Flow and Baffle Configurations of Reactor and Settling Pond for Treatment of Mine Drainage

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Abstract

This study assessed various flow configurations with baffles and weirs in substrate reactors and settling ponds on a bench- and pilot-scale. Also, required hydraulic heads for several types of substrate reactor were assessed to give the range of maximum allowable flow rate for several types of the reactor. If the hydraulic head difference is sufficiently high by pumping or the flow rate is sufficiently low, application of zigzag baffles in the longitudinal direction is highly encouraged in substrate reactors. Moreover, the installation of hanging baffles rather than zigzag baffles is recommended in settling ponds.

Keywords: Flow configuration, baffle, substrate reactor, settling pond, mine water treatment

Introduction

Efforts for the passive treatment of mine drainage have developed various reactors such as adsorption reactors, successive alkalinity producing system (SAPS), bioreactors, slag leach beds, and slag reactors (Ziemkiewicz 1998; Younger *et al*. 2002; Hamilton *et al*. 2007; Skousen *et al*. 2017; Kim *et al*. 2022a, b). The flow configuration of reactors is generally vertical, including column reactors and vertical flow ponds. Improvements in the shape and flow configuration can increase the actual residence time and decrease the dead zone in the reactor and settling pond, which can reduce the required area and construction cost for the facilities.

The objectives of this study are to 1) improve the shape and flow configurations of a reactor to treat low-flow contaminated water which includes longitudinal and latitudinal directions of baffles and 2) suggest a more efficient baffle configuration for settling ponds between zigzag and hanging baffles. To achieve these objectives, this study assessed various flow configurations with baffles and weirs in substrate reactors and settling ponds on a bench- and pilot-scale using results of treatment efficiencies. Also, required hydraulic heads for several types of substrate reactor were assessed to give the range of maximum allowable flow rate for each type of the reactor.

Methods

Characteristics of substrate

The slag reactors used in this study contained 40% steelmaking slag and 60% limestone in a volumetric percentage. The slag and limestone used in this study had sizes of 2–5 mm and 2–3 cm, respectively. The slag was generated in a basic oxygen furnace and contained 36.5% CaO and 40.9% Fe_2O_3, as demonstrated by x-ray fluorescence spectrometry.

Pilot-scale experiments

Three types of pilot-scale slag reactors were installed and operated at the same time to treat adit drainage from the abandoned Cheongsan coal mine in South Korea. The slag reactor can increase the pH and decrease the Mn concentration in mine drainage owing to the generation of OH- and precipitation of Mn carbonates and/or (oxyhydr)oxides (Kim *et al*. 2022a, b). The reactor types were baffle, weir, and column. All reactors had a length-to-width ratio of 3:1. In the baffle-type slag reactor, five zigzag baffles were installed in the longitudinal direction, and auxiliary hanging baffles were installed (Fig. 1). Zigzag-shaped weirs were installed at the inflow of the weir-type slag reactor to distribute the flow lines laterally, and the outflow part was cone shaped to evenly collect the flow lines. The flow direction of the column-type slag reactor was downward, and the inflow part had a perforated circular plate to distribute the flow lines laterally.

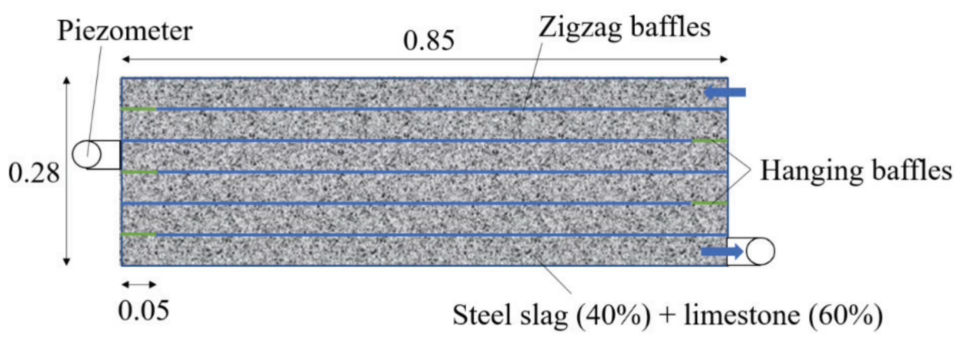
A pilot-scale rectangular settling pond was installed to reduce the suspended solids (SS) in the adit drainage. It had two types of baffle configurations that could be attached and detached: zigzag baffles and hanging baffles (Fig. 2). There were four zigzag baffles, and the baffle direction was longitudinal. The depth of the hanging baffles was 40% (0.28 m) of the water depth (0.7 m), and they were located at 1/3 and 2/3 of the length of the pond because these conditions were reported to be efficient (Yoon *et al*. 1999; MIRECO 2011). To laterally distribute flow lines in the settling pond with hanging baffles, weirs were installed at the inflow and outflow.

