THE STATUS OF THE PASSIVE TREATMENT SYSTEMS FOR ACID MINE DRAINAGE IN SOUTH KOREA[1]

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Abstract. This study has been carried out to investigate the operating status, evaluate their problems, and discuss the possible improvement methods of passive treatment systems for acid mine drainage in South Korea. Thirty-five passive treatment systems in 29 mines have been constructed since 1996 using SAPS as a main process.

Out of 29 systems investigated (two for metal mines), 19 systems revealed various problems. Overflows of drainage from SAPS or wetland or oxidation pond were caused by flow rate exceeding the capacity of the facility or the low permeability of the organic substance layer. At various places in systems leakages happen. Sometimes clogged and broken pipes at the mouths of the mine adits made the whole system useless. Some systems showed very low efficiencies without apparent leakage or overflow. Even though systems show fairly good efficiencies in metal removal (mainly iron) and pH control, sulfate removal rates were very poor except for three systems, which may indicates very poor sulfate reductions by SRB.

As an alternative method In-Adit-Sulfate-Reducing System, the method of placing the SAPS inside the adit, to keep the temperature constant about 15℃ was suggested.

Additional Key Words: acid mine drainage, SAPS, SRB, In-Adit-Sulfate-Reducing System

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Introduction

From 1989, over 98% of coal mines in Korea have been closed by the coal industry promotion program and only ten coal mines are operating. Also about nine hundred metal mines were closed or interrupted with presently operating 19 mines (CIPB, 2003). Since 1996, 35 passive treatment systems in 29 mines have been constructed to treat the acid mine drainage from the closed or abandoned mines. More than one process including SAPS (successive alkalinity producing systems), ALDs (anoxic limestone drains), anaerobic wetland, aerobic wetland, and oxidation pond was combined and applied in the construction of passive treatment system (Fig. 1.).

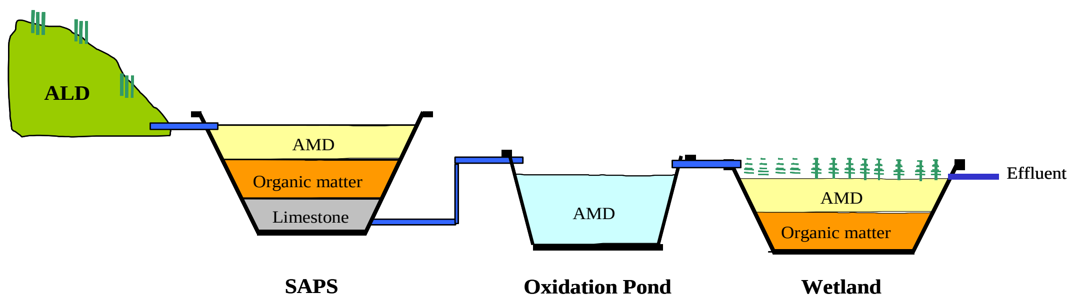

Fig. 1. A generalized schematic diagram of the passive treatment system in Korea.

SAPS is the main treatment process for AMD treatment in Korea. In SAPS, the AMD flows downward through the organic layer, which has two essential functions. First, dissolved oxygen in AMD is removed by bacteria, utilizing biodegradable organic compounds as energy source. Then, bacterial sulfate reduction in the anaerobic zone of organic layer generates alkalinity (Hedin et al., 1994). Then water flows through the limestone bed. Because dissolved oxygen was removed before contacting the limestone, coating of metal-hydroxide is not made on limestone surface. Therefore alkalinity can be produced successively. Reduction of sulfate by SRB reduces the concentrations of dissolved metal ions directly by the precipitation of metal sulfides. AMD treatment utilizing SRB for the alkalinity production and metal removal also occurred in the anoxic wetland.

Research and investigation on the passive treatment systems in Korea mostly focused on the removal efficiency of metals (mainly iron) and pH control (Sung et al., 1997, Bae et al., 2001), but did not concern the removal of sulfate. However, many systems reveal very low removal ratio or even increased concentrations of sulfate (Cheong et al., 2001, Ji et al., 2003), which may indicate poor or even no biological sulfate reduction in the system. Therefore this study has been carried out to evaluate the problems, if they exist, of the passive treatment systems and especially has focused on the status of sulfate removal process.

