Experimental Approach to Designing a Flushing System for SAPS Pond

Dong-Kil Lee, Youngwook Cheong, Sangwoo Ji, Giljae Yim, Yong-chan Cho

Korea Institute Geoscience and Mineral Resources (KIGAM), 124 Gwahang-no, Yuseong-gu, Daejeon 34132, South Korea, ldk@kigam.re.kr

Abstract

Successive alkalinity-producing systems (SAPS) effectively treat acid mine drainage but suffer reduced efficiency and lifespan due to sludge accumulation in the limestone layer. Flushing systems, comprising perforated pipes, periodically discharge water to restore limestone porosity. However, existing designs lack scientific rigor. This study introduces a hydrodynamic approach to optimize flushing system design by evaluating orifice size and spacing. A novel performance index, orifice influence radius, was developed to calculate optimal configurations. The results provide a practical framework for improving flushing efficiency, extending SAPS lifespan, and enabling predictable facility management, offering critical insights into the engineering of mine drainage treatment systems.

Keywords: Successive alkalinity-producing system, acid mine drainage, flushing system, sludge removal, orifice influence radius

Introduction

The successive alkalinity-producing system (SAPS) is a widely implemented passive treatment method for mitigating acid mine drainage (AMD), utilizing stratified layers of water, organic matter, and limestone. While SAPS initially exhibits high treatment efficiency, the gradual accumulation of sediment in the organic and limestone layers significantly diminishes its performance and reduces its operational lifespan, which is typically designed for 20–25 years (Kepler and McCleary 1994; Zipper 2001). To mitigate these challenges, flushing systems have been introduced, comprising perforated pipes embedded within the limestone layer that periodically discharge accumulated sediment and AMD through controlled flushing (Weaver *et al*. 2004).

The efficacy of a flushing system depends on several interrelated factors: the physical properties of the limestone layer, sediment characteristics, system flow dynamics, and the design parameters of the flushing device, including orifice size and spacing. However, existing research often evaluates system performance as a whole without isolating the contribution of individual design elements, limiting the ability to optimize system configurations. A deeper understanding of these mechanisms is critical to advancing SAPS design and improving long-term performance.

This study modified from Lee and Cheong (2021) focuses on the specific role of flushing device characteristics in sediment removal. By standardizing the basic experimental conditions for the limestone layer, sediment properties, and flow dynamics, the investigation isolates the impact of orifice design and proposes a radius of influence for orifices as a guiding parameter for the optimal design of flushing systems. These findings offer practical insights for enhancing the efficiency and predictability of SAPS operation, addressing a critical gap in current treatment methodologies.

Experimental methods

To isolate the influence of flushing device characteristics, the experiment was conducted under controlled conditions, ensuring consistent properties for the limestone layer, sediment, and flow dynamics. Glass beads of uniform size and shape were utilized to simulate the limestone layer, while sediment with consistent density and origin was employed to represent the sludge. A constant hydraulic head was maintained to replicate natural drainage conditions in SAPS.

The experimental apparatus consisted of a rectangular tank (1 m × 0.5 m × 1.2 m) equipped with adjustable pipe connections and valves shown in Fig. 1. A 19 cm-thick layer of glass beads, with a spherical diameter of 20 mm and porosity of 39.0%, was placed above the pipe network to simulate the limestone layer. Three pipe diameters (16 mm, 25 mm, 50 mm) and orifice sizes (3 mm, 6 mm, 9 mm) were tested at varying orifice spacings (100 mm, 200 mm, 300 mm) to evaluate their effects on flushing efficiency. The lateral spacing of the pipe is 250 mm.

The sediment used in this study, primarily composed of iron oxide, was sourced from the Hwangji-Yoochang passive treatment facility in South Korea. Its dry density was 3.85 g/cm^3. For each test, a fixed dry weight of sediment (740 g) was mixed with water and uniformly distributed over the water surface in the tank. The sediment was allowed to settle completely into the glass bead layer before flushing commenced.