Results and discussion

Treatment efficiencies of various flow configurations at pilot-scale slag reactors

Mn treatment efficiencies of weir-type, baffle-type, and column-type slag reactors were assessed on a pilot scale to decrease Mn from 3.8–4.6 mg L^{-1}. The residence time required to decrease the Mn concentrations in the reactor with baffles was evidently lower than that in the reactor with a weir (Fig. 3; Kim *et al*. 2022c). For example, the maximum residence times to fulfill the effluent standard of Mn (2 mg L^{-1}) were inferred by each regression line of four samples at the boundary of maximum residence times for the weir-type and baffle-type reactors. The estimated maximum

a)



b)

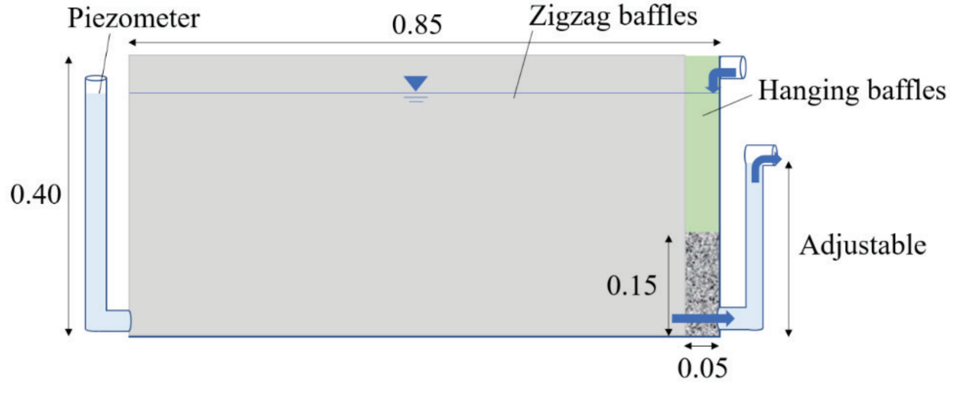


Figure 1 *(a) Plan view and (b) cross-section of baffle-type slag reactor. The unit of dimension is m.*

residence times with respect to 2 mg L^{-1} of Mn were ~40 min and ~100 min in the baffle-type and weir-type reactors, respectively, which resulted in an approximate ratio of 2.5. This difference indicates that the baffle-type reactor can increase the actual residence time by ~2.5 times from the weir-type reactor. Moreover, the column-type reactor exhibited Mn removal efficiencies comparable to those of the weir-type reactor.

Consideration of hydraulic head and suggestion of flow configuration

The required hydraulic heads to determine the allowed maximum flow rates were assessed in weir-type, baffle-type, and column-type reactors. For each type of reactor, the maximum allowable flow rates according to the difference in hydraulic head and hydraulic conductivity are shown in Fig. 4 (Kim *et al*. 2022c). The number of zigzag baffles was assumed to be two. In Fig. 4a, the hydraulic conductivity was assumed to be 0.03 cm s-1, which was measured in the slag reactors after ~1 yr of operation. The differences in the hydraulic head were assumed to be the height of the substrate (1.5 m for weir-type and baffle-type reactors and 2.5 m for the column-type reactor) in Fig. 4b, and they were assumed to be 10 m for the case of pumping for all types in Fig. 4c.

