Assessment of Dewatering Process Using Flocculation and Self-filtration According to the Characteristics of Mine Drainage Sludge

Duk-Min Kim, Dong-Kwan Kim

MIRECO (Korea Mine Reclamation Corporation), Segye-ro 2, Wonju 26464,
South Korea, dmkim@mireco.or.kr

Abstract Geotextile tubes, geotextile bags, and gunny bags were used to dewater sludge via flocculation and self-filtration at passive and semi-active mine drainage treatment facilities. The relationship between the discharge rate in one day and the initial volume of the sludge indicated dewaterability of sludge regardless of the dewatering material and its shape. The water content of sludge from the passive treatment facilities decreased to <80% in one day. The effects of oxidation and precipitation on the particle surface increasing the particle size and decreasing the in situ water content might have enhanced the dewaterability at the passive treatment facilities.

Key words Mine drainage sludge, Geotextile, Self-filtration, Dewatering, Water content

Introduction

Accumulation of sludge is inevitable at mine drainage treatment facilities due to metal precipitation. For example, Fe hydroxides accumulate during vertical flow at successive alkalinity-producing systems (SAPS) (Kepler and McCleary 1994), and OH^-, supplied by added chemicals, reacts with dissolved metals such as Fe, Mn, and Zn to generate flocs at (semi-)active treatment facilities. Semi-active treatment systems generally accumulate sludge over a long period in rectangular settling ponds with horizontal flow, while active treatment systems continuously treat sludge. Developing a simple and efficient method to treat accumulated sludge is needed for both passive and semi-active treatment systems.

Geotextile is a polymerized textile material used for sand, soil, or gravel during construction, which may be woven or non-woven (Jeon et al. 2014). Furthermore, it is used as a filter material to reduce the water content of sludge and sediment. Flocculation and self-filtration using geotextile or other materials simplifies the operation and required machinery compared with sludge dehydrators. Several studies and field applications have assessed the use of geotextile tubes for dewatering (Fowler et al. 2000; Mastin et al. 2008; Howard et al. 2009; Kaye 2016). However, there are few studies on the differences in dewatering efficiency according to the characteristics of the treatment facilities and sludge.

Therefore, the objectives of this study were to elucidate the principal factors affecting the dewatering efficiency of mine drainage sludge, including physical differences in sludge between passive and semi-active treatment facilities and the material or shape of dewatering tubes or bags.

Methods

Target facilities

The target facilities for this study included two passive and two semi-active mine drainage treatment facilities. The semi-active treatment facilities (OD and YD) had pH adjustment tanks in which slaked lime emulsion was injected, slow-speed agitation tanks, and rectangular settling ponds. Both the passive treatment facilities (SW and WR) employed SAPS. In the semi-active and passive treatment facilities, the sludge intended for disposal was held in a settling pond and the SAPS, respectively.

Sludge dewatering system

Sludge pumped by a peristaltic hose pump reacted with flocculant in a flocculation tank for 10 min to form larger flocs, which were concentrated and dewatered in a geotextile tube, geotextile bag, or gunny bag. The geotextile was composed of polypropylene with an apparent opening size of <259 µm. The geotextile tube was flat and rectangular in shape with an opening on the upper side (Fig. 1). The geotextile and gunny bags were square-shaped and required supports to maintain their shapes.

Figure 1 *Materials for self-filtration: a: geotextile tube, b: geotextile bag, c: gunny bag.*

The flocculants and injection ratios were selected based on jar tests with adjustments in the field. The selected flocculants included OCI N-100E non-ionic polyacrylamide for the OD facility and Nalco-855 cationic polyacrylamide for the YD, SW, and WR facilities.

Measurements and analysis

The discharge rate of the filtrate from sludge dewatering was calculated by dividing the decrease in the volume of sludge with time. The sludge particle size distribution was analyzed using Mastersizer 2000 (Malvern Instruments). To measure the size of sludge floc rather than that of each particle, the agitation speed was set at the lowest setting of 1000 RPM without application of ultrasonic agitation to minimize the breakdown of sludge flocs during analysis. The zeta potential of the sludge was analyzed using ELSZ-1000 (Otsuka). The microstructure and composition of sludge were analyzed using scanning electron microscopy-energy dispersive spectroscopy (model Supra40, Carl Zeiss) at the Institute of Mine Reclamation Technology (IMRT), Korea Mine Reclamation Corp. (MIRECO). Sludge samples were weighed, dried for >4 h at 105–110°C, and weighed again, and the water content of the sludge was calculated using Equation 1.

$$\theta = \frac{(m_i - m_t)}{m_i} \times 100 \qquad (1)$$

where θ, m_i, and m_t are the gravimetric water content (%), initial mass of the sample, and dried mass of the sample, respectively.