Flushing was initiated by rapidly opening the valve connected to the pipe network, allowing water to flow and mobilize the sediment. The expelled sediment-water mixture was collected, and the sediment was separated, dried at 80 °C, and weighed to quantify removal efficiency. This procedure was repeated for each combination of orifice spacing and pipe diameter. Prior to sediment flushing, flow consistency was verified against theoretical models such as the Bernoulli and Blake–Kozeny equations using water-only tests.

Experimental results

Volumetric Flow Rate Without Sediment

The discharge flow rate exhibited a direct relationship with orifice diameter, as illustrated in Fig. 2. A proportional increase in flow rate was observed with both larger orifice diameters and an increased number of orifices, consistent with theoretical predictions. The measured and calculated values showed strong agreement, demonstrating the robustness of the employed experimental framework.

Flow Rate Reduction Through the Glass Bead Layer

The introduction of the glass bead layer resulted in a measurable reduction in discharge flow rate due to the additional flow resistance, as depicted in Fig. 3. The calculated flow

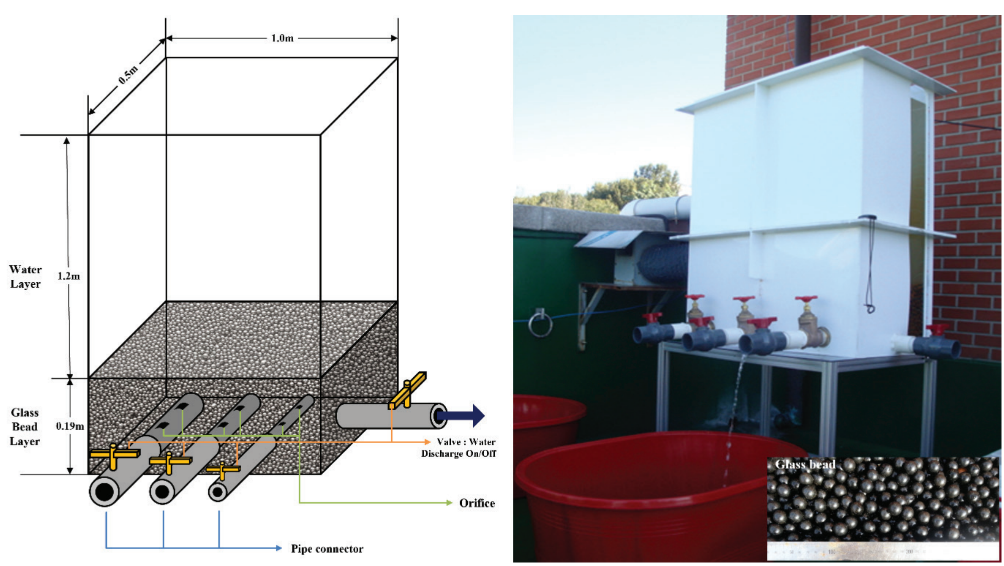

***Figure 1** Schematic diagram and photograph of the flushing experiment apparatus.*

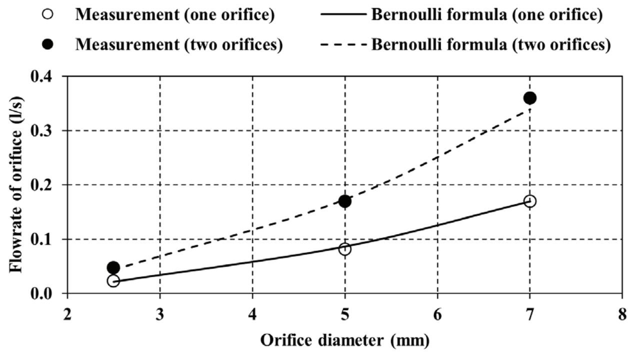

Figure 2 *Discharge flow rate according to orifice diameter and number of orifices in the case without deposits.*

