# Factors Influencing Difference Between Theoretical and Actual Lime Dosages Including Lime Concentration and Dosing Rate

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## Abstract

In the Samtan and Daedeok mine drainage treatment facilities in South Korea, lime is used as an alkaline reagent. Previous evaluations of the required lime dosage, using S/W modelling and batch tests for the influent of these facilities, showed discrepancies between the two approaches. Batch experiments were conducted to evaluate the effects of additional operational factors, specifically the concentration of the lime slurry and the dosing rate, on the required lime dosage. The results indicated that lower lime concentrations and slower dosing rates led to reduced lime consumption during the neutralization process.

**Keywords:** Mine drainage, hydrated lime, lime slurry concentration, dosing rate

## Introduction

Hydrated lime ($Ca(OH)_2$) is widely used in mine drainage treatment to increase pH and reduce dissolved metal concentrations. Although predictive tools such as PHREEQC–AMDTreat are commonly used to estimate the required dosage of alkaline reagents, additional factors can influence the actual lime requirements. Understanding these operational factors and their underlying mechanisms is essential for optimizing lime dosage, reducing treatment costs, and lowering carbon emissions associated with hydrated lime production.

This study compared three dosage estimates: (1) predictions from PHREEQ-N–AMDTreat-based design software, (2) experimental dosages determined through batch dosing tests, and (3) actual operational dosages at two mine drainage treatment facilities in South Korea (the Daedeok treatment facility and the Samtan leachate treatment facility). To evaluate the effect of lime slurry concentration, batch tests using influent from the Samtan facility were conducted with 1%, 6%, 11%, and 17% (wt%) hydrated lime slurries to reach pH 9. In addition, dosing-rate experiments were performed using influent from the Daedeok facility and synthetic influent prepared with $FeCl_3$ and $AlCl_3$

## Methods

### *Treatment facility investigation*

During both the dry and wet seasons, water quality was measured at each unit process of the Samtan leachate treatment facility and the Daedeok treatment facility. In addition, hydrated lime consumption and sludge generation at each facility were evaluated.

### *PHREEQ-N-AMDTreat-based design software prediction*

Based on the influent water quality data obtained from the facility investigation, the required hydrated lime dosage and the amount of sludge generated at pH 7, 8, 9, and 10 were predicted using software designed based on PHREEQC–AMDTreat.

### *Experimental dosage determined through batch dosing tests*

Influent water collected from each facility during the treatment facility investigation was titrated to pH 7, 8, 9, and 10 using a 1% (W/V) hydrated lime solution. The lime dosage and sludge generation at each pH condition were evaluated and subsequently compared with the values predicted by the software.

*Table 1* Water quality of influent water from each treatment facility.

| Treatment Facility | pH | Fe (mg/L) | Al (mg/L) | Mn (mg/L) | $SO_4^{2-}$ (mg/L) |
|---|---|---|---|---|---|
| Samtan leachate | 3.51 | 1.0 | 51.3 | 8.3 | 588.8 |
| Daedeok | 2.67 | 416.9 | 230 | 6.5 | 6271.4 |

*Table 2* Hydrated lime dosage at concentrations of 1%, 6%, and 11% to reach pH 9.

| Lime concentration (wt%) | 1 | 6 | 11 |
|---|---|---|---|
| Lime dosage (mg/L) | 110.8 | 168.0 | 187.5 |

*Table 3* Hydrated lime dosage at concentrations of 6%, 11%, and 17% to reach pH 9.

| Lime concentration (wt%) | 6 | 11 | 17 |
|---|---|---|---|
| Lime dosage (mg/L) | 243.6 | 278.2 | 300.0 |

### *Batch test to evaluate the effect of lime slurry concentration and dosing rate*

To evaluate the effect of hydrated lime concentration on lime dosage, influent water collected from the Samtan leachate treatment facility during the wet season was titrated to pH 9 using hydrated lime solutions with concentrations of 1%, 6%, 13%, and 20%. The lime dosage and sludge generation were then evaluated and compared according to lime concentration.

To evaluate the effect of lime dosing rate on lime consumption, influent water collected from the Daedeok treatment facility during the dry season was dosed with a 1% (W/V) hydrated lime solution at rates of 0.5, 1, and 5 mL/min until a total volume of 50 mL was added. The final pH reached at each dosing rate was then evaluated.