For the water samples, pH was measured using a pH/ORP meter (model Orion 3-Star, Thermo). Suspended solids were determined using a portable colorimeter (model DR-890, Hach) following the photometric method (Krawczyk and Gonglewski 1959).

Water samples for the analysis of cations were filtered through a 0.45-µm pore size membrane and filled into 50-mL polyethylene conical tubes. Cations were analyzed by inductively coupled plasma optical emission spectroscopy (720-ES, Varian) at IMRT, MIRECO.

Results and discussion

Dewatering characteristics of sludge

In the sludge dewatering experiments at the four facilities, sludge water content and concentration ratio were monitored over time (Fig. 2). The concentration ratio was defined as the decrease in the ratio of sludge mass, which was calculated using the water content of sludge before and after dewatering (Equation 2). Although the concentration ratio at the OD facility reached 90% after 22 days, the water content was still high, above 90%. In comparison, the water content of sludge at the YD facility was 88.0% after only 4 days of dewatering, which was lower than that of sludge from the OD facility.

$$Concentration\,ratio = (1 - \frac{100 - P_i}{100 - P}) \times 100 \qquad (2)$$

where *Pi* and *P* are the water contents of sludge before and after dewatering, respectively.

At the SW passive treatment facility, the water content of the concentrated sludge reached 80% in only one day, with a concentration ratio of above 95%. The other passive treatment facility, WR, showed a low water content (73.4%) after only 1 h. At all four facilities, the suspended solids concentrations decreased from 4000–40000 mg/L in the sludge to 1–41 mg/L in the filtrate. The two semi-active treatment facilities (OD and YD) maintained relatively high water contents, while the two passive facilities (SW and WR) reached low water contents in a short period (Fig. 2).

Various efficiencies have been reported using geotextile tubes to dewater sludge or sediment. In Pennsylvania, the water content of mine drainage sludge decreased from 97–99% to 65–70% after several days (Kaye 2016). During dredging of riverbed sediments in New York, the water content decreased from 85–90% to 70–75% after 7 days (Gaffney 2008).

Conversely, the water content was 80.4% after 53 days of dewatering sewage sludge, with 92% water content, in Massachusetts (Fowler et al. 2000). The efficiencies in our experiments, especially those at the passive treatment facilities, were similar or better than those reported previously.

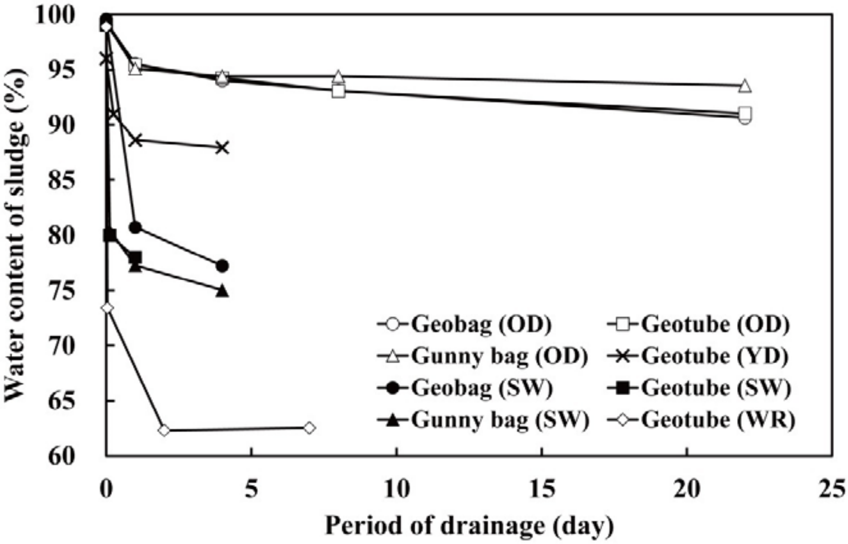

Figure 2 *Water content of sludge over elapsed time for drainage at four treatment facilities.*