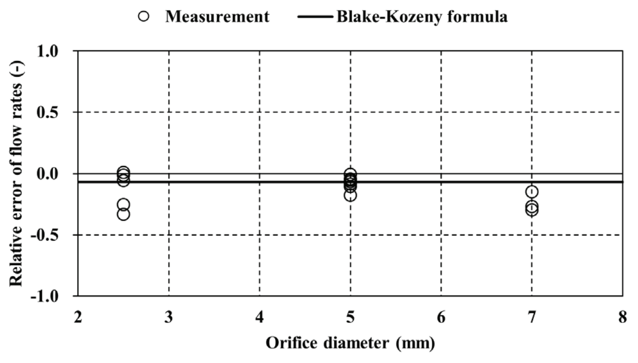

Figure 3 *Relative error of flowrate according to orifice diameter when water flows through the glass bead layer.*

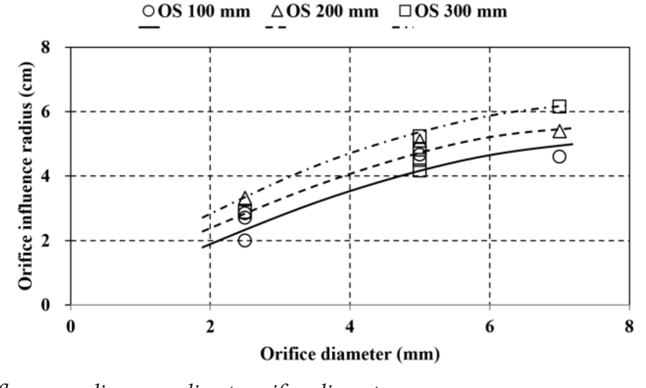

Figure 4 *Orifice influence radius according to orifice diameter.*

rate showed an approximate 6.9% decrease under identical conditions, corroborating experimental measurements. Deviations in the measured results were attributed to occasional blockage of orifices by glass beads. Nevertheless, a consistent alignment between theoretical and experimental values validated the methodology.

Orifice Influence Radius for Sediment Removal

The orifice influence radius, representing the effective sediment removal zone, was quantitatively assessed using Equation (1). Fig. 4 demonstrates that larger orifice diameters yielded greater influence radii, although the rate of increase diminished beyond a diameter of 5 mm due to limitations imposed by the dynamic flow behavior. This trend underscores the need to optimize orifice size to balance sediment removal efficiency and hydraulic constraints.

$$R_l = \sqrt[3]{\frac{3}{4\pi}\,\frac{W_S}{n_o \rho_D}} \qquad (1)$$

where, $\mathbf{W_S}$: dry weight of the iron sediment recovered at the orifice (g)

$\boldsymbol{\rho_D}$: distribution density of the iron sediment in the glass bead layer (g/m^3)

$\mathbf{n_o}$: number of orifices

Impact of Orifice Spacing

As shown in Fig. 5, the influence radius expanded with increasing orifice spacing before reaching a plateau. This behavior reflects the reduction of overlapping influence zones as spacing increases. Smaller orifices exhibited limited overlap separation at shorter distances, whereas larger orifices required greater spacing to achieve similar separation. Under the conditions of this study, the maximum influence radii were determined to be 3.2 cm, 5.3 cm, and 6.1 cm for orifice diameters of 2.5 mm, 5 mm, and 7 mm, respectively. These findings provide critical insights for designing flushing systems with optimized orifice configurations.

Discussion

This study established an orifice influence radius of up to 7 cm under an average hydraulic head of 0.99 m within a glass bead layer. Consequently, the optimal orifice spacing was determined to be 14 cm, which is slightly smaller than the 15 cm recommended by Weaver *et al.* (2004). It should be noted that these experimental results were obtained using glass beads with a diameter of 20 mm, which may differ from actual conditions where limestone aggregates are used. Nevertheless, the findings underscore the feasibility of employing the experimentally derived influence radius as a fundamental parameter in the design of lateral pipe configurations for flushing systems.