Field Excursions, Sampling and Analysis

Water samples were collected at the mine adits and the effluent spot of each treatment system, both during the dry season (from November to March) and the wet season (from July to September). Water samples for cation determination were filtered through a 0.45μm cellulose nitrate membrane filter using a hand pump, and were immediately acidified to pH<2.0 by adding HNO_3. Water samples for alkalinity and anion determinations were filtered but not acidified.

The pH, ORP, temperature, DO, conductivity and TDS were measured in situ. Analysis for dissolved cations was performed using an inductively coupled plasma atomic emission spectrophotometer (ICP-AES; Jobin Yvon Co. 138 Ultrace) at the Seoul branch of Korea Basic Science Institute. Anions were determined using ion chromatography (IC; Dionex series 500DX) at the Pusan branch of Korea Basic Science Institute, and alkalinity was determined by the titration method. Acidity was calculated by the following equation (Hedin et al., 1994).

$$\mathrm{Acid}_{\mathrm{Calc.}} = 50\left(\frac{2\mathrm{Fe}^{2+}}{56} + \frac{3\mathrm{Fe}^{3+}}{56} + \frac{3\mathrm{Al}^{3+}}{27} + \frac{2\mathrm{Mn}^{2+}}{55} + 1000(10^{-\mathrm{pH}})\right) \qquad (1)$$

(50 : the equivalent weight of $CaCO_3$, Unit of metal concentration : mg/l)

The Operating Status of the Treatment Systems

Table 1 shows the operating status of 29 passive treatment systems. Normal means that the systems are working properly with no leakage or overflow. Overflow means that overflow occurs at a certain stage of the system. The reason of overflow could be that flow rate is exceeding the capacity of the facility or lowered permeability by coating of hydroxides in SAPS prevents water from flowing through the organic substance layer. Leakage means the leaking of AMD at various places in the system. Unusable means that whole system was useless due to various reasons such as clogged and/or broken pipes at the mouths of the mine adits. Inefficiency means that no apparent leakage or overflow is observed but the efficiency is very low.

Table 1. Operating status of the passive treatment systems

Operation status	Number of system	Mines
Normal	10	Hanyang, Sungwon, Hambaek-imok, Hambaek-mireuk 1, Hambaek-mireuk 2, Samwang 1, Samwang 2, Dongwon-taeheung 1, Dongwon-taeheung 2, Sukkong-sinsung
Overflow	7	<u>Youngdong</u>, <u>Hanchang</u>, <u>Sungbong</u>, <u>Danbung</u>, Gapjung, Dongbok, Hotan-taebaek
Leakage	7	Hwangji, <u>Donghea</u>, <u>Hanchang</u>, Bongmyung, <u>Sungbong</u>, <u>Danbung</u>, <u>Ilkwang*</u>
Unusable	6	Pungwon, Samma-taejung, Hambaek-bangjae, Hambaek-jami, <u>Hanchang</u>, Honam 2nd
Inefficiency	7	<u>Youngdong</u>, Waryong-taewoo, <u>Donghea</u>, Dongwon-kwangjung, <u>Sungbong, Ilkwang*, Dalsung*</u>

*: Metal mine
Underlined mines have problems more than one

The Efficiency of the Treatment Systems

Investigation for 27 systems for coal mine drainages showed that metal removal ratios and acidity removal ratios were fairly good. However, sulfate removal ratios were very low (Table 2). Similar results were reported by Sung et al. (1997) and Cheong et al. (2001). It might indicate that sulfate reduction by SRB was very low or even does not occur in SAPS and/or constructed wetlands. Systems for metal mine drainages showed very poor efficiency in metal removal. Even though systems show fairly good efficiencies in metal removal and pH control, poor sulfate removal ratio might indicate that the major metal removal process is not the precipitation of metal sulfides but just the adsorption on organic substrates.

Table 2. The efficiencies of the passive treatment systems.