To identify the factors influencing differences in lime dosage according to dosing rate, synthetic influent prepared using $FeCl_3$ and $AlCl_3$ (Fe 400 mg/L, Al 250 mg/L) was used. A 1% (W/V) hydrated lime solution was dosed into the synthetic influent at rates of 0.5, 1, and 5 mL/min, and the pH values measured 30 minutes after dosing were evaluated.

## Results and discussion

A comparison between the actual lime consumption at the treatment facilities and the lime dosage determined from batch experiments showed that, although the full-scale operational dosage was not excessive compared to the modeled dosage, it was higher than the batch experiment results. Specifically, it was approximately 36% higher for the Samtan facility and 16% higher for the Daedeok facility than the values obtained from batch experiments.

This discrepancy observed between the batch experimental results and the full-scale treatment facility dosages at both facilities was considered to be influenced by additional factors during the lime dosing process. Among these factors, hydrated lime concentration and lime dosing rate were identified as potential contributors. Therefore, additional batch experiments were conducted to evaluate the effects of these two factors.

The results of tests evaluating the effect of hydrated lime concentration on lime dosage showed that lower lime concentrations required smaller amounts of lime to achieve pH 9 (Tables 2 and 3).

The reactor dosed with 1% hydrated lime required 34% and 40% less lime than the reactors dosed with 6% and 11% lime, respectively. In addition, the reactor dosed with 6% lime required 12% and 19% less lime than the reactors dosed with 11% and 17% lime, respectively. These results indicate that lower hydrated lime concentrations require smaller amounts of lime to reach a given pH.

Batch experiments were conducted using influent from the Daedeok treatment facility to evaluate the effect of lime dosing rate on lime dosage. The results showed that lower dosing rates resulted in reduced lime consumption (Fig. 1).

Little increase in pH was observed near pH 3.0 and 4.3, whereas in other pH ranges, pH increased with different slopes under all three conditions. In addition, higher lime dosing rates required larger amounts of lime to overcome the pH plateau and further increase the pH. As a result, even when the same amount of lime was added, differences in the final pH achieved were observed depending on the dosing rate. Additionally, the increase in pH within the pH range of 5.8–9.0 became smaller as the lime dosing rate increased, even at the same lime dosage. This behavior was considered to result from the greater influence of gypsum on hydrated lime particles at higher dosing rates, which affected the pH elevation behavior. (Fig. 1).

Two possible explanations were considered for this phenomenon. First, the high sulfate concentration in the influent may lead to gypsum formation, which could coat the surface of hydrated lime particles. Second, the pH ranges around 3.0 and 4.3 correspond to the precipitation regions of $Fe(OH)_3$ and $Al(OH)_3$, suggesting that the presence of dissolved metal ions may influence the reaction behavior. To examine these hypotheses, synthetic influent with negligible sulfate concentrations was prepared using $FeCl_3$ and $AlCl_3$, and batch experiments were conducted.

Batch experiments conducted using the synthetic influent with negligible sulfate showed results similar to those obtained with influent from the Daedeok treatment facility. Little increase in pH was observed at pH 3.0 and 4.3, whereas in other pH ranges, pH increased with a similar slope under all conditions. In addition, the amount of lime required to further increase the pH differed depending on the dosing rate (Fig. 2).

The experimental results suggest that the difference in lime dosage according to dosing rate was primarily influenced by dissolved metal ions. When the pH change was evaluated 30 minutes after lime addition, the decrease in pH in the reactor dosed at 1 mL/min was smaller than that observed in the reactor dosed at 0.5 mL/min. In contrast, the reactor dosed at 5 mL/min showed a slight increase in pH. These results suggest that metal ions may coat the surface of hydrated lime particles and that higher dosing rates may lead to a greater extent of particle coating. As time passes, the coated