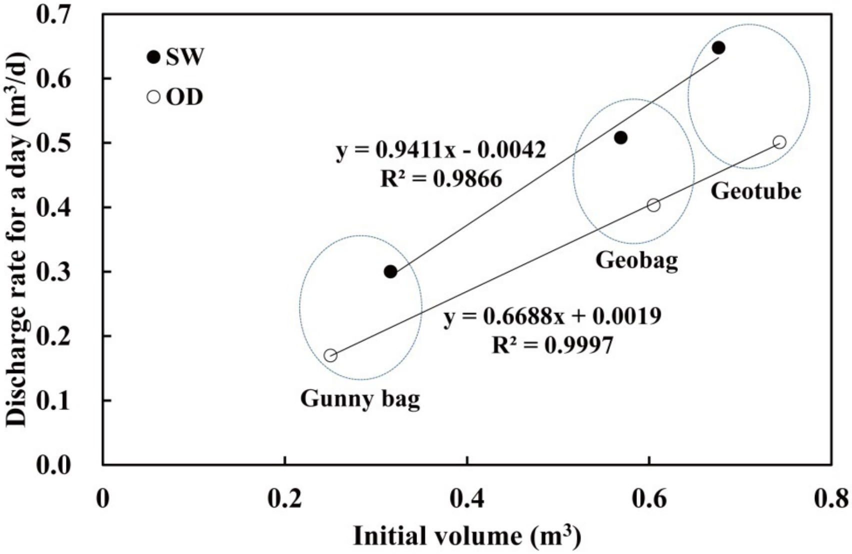

Figure 3 *Relationship between the discharge rate of filtrate in one day and initial volume of sludge in geotextile tubes, geotextile bags, or gunny bags at the SW and OD facilities.*

The discharge rate of the filtrate in one day was plotted against the initial volume of sludge in the geotextile tubes and bags at the OD and SW facilities (Fig. 3). The discharge rate revealed positive relationships with the initial volume (R^2: 0.9997 at OD, 0.9866 at SW) and y-intercepts near zero. This suggests that the texture or shape of tubes and bags have little effect on the discharge rate, and that the characteristics and initial volume of the sludge may determine the discharge rate. This in turn could indicate that the decrement in water content would be nearly constant for a specific sludge, regardless of the type of dewatering tubes or bags used. The trend expressed by the slope in the plot was 1.4 times higher for SW than that for OD, representative of the higher dewaterability of the SW sludge.

Effect of in situ water content and particle size

Sludge was collected at each pond or SAPS using an *in situ* sampler and settled for several days to evaluate the *in situ* water content (Table 1). The water contents of the sludge from the semi-active facilities were high as 95.1% and 98.1%, while those at the passive facilities were as low as 65.1% and 84.3% (refer to Hwang et al. 2016). This difference may be also reflected as the water content after dewatering (Fig. 2). This indicates that the intrinsic characteristics of the sludge determine its dewaterability, although the water contents of the pumped sludge were similar (96.0–99.6%) due to dilution with ambient water during pumping.

Table 1 *Physical properties of sludge from mine drainage treatment facilities.*

Type	Mine	In situ water content (%)	Particle size according to volume fraction (µm)			Zeta potential (mV)	Period of accumulation (yr)
			d_{10}	d_{50}	d_{90}		
Semi-active	YD	95.1	4.4	11.0	23.2	3.81±0.40	1
	OD	98.1	6.7	17.4	38.4	-2.49±0.03	4
Passive	SW	84.3	6.6	40.6	176.4	-3.41±0.11	15
	WR[a]	65.1	10.8	58.4	110.7	9.88±0.20	8

[a] The particle size distribution of sludge from WR mine is provided by Oh (2015).

The particle size distribution in the pumped sludge was evaluated before flocculation at the four facilities. The large particle sizes of sludge at the passive treatment facilities were a distinguishing characteristic contrary to that of the semi-active facilities. However, the zeta potential did not appear to determine the particle size, because the values for all four facilities were within ±10 mV, indicating a commonly low repulsive electric force among particles (Table 1). Because the injected neutralizing agent increased the pH in a pH-adjustment tank at the semi-active treatment facilities, metal precipitates were generated homogeneously and sporadically (Liang et al. 1993). Meanwhile, oxidation of Fe occurred on the surface of existing Fe(III) (hydr)oxides as heterogeneous oxidation at the passive treatment facilities (Ames 1998), resulting in accretionary growth of particles (Ackman 1982; Brown et al. 1993; Hsieh 1993; Dempsey and Jeon 2001). In addition, the vertical downward flow at the

SAPS may have contributed to compaction, resulting in enlarged particles, as reported by MIRECO (2016).

Media with large particle sizes have high hydraulic conductivities for drainage (Hazen 1911; Shepherd 1989). Although polymers also bind flocs from the sludge at the semi-active treatment facilities, the low discharge rate of the sludge suggests that the intrinsic characteristics of sludge are more important than polymerization. Moreover, intrinsic characteristics such as specific resistance to filtration and viscosity are considered to be high for sludge from (semi-)active treatment facilities, as reported by Dentel and Abu-Orf (1995) and Dempsey and Jeon (2001).