Pilot-scale experimental results and suggestions of baffle configurations in the settling pond

The settling pond was operated with zigzag baffles and hanging baffles. The treatment efficiencies of the SS for each baffle configuration were compared. To decrease SS to 21–22 mg L^{-1} with removal efficiencies of 57%–61%, the zigzag baffle configuration required residence times of 72–81 h, whereas the hanging baffle configuration required a residence time of 41–50 h (51–69%) to

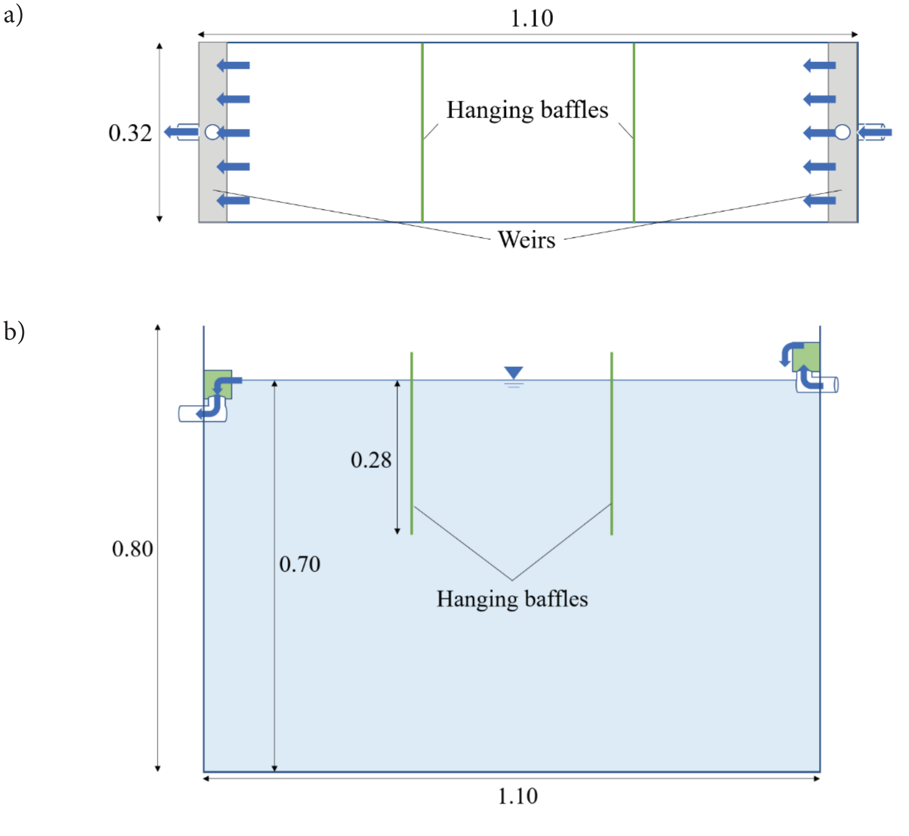


Figure 2 *(a) Plan view and (b) cross-section of the pilot-scale settling pond with hanging baffles. The unit of dimension is m.*