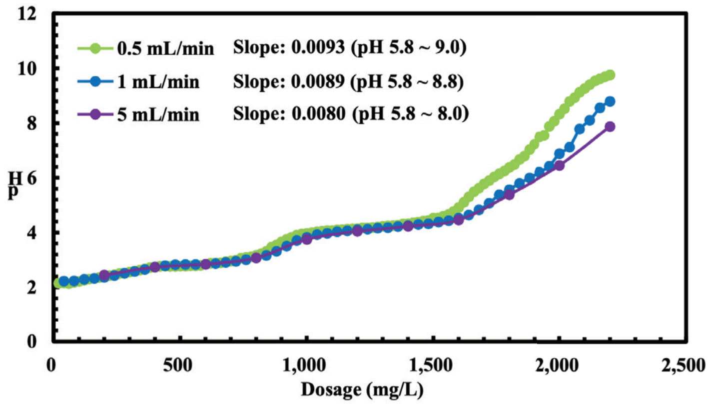

***Figure 1*** *pH variation with lime dosage at different dosing rates for influent from the Daedeok mine drainage facility.*

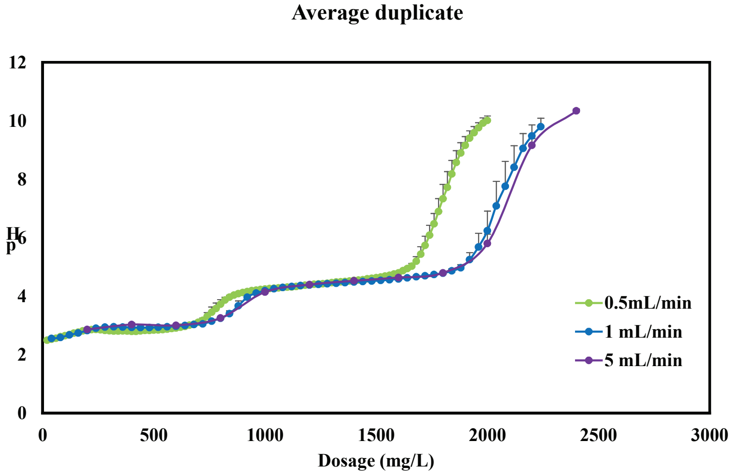

*Figure 2 pH variation as a function of lime dosage at different dosing rates for synthetic influent with negligible sulfate concentrations.*

*Table 4 Difference in pH between immediately after lime addition and after 30 minutes at different dosing rates.*

| Dosage rate | pH after 0 min (A) | pH after 30 min (B) | pH change (B-A) |
|---|---|---|---|
| 0.5 mL/min | 10.16 | 9.88 | -0.28 |
| 1 mL/min | 10.19 | 9.99 | -0.20 |
| 5 mL/min | 10.32 | 10.45 | 0.13 |

lime gradually dissolves, which is considered to contribute to the observed pH behavior (Table 4).

According to the PHREEQ-N-AMDTreat modeling results, precipitation of $Fe(OH)_3$ and $Al(OH)_3$ was predicted to occur near pH 3.0 and 4.3, respectively (Figs. 3 and 4), in both the experiment using influent from the Daedeok treatment facility and the experiment using synthetic water containing negligible sulfate concentrations. These pH ranges corresponded to buffering zones in which pH elevation was temporarily inhibited, suggesting that the formation of fine metal hydroxide precipitates retarded the dissolution of $Ca(OH)_2$.

Furthermore, in the experiment using the Daedeok influent, the predicted amount of precipitated gypsum reached its maximum near the pH at which rapid pH increase begam. Differences in the pH increase gradient were also observed between the two experimental conditions. These findings suggest that gypsum formation influenced the pH elevation behavior. As shown in Figs 1 and 2, gypsum precipitation was considered to contribute to the differences in the pH elevation gradients observed between two experiments.

## Conclusions

In this study, hydrated lime concentration and lime dosing rate were evaluated as key factors affecting lime consumption. The results showed that lower lime concentrations required smaller amounts of lime to reach the target pH. In addition, lower dosing rates also resulted in reduced lime consumption. The variation in lime dosage with dosing rate can be attributed to two main factors. First, the coating of hydrated lime particles by dissolved metal ions leads to a temporary stagnation in pH increase, and the amount of lime required to overcome this region varies depending on the dosing rate. Second, differences in the