Furthermore, the results indicate that the influence radius is significantly affected by key factors such as hydraulic head, orifice diameter, and the effective porosity of the limestone layer. For instance, an increase in hydraulic head was observed to enhance the discharge flow rate, thereby expanding the influence radius and potentially permitting larger orifice spacing. Traditionally, flushing system designs have largely overlooked these complex interdependencies. By adopting the methodological framework developed in this study, engineers can systematically integrate these critical parameters into design considerations, thereby improving the efficiency and adaptability of flushing systems.

Conclusions

This study confirmed that the flow rates through orifices embedded in a porous glass bead layer under constant head conditions closely align with theoretical predictions based on the Blake–Kozeny equa-

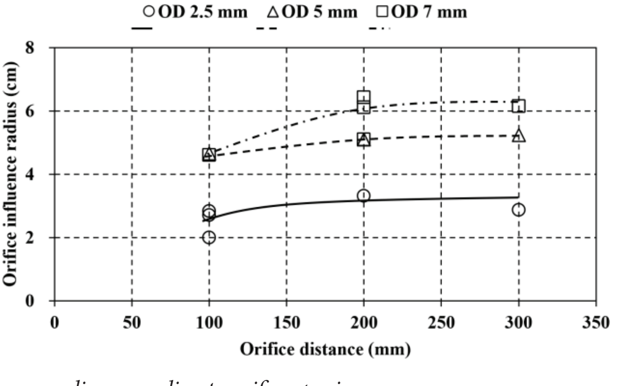

***Figure 5** Orifice influence radius according to orifice spacing.*

tion. Additionally, the study introduced the concept of the orifice influence radius as a quantitative performance index and provided a comprehensive methodology for its evaluation. Experimental findings demonstrated that, at an average hydraulic head of 0.99 m, the maximum influence radius was 7 cm, corresponding to an optimal orifice spacing of 14 cm or less in the glass bead layer. This result is consistent with, albeit slightly more conservative than, previously proposed guidelines. It is important to acknowledge that these experimental results may not fully replicate real-world scenarios where limestone aggregates are utilized.

The proposed design methodology offers a practical framework for optimizing orifice configurations, including spacing and distribution, tailored to specific operational conditions. Moreover, this study highlights the crucial influence of key parameters such as differential head, orifice diameter, and limestone layer porosity on the performance of flushing systems. The application of this experimental approach paves the way for more scientifically robust and operationally efficient designs, ultimately enhancing the longevity and effectiveness of successive alkalinity-producing systems.

Acknowledgements

This research was supported by the Basic Research Project (25-3414) of the Korea Institute of Geoscience and Mineral Resources (KIGAM) funded by the Ministry of Science, ICT of Korea and Korea Mine Rehabilitation and Mineral Resources Corporation (KOMIR).

References

Kepler DA, McCleary EC (1994) Successive alkalinity-producing systems (SAPS) for the treatment of acid mine drainage. Proc Int Land Reclamation and Mine Drainage Conf, Apr 24–29, Pittsburgh, PA, USA, pp. 195–204

Lee DK, Cheong YW (2021) Experimental study of the adoption of flushing technique in successive alkalinity-producing systems with a focus in influence radius of orifice. Environ Earth Sci 80:805

Weaver KR, Lagnese KM, Hedin RS (2004) Technology and design advances in passive treatment system flushing. 2004 National Meeting of the American Society of Mining and Reclamation and the 25th West Virginia Surface Mine Drainage Task Force, Apr 18–24, Morgantown, WV, USA.

Zipper C, Skousen J, Jage C (2011) Passive Treatment of Acid-Mine Drainage with Vertical Flow Systems. Virginia Cooperative Extension Publication No. 460-133, June 2001.