Conclusions

The positive relationship between the discharge rate for one day and the initial sludge volume suggests that the intrinsic characteristic of sludge is a more important determinant of dewaterability than the texture or shape of dewatering tubes or bags. The slope of the relationship can be used as a parameter to assess sludge dewaterability. Accretionary growth of particles and compaction during vertical flow at the SAPS of the passive treatment facilities could have resulted in the large flocs, with 50% particle size distribution (d_{50}) values of 40.6–58.4 µm, and low *in situ* water contents. Thus, the water content of the sludge could be effectively reduced to <80% using flocculation and self-filtration after ~1 day at the passive treatment facilities, even though the water content was ~99% in the pumped sludge.

Acknowledgements

This work was supported by the Korea Mine Reclamation Corporation funded by the Korean Government Ministry of Trade, Industry, and Energy.

References

Ackman TE (1982) Sludge disposal from acid mine drainage treatment. Bureau of Mines Report of Investigations RI 8672, USA

Ames RP (1998) Iron oxidation, gas transfer, and solids formation in passive treatment systems for mine drainage. Dissertation, The Pennsylvania State University, USA

Brown H, Skousen J, Renton J (1993) Floc generation by chemical neutralization of acid mine drainage. Green Lands 23:44—51

Dempsey BA, Jeon BH (2001) Characteristics of sludge produced from passive treatment of mine drainage. Geochem-Explor Env A 1:89—94

Dentel SK, Abu-Orf MM (1995) Laboratory and full-scale studies of liquid stream viscosity and streaming current for characterization & monitoring of dewaterability. Water Resour 291:2663—2672

Fowler J, Bagby RM, Trainer E (2000) Dewatering sewage sludge with geotextile tubes. In: Pederson J, Adams EE (Eds), Dredged Material Management – Options and Environmental Considerations, Proc. of a conference, MIT Sea Grant College Program, p 80—83

Gaffney DA (2008) Use of poor quality geo-material in geotextile tubes for structural applications. In: Proc. 2008 Geotextile Tubes Workshop, Mississippi State University, Starkville, MS, USA

Hazen A (1911) Discussion: Dams on sand foundations. T Am Soc Civ Eng 73:199

Howard IL, Smith M, Saucier CL, White TD (2009) Geotextile Tubes Workshop, SERRI Report 70015-002, USA

Hsieh Y (1993) Effect of ion adsorption with various hydrolysis characteristics on the dewaterability of Fe2O3 sludge. Water Sci Technol 28(7):23—30

Hwang WJ, Oh TG, Lee JU, Kim DM, Cha J (2016) Characteristic research of sludges in passive mine water treatment system of Waryong, Donghae (6th adit) and Honam mine. J Korean Soc Miner Energy Resour Eng 53(5):489—497

Jeon HY, Jang YC, Jang JW, Jeong YI, Park YM (2014) Geosynthetics design and construction. CIR Press, Korea

Kaye P (2016) Successful dewatering of acid mine drainage materials. http://www.bishopwater.ca/case-studies.php. Accessed 15 March 2017

Kepler DA, McCleary EC (1994) Successive alkalinity-producing systems (VFW) for the treatment of acidic mine drainage. In: Proc. International Land Reclamation and Mine Drainage Conference. USDI, Bureau of Mines SP 06A-94, Pittsburgh, PA, USA

Krawczyk D, Gonglewski N (1959) Determining suspended solids using a spectrophotometer. Sew Ind Wastes 31:1159—1164

Liang L, McNabb JA, Paulk JM, Gu B, McCarthy JF (1993) Kinetics of Fe(II) oxygenation at low partial pressure of oxygen in the presence of natural organic matter. Environ Sci Technol 27:1864—1870

Mastin BJ, Lebster GE, Salley JR (2008) Use of Geotube® dewatering containers in environmental dredging. In: GeoAmericas Conference Proceedings 2008, p 1467—1486

MIRECO (Korea Mine Reclamation Corp.) (2016) Development of technology for removing sludge and scales around mine drainage treatment facilities. Report 2015-041, MIRECO, Wonju, Korea, p 161—172

Oh TG (2015) A study on turbidity improvement and precipitation characteristic of mine drainage using coagulant. Dissertation, Dong-A University, Busan, Korea

Shepherd RG (1989) Correlations of permeability and grain size. Ground Water 27:633—638