

Development of Design Software for Mine Drainage Treatment Facilities

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Abstract

A software tool was developed for the design and operation of passive, active, and semi-active mine water treatment systems. Using input parameters such as flow rate, water quality, and available area, the software generates recommended treatment trains, dimensions of individual treatment units, and operational parameters including lime dosage and sludge generation. Compared with existing tools such as AMDTreat, the present software additionally predicts Mn concentrations based on co-precipitation and sorption by Fe and incorporates a dedicated module for settling analysis. It also integrates recently published models for Fe oxidation and slag reactor performance.

Keywords: Mine drainage; treatment facilities; design software; operational factor; settling; Mn treatment

Introduction

Software tools can improve design accuracy and enhance efficiency by minimizing human error. In the design of mine drainage treatment systems, existing software such as AMDTreat (Cravotta, 2020, 2021) has been widely used to design treatment facilities and to predict key operational parameters, as well as associated costs.

The aim of this software development is to incorporate additional factors and modules based on recent findings, whereas the models are largely empirical. In particular, Mn removal is strongly influenced by co-precipitation and sorption by Fe, and recent studies addressing these processes have been integrated into the software. Furthermore, recent advances in Fe oxidation kinetics in mine drainage and the performance of slag reactors have been incorporated. A settling module has also been developed to predict settling efficiency in settling tanks based on column experiment data.

Methods

The developed software requires input parameters such as influent water quality, flow rate, and available area (Fig. 1). After selecting

one of the treatment methods (passive, active, or semi-active), the program automatically generates a design, including the dimensions of the treatment facilities.

Passive Treatment

Oxidation rates of ferrous iron are calculated using newly derived equations based on experimental data and field observations from mine drainage treatment sites. The Fe oxidation algorithm determines the required oxidation time, the amount of precipitate accumulation in the SAPS (Successive Alkalinity Producing System), and the need for an oxidation pond. Within the water layer of the SAPS, the concentration of Fe(III) generated by oxidation of Fe(II) is calculated and added to the existing Fe(III) concentration. A fraction (e.g., 50%) of the resulting Fe(III) is assumed to be converted into total suspended solids (TSS), which is then added to the influent TSS. If the resulting TSS concentration is sufficiently high (e.g., $>50 \text{ mg L}^{-1}$) to cause rapid sludge accumulation in the SAPS, an oxidation-settling pond is designed upstream of the SAPS.

The applicability of SAPS is determined by comparing the acidity and alkalinity of

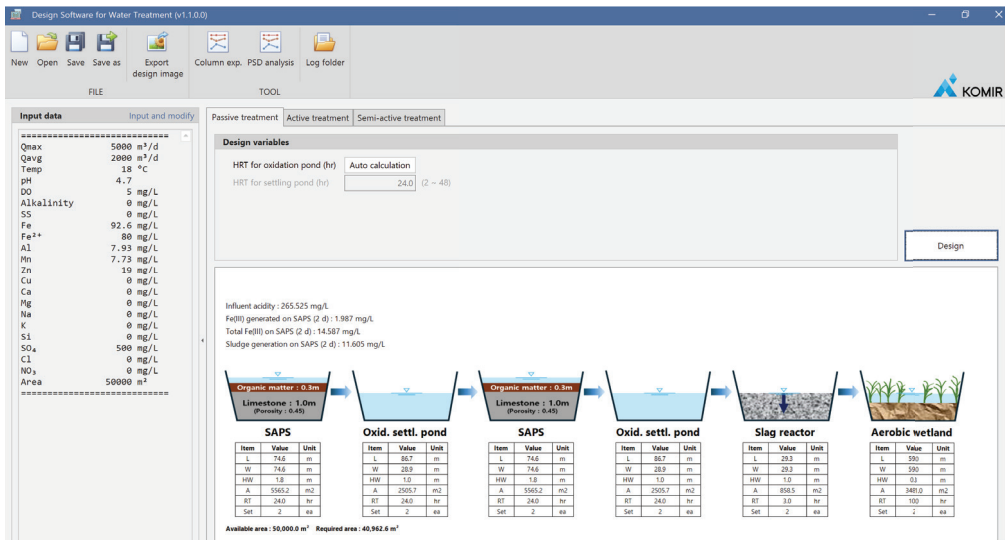


Figure 1 Developed software for mine water treatment, showing a design example of a passive treatment system.

the influent. The number of SAPS units is estimated using the empirical equation proposed by Zipper *et al.* (2018), which predicts alkalinity generation from limestone.

For the slag reactor, its applicability is evaluated based on the predicted Mn concentration after sequential treatment through SAPS, oxidation-settling ponds, and an aerobic wetland. The average Mn removal rates in passive treatment unit processes have recently been reported by Kwon *et al.* (2025) and were used to assess whether the passive treatment system can reduce Mn concentrations below the effluent standard (e.g., 2 mg L⁻¹).

The size of the slag reactor is estimated using an empirical relationship between hydraulic retention time (HRT) and Mn removal efficiency in slag reactors (Kim 2021). In addition, an HRT of 10 h is applied for the aerobic wetland following the slag reactor to reduce pH to meet effluent standards, as suggested by several case studies (Kim 2021).

(Semi-)Active Treatment

The optimal target pH is determined based on contaminant concentrations—primarily Mn and Fe—by considering co-precipitation and adsorption behaviors described by empirical equations (Kim *et al.*, 2022). The resulting pH

value is displayed in the software output, and users can apply it as the target pH by clicking the “Apply” button (Figure 2).

The dosage of hydrated lime and the amount of precipitate generated are computed using PHREEQ-N-AMDTreat, and the results are adjusted using additional coefficients suggested by Kim *et al.* (2023). The estimated precipitate mass is then used to determine the required flocculant dosage and annual sludge production.