Treatment System	Inflow				Outflow				Fe T.E (%)	Acid. T.E (%)	SO_4^{2-} T.E (%)
	pH	Fe (mg/l)	Acid. (mg/l)	SO_4^{2-} (mg/l)	pH	Fe (mg/l)	Acid. (mg/l)	SO_4^{2-} (mg/l)			
Waryong-taewoo	-	-	-	-	2.12	158.0	471.9	3,941	-	-	-
Youngdong	2.87	276.0	1,182	3,510	-	-	-	-	-	-	-
Samma-taejung	2.21	134.2	1,076	2,746	-	-	-	-	-	-	-
Hwangji	6.35	73.6	143.0	2,008	7.23	n.d.	6.71	1,406	100	95.3	30.0
Pungwon	6.67	10.8	26.2	796.6	6.90	n.d.	8.3	762.6	100	68.3	4.3
Hanyang	6.38	18.9	41.7	834	6.66	1.19	7.1	723.8	89.9	82.97	13.2
Donghea	5.80	127.0	241.0	1,413	2.98	20.1	125.5	763.7	84.2	47.93	46.0
Sungwon	7.09	n.d	0.71	574.3	7.54	n.d	0.28	537.3	~	60.6	6.4
Hanchang	6.60	13.3	25.9	247.7	8.30	0.03	0.64	218.7	99.8	97.5	11.7
Hambaek-imok	6.93	n.d	4.59	52.1	7.04	1.14	75.66	52.4	~	~	~
Hambaek-bangjae	6.62	555	1,084	81.3	6.92	65.0	223.6	137.6	88.3	79.4	~
Hambaek-jami	6.63	18.5	38.1	170.3	-	-	-	-	-	-	-
Samwang 1	6.49	5.58	11.85	68.9	7.41	0.04	0.43	64.3	99.3	96.4	6.7
Samwang 2	6.42	4.48	10.93	138.2	7.35	0.04	0.68	127.4	98.6	93.8	7.8
Dongwon-taeheung 1	6.26	8.82	18.4	92.2	6.30	3.48	8.7	93.1	60.5	52.72	~
Dongwon-taeheung 2	6.11	0.16	0.6	2.47	6.59	0.16	0.5	2.45	~	16.67	~
Hambaek-mireuk 1	6.32	1.16	4.6	69.4	6.19	0.57	2.3	69.1	50.9	50.0	0.4
Hambaek-mireuk 2	6.67	3.75	16.2	82.3	-	-	-	-	-	-	-
Dongwon-kwangjung	-	-	-	-	2.35	91.4	512.7	820.8	-	-	-
Danbung	7.50	n.d	10.49	1,144	7.08	n.d	0.57	975.6	-	94.6	14.7
Sungbong	2.11	0.275	788.2	2,289	3.43	n.d	423.3	2,079	100	46.3	9.2
Gapjung	4.77	n.d	2.43	1,213	7.00	n.d	0.29	1,189	-	88.1	2.0
Bongmyung	2.73	26.2	305.2	1,009	7.77	0.08	14.0	221.8	99.7	95.32	78.0
Dongbok	6.31	0.37	0.7	71.3	6.67	n.d.	0.01	68.2	100	98.6	4.3
Honam 2nd	5.54	32.7	73.4	541.3	6.65	n.d.	13.1	792.2	100	74.0	~
Hotan-taebaek	6.71	0.4	2.6	169.5	7.14	0.02	0.3	272	95	88.5	~
Sukkong-sinsung	6.29	6.77	13.8	88.3	7.23	n.d.	0.6	87.2	100	95.65	1.2
Ilkwang*	2.80	496.1	1,353	3431	2.85	439.4	1,217	3081	11.42	10.07	10.2
Dalsung*	5.09	164.0	443.2	3046	3.07	35.2	287.1	2884	78.5	35.24	5.3

T.E : Treatment efficiency n.d : Not detected - : One of the samples (inflow or outflow) was not sampled. ~ : TE < 0

In this case the treatment efficiencies would decrease quickly when the available surface area of organic substances are occupied with adsorbed metals. Considering the optimal temperature of 30~55℃ for the SRB activity, because of the cold weather in Korea, SRB activity could be very low or even nil during the winter. Also since flow rate decreases in winter, very low flow rate could often result in the exposure of organic layer to the air. From one of the pilot treatment systems in England, it was reported that SRB activity was stressed due to the low water level and air temperature during the winter. Since the stressed SRB were hit with an acidity overload, the metal removal performance of the system suffered (Gusek, 2001). Similar situation was reported at the Burleigh Tunnel in Colorado. This pilot scale treatment system for drainage which has neutral pH and about 50 ~ 60mg/l of dissolved Zn. It was exposed to a high of water with a high concentration (pH 4.1, Zn 109mg/l) in response to the snowmelts. The acidity loading also increased and despite some self-buffering capacity of the substrate, performance of the system suffered (Gusek, 2001).