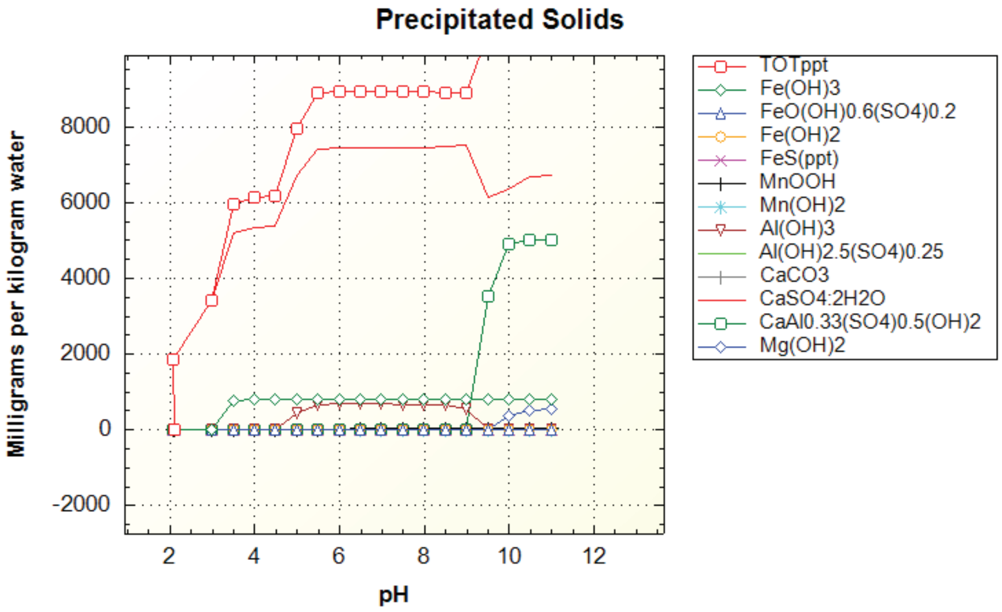

***Figure 3*** *Amount of precipitated solids according to pH after pH after lime dosing for the Daedwok mine drainage, which was predicted using PHREEQ-N-AMDTreat.*

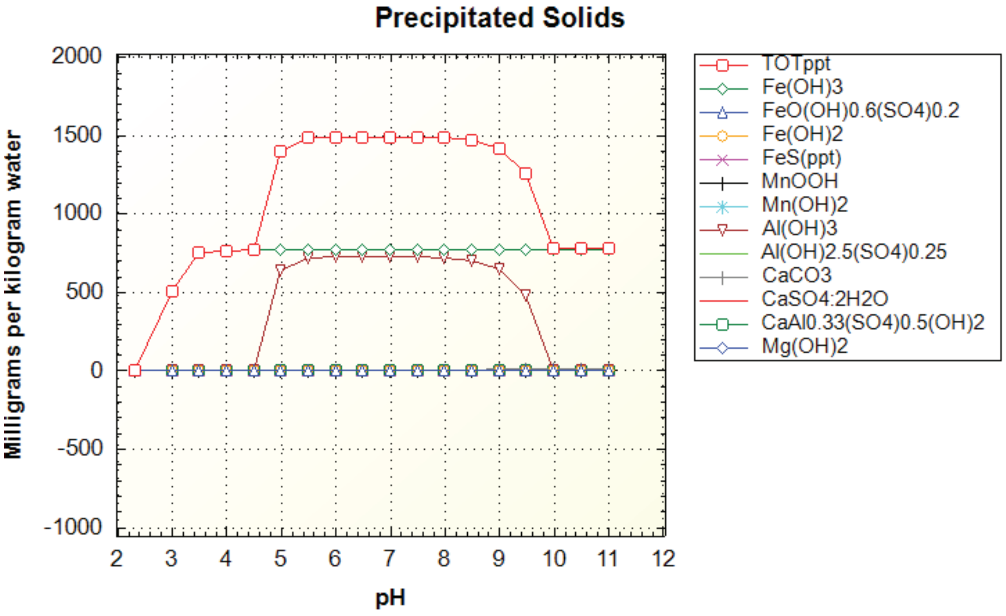

***Figure 4*** *Amount of precipitated solids according to pH after lime dosing for synthetic influent with negligible sulfate, which was predicted using PHREEQ-N-AMDTreat.*

slope of pH increase suggest that gypsum formation contributes to the coating of lime particles, thereby influencing the overall pH evolution behavior.

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