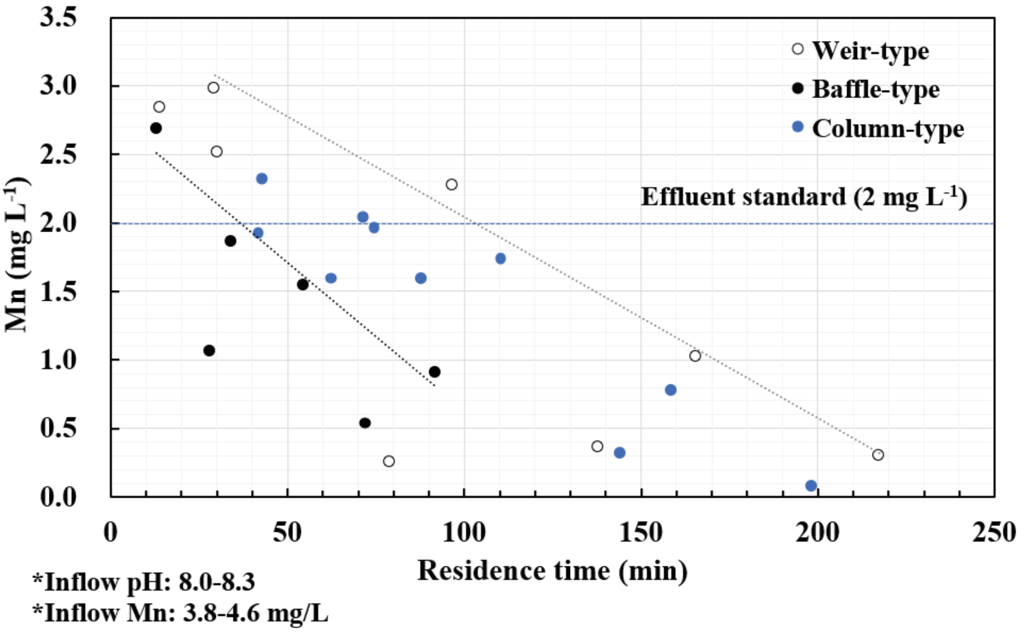


Figure 3 *Relationship between Mn concentrations and residence time for weir-type, baffle-type, and column-type slag reactors in pilot scale. Each regression line was derived from four samples at the boundary of maximum residence times for the weir-type and baffle-type reactors (Kim et al. 2022c)*

decrease SS to 18–21 mg L^{-1} with removal efficiencies of 64%–69% (Table 1; Kim *et al*. 2022c). Thus, the application of hanging baffles exhibited higher SS treatment efficiencies than those of zigzag baffles.

Although the zigzag baffles could efficiently utilize the horizontal area of the pond, they could not help to utilize the lower part of the settling pond. In contrast, the hanging baffles could induce the flow utilizing the lower part. Moreover, the weir could be installed at the inflow and outflow when the hanging baffles were applied, which could distribute the flow to facilitate efficient utilization of the horizontal area of the pond, as in the case of the weir-type slag reactor. Notably, for the treatment of adit drainage, because the surface flow is likely to occur in winter because the adit drainage at the inflow of the pond is generally warmer and lighter than the stagnant water in the settling pond, hanging baffles to reduce the surface flow are necessary. Therefore, the application of hanging baffles is suggested over that of zigzag baffles in settling ponds.

Conclusions

Efficient flow and baffle configurations of reactors and settling ponds for the treatment of low-flow water were studied. The pilot-scale baffle-type reactor with zigzag baffles in the longitudinal direction exhibited the highest treatment efficiencies among the baffle-type, weir-type, and column-type reactors. Nevertheless, the required hydraulic head is a critical constraint for the application of various types of reactors. If the hydraulic head difference is sufficiently high by pumping or the flow rate is sufficiently low, application of zigzag baffles in the longitudinal direction is highly encouraged in substrate reactors. Furthermore, the pilot-scale experiments with a settling pond with zigzag baffles and hanging baffles indicated that the prevention of surface flow using the hanging baffles reduced the required residence times to 51%–69% of those at the pond with the zigzag baffles. This difference suggests that the installation of hanging baffles rather than zigzag baffles is recommended in settling ponds in passive and semi-active