Another reason for a poor sulfate removal ratio might be insufficient hydraulic retention time (HRT). From the experiments with model SAPS suitable HRT was reported to be 8 to twelve days (Lee, 2003), where as the HRT of the presently operating treatment systems are mostly about 5 days.

Also in the treatment systems using SAPS or anaerobic wetland, effluents show high COD concentration in the beginning of the operation, which could result in another source of pollution and cause the lack of carbon source. In addition, the sludge cake formed on the surface of the organic layer in SAPS would hamper the flow of AMD, which would result in the malfunction of the system in the long run. In Korea, since most mines are located in mountainous area, lack of the space for the construction of treatment system is also a very critical problem.

Recommended Design Improvements to Treatment Systems

The improvement method for each problem is suggested as follows. High COD in effluents in the beginning of the operation could be reduced by inducing slow dissolution of organic substrates. Sludge cake on the surface of organic layer could be improved by designing the water flow as the up-flow type. The problem of poor sulfate removal ratio would be improved by inducing sulfate reduction with suitable HRT, and the problem of poor SRB activity during winter would be improved by inducing sulfate reduction at constant temperature condition such as the inside the mine adit. The problem of lack of the space also could be solved to some extent by the construction of the system inside the mine adit.

The In-Adit-Sulfate-Reducing System (IASRS) was suggested as an alternative method to improve the treatment systems. IASRS is simply placing the SAPS inside the mine adit. Since whole systems are placed inside the mine adit, temperature would be maintained constant and the anoxic condition would be maintained even if the flow rate decreases. Therefore conditions for the proper sulfate reduction could be maintained (Fig.2). The experiment on the model system is in progress.

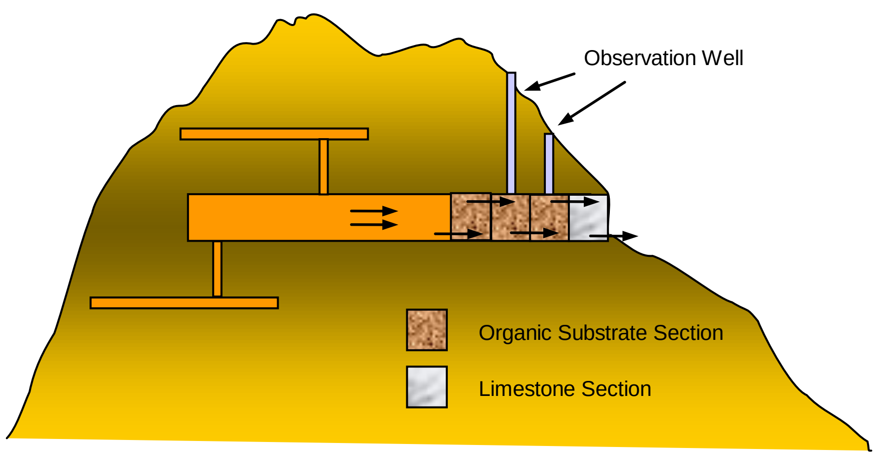

Fig. 2. Schematic Diagram of the In-Adit-Sulfate-Reducing System

Conclusions

Out of 29 investigated systems only 10 systems were working properly with no leakage or overflow. Others have problems such as overflow, leakage, unusable, and inefficiency. All of the treatment systems showed very poor ratios in sulfate removal, even though they showed good efficiencies in metal and acidity removals. The poor sulfate removal ratio might be the result of insufficient HRT for the sulfate reduction or low temperature and/or low rainfall during winter.

Also in the treatment systems using SAPS or an anaerobic wetland, effluents mostly show high COD concentration in the beginning of the operation, which could result in another source of pollution. The sludge cake formed on the surface of organic layer in SAPS would hamper the flow of AMD, which would lead to the malfunction of the system in the long run.

As an alternative method for the improvement of the operating systems, the In-Adit-Sulfate-Reducing System was suggested. IASRS can be operated at constant temperature all year long, so SRB activity could be maintained and sulfate reduction could occur all year long. The construction of the treatment system inside the mine adit would minimize the site area needed and no leakage or plugging, which usually occur between the mine adit and the system, will happen, and would make the system safe from bad climate such as heavy rain and typhoons.

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