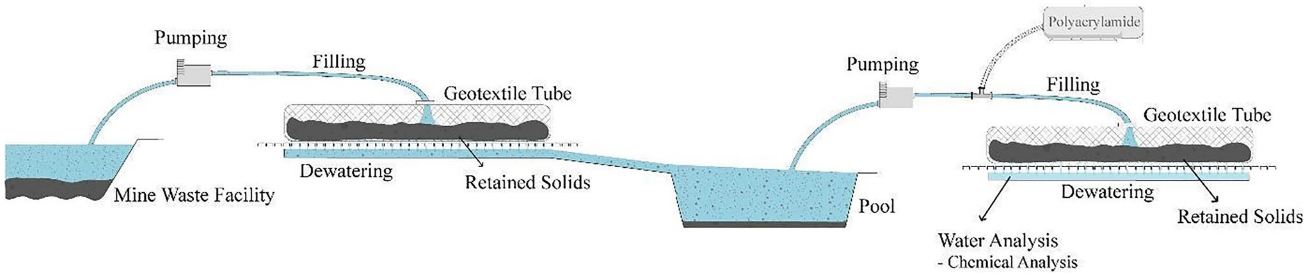


Fig. 12 Dewatering alternative with **a** single geotextile tube and **b** two geotextile tubes

The application of the second alternative has economical advantages in terms of materials and environmental benefits as well as some other positive impacts. For instance, the waste material accumulated in the tube at the first stage has lower *w* and it is unprocessed and thus ready to be used in positive applications such as nonhazardous soil-based material. Therefore, approximately 93% less waste material will be generated compared to the first alternative. This will provide a major benefit in terms of protecting the environment and ecosystem. It is thought that the volume of geotextile tubes will be used 40% more efficiently in the second alternative.

Water recovery is of the utmost importance in the mining sector. The water is obtained from the receiving environment nearest to the mines. Discharging the effluent into the receiving environment or recycling it for reuse in mining applications will aid efforts to meet national and international standards for potable water quality.

6 Conclusion

The aim of this study is to propose a methodology for the dewatering of quarry mine waste in an efficient and economical manner, in order to render the material and water ready for beneficial alternative applications. In this respect, the method of dewatering in geotextile tubes and PAM conditioning of the waste suspension are evaluated and the findings are as follows:

- In flocculation tests, anionic PAMs yielded better results than cationic PAMs for the flocculation of mine waste.
- Results obtained in the rapid dewatering test (RDT) and geotextile dewatering test (GDT) were found to be consistent with each other in terms of ISC.
- Two scenarios were evaluated for dewatering mine waste in aggregate quarries using geotextile tubes. The first scenario involves dewatering the mine waste after PAM-conditioning in a geotextile tube, which reduces turbidity. The second scenario involves the use of two geotextile tubes and accelerates the dewatering process and optimizes the efficiency of the geotextile in use. Similar levels of ISC and turbidity were maintained for the discharged effluent. Moreover, the second option offered a 93% decrease in chemical PAM dependency and 40% more efficient use of geotextile tubes in terms of the dry weight of filled waste material. Consequently, the second option is proposed to provide economic and environmental benefits.
- The final leachate generated by the use of geotextile tubes in dewatering applications for mine waste after PAM-conditioning was found to meet national and international standards for potable water. In this regard, discharging the waste water to the surrounding area will not

cause environmental issues, and recycling it for use in mining activities will be an appropriate economic action.

Further studies using the proposed method are needed to determine the alternative beneficial applications of PAM-free soil-based materials and PAM-conditioned fine-grained material stored in the first and second tubes, respectively. Considering the large amount of mine waste produced globally, such contributions will be beneficial for the world economy and environmental health.

Declarations

Conflict of Interest The authors declare no competing interests.

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