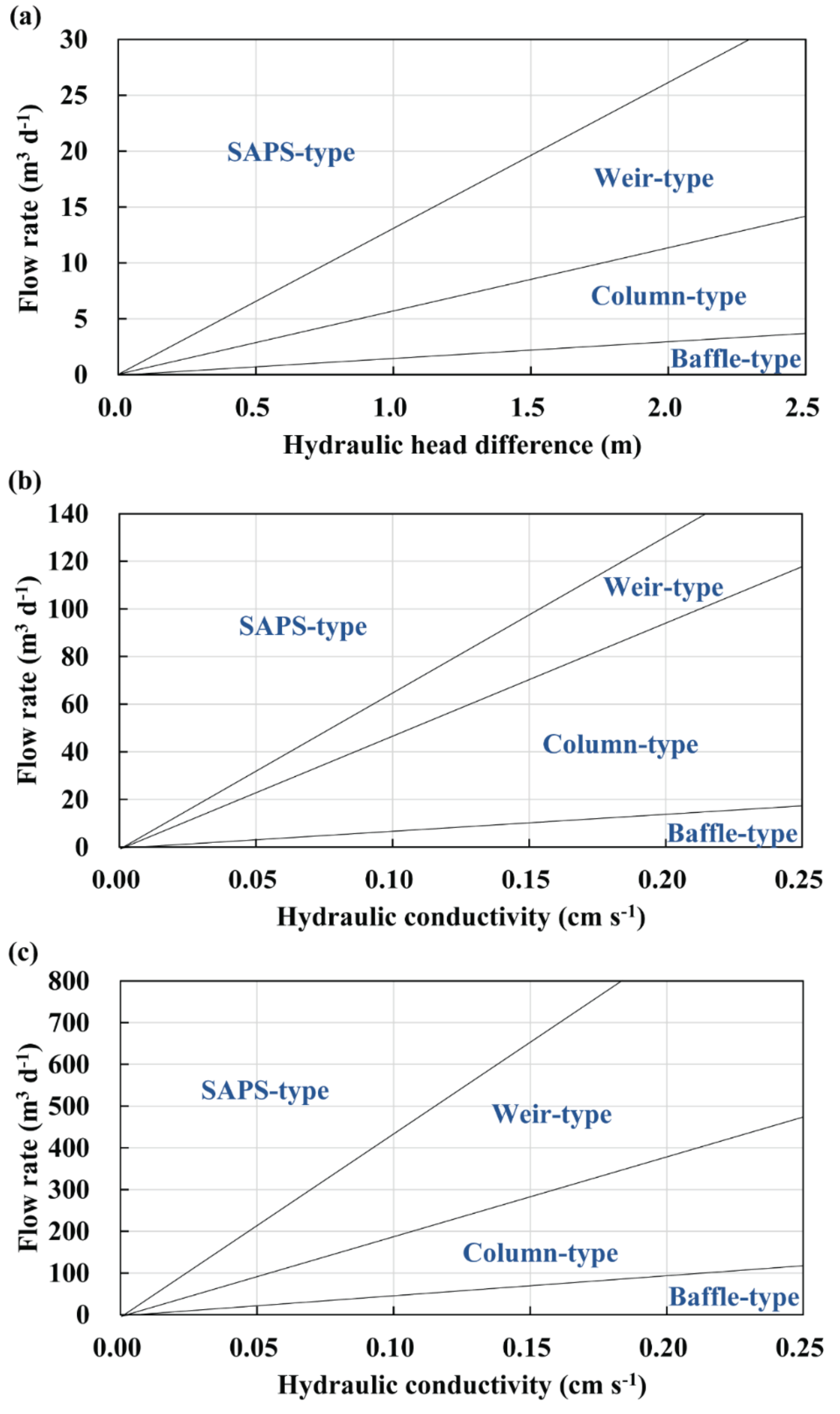


Figure 4 Applicable types of reactors according to flow rate and (a) difference in hydraulic head and (b, c) hydraulic conductivity (Kim et al. 2022c). The hydraulic conductivity in (a) was assumed to be 0.03 cm s^{-1}. Differences in the hydraulic head were assumed to be 1.5 m for the weir-type and baffle-type reactors and 2.5 m for the column-type reactor in (b) and were assumed to be 10 m in (c).

Table 1 Treatment efficiencies of SS for application of zigzag baffles and hanging baffles in pilot-scale settling pond (Kim et al. 2022c).

Baffle configuration	Residence time (d)	SS Inflow (mg L^{-1})	Outflow	Treatment efficiency
Hanging baffle	41	67	21	69%
	50	50	18	64%
Zigzag baffle	81	53	21	61%
	72	51	22	57%

treatment facilities. The increased efficiency of the suggested reactors and settling ponds will decrease the required area and cost of construction.

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