The required residence time for settling tanks is calculated using a module that utilizes either column test results or particle size distribution (PSD) data (Figure 3). Between the two datasets, PSD-based estimates are generally less reliable than those based on column tests. Users input measured TSS concentrations at a specific depth in the column as a function of time. In addition, the depth of the full-scale settling tank and the influent TSS concentration are provided as input parameters. After running the module, the predicted TSS concentrations corresponding to different HRTs are displayed. Subsequently, the required areas for active, semi-active, and passive treatment systems are compared with the available area to evaluate installation feasibility.



(a)

Design Software for Water Treatment (v1.1.0.0)

Input data

| | |
|------------------|------------------------|
| Qmax | 5000 m ³ /d |
| Qavg | 2000 m ³ /d |
| Temp | 18 °C |
| pH | 4.7 |
| DO | 5 mg/L |
| Alkalinity | 0 mg/L |
| SS | 0 mg/L |
| Fe | 92.6 mg/L |
| Fe ²⁺ | 80 mg/L |
| Al | 7.93 mg/L |
| Mn | 7.73 mg/L |
| Zn | 19 mg/L |
| Cu | 0 mg/L |
| Ca | 0 mg/L |
| Mg | 0 mg/L |
| Na | 0 mg/L |
| K | 0 mg/L |
| Si | 0 mg/L |
| SO ₄ | 500 mg/L |
| Cl | 0 mg/L |
| NO ₃ | 0 mg/L |
| Area | 50000 m ² |

Design variables

Target pH: 8.4 (5 - 13) **Optimal pH : 8.4** Apply

Moisture content (%): 99.0 (0 - 100)

Oxid.-neut. tank HRT (min): 30.0 (5 - 120)

pH adjust. tank HRT (min): 20.0 (5 - 120)

Aeration tank HRT (hr):

Influent tank HRT (hr): 6.0 (2 - 48)

Flocculation tank HRT (min): 20.0 (5 - 120)

Cylindrical settling tank HRT (hr): 6.0 (2 - 48)

pH readjust. tank HRT (min): 20.0 (5 - 120)

Process Flow: Oxid.-neut. tank → Flocculation tank → Cyl. settl. tank

Oxid.-neut. tank

| Item | Value | Unit |
|------|-------|----------------|
| L | 3.8 | m |
| W | 3.8 | m |
| HW | 3.8 | m |
| A | 14.5 | m ² |
| RT | 30.0 | min |
| Set | 2 | ea |

Flocculation tank

| Item | Value | Unit |
|------|-------|----------------|
| L | 3.3 | m |
| W | 3.3 | m |
| HW | 3.3 | m |
| A | 10.9 | m ² |
| RT | 20.0 | min |
| Set | 2 | ea |

Cyl. settl. tank

| Item | Value | Unit |
|------|-------|----------------|
| D | 14.2 | m |
| HW | 4.0 | m |
| A | 158.4 | m ² |
| RT | 6.0 | hr |
| Set | 2 | ea |

SS concentration: 270.4 mg/L
Max. sludge generation: 19206 kg/day
Annual sludge generation: 19740.1 t/yr

Available area : 50,000.0 m² Required area : 367.6 m²

(b)

Design Software for Water Treatment (v1.1.0.0)

Input data

| | |
|------------------|------------------------|
| Qmax | 5000 m ³ /d |
| Qavg | 2000 m ³ /d |
| Temp | 18 °C |
| pH | 4.7 |
| DO | 5 mg/L |
| Alkalinity | 0 mg/L |
| SS | 0 mg/L |
| Fe | 92.6 mg/L |
| Fe ²⁺ | 80 mg/L |
| Al | 7.93 mg/L |
| Mn | 7.73 mg/L |
| Zn | 19 mg/L |
| Cu | 0 mg/L |
| Ca | 0 mg/L |
| Mg | 0 mg/L |
| Na | 0 mg/L |
| K | 0 mg/L |
| Si | 0 mg/L |
| SO ₄ | 500 mg/L |
| Cl | 0 mg/L |
| NO ₃ | 0 mg/L |
| Area | 50000 m ² |

Design variables

Target pH: 8.4 (5 - 13) **Optimal pH : 8.4** Apply

Moisture content (%): 97.0 (0 - 100)

Oxid.-neut. tank HRT (min): 30.0 (5 - 120)

pH adjust. tank HRT (min): 20.0 (5 - 120)

Aeration tank HRT (hr):

Influent tank HRT (hr): 6.0 (2 - 48)

Flocculation tank HRT (min): 20.0 (5 - 120)

Rectangular settling pond HRT (hr): 24.0 (2 - 48)

Aerobic wetland HRT (hr): 10.0 (2 - 48)

pH readjust. tank HRT (min): 20.0 (5.0 - 13.0)

Process Flow: Oxid.-neut. tank → Flocculation tank → Rect. settl. pond

Oxid.-neut. tank

| Item | Value | Unit |
|------|-------|----------------|
| L | 3.8 | m |
| W | 3.8 | m |
| HW | 3.8 | m |
| A | 14.5 | m ² |
| RT | 30.0 | min |
| Set | 2 | ea |

Flocculation tank

| Item | Value | Unit |
|------|-------|----------------|
| L | 3.3 | m |
| W | 3.3 | m |
| HW | 3.3 | m |
| A | 10.9 | m ² |
| RT | 20.0 | min |
| Set | 2 | ea |

Rect. settl. pond

| Item | Value | Unit |
|------|-------|----------------|
| L | 43.5 | m |
| W | 14.5 | m |
| HW | 4.0 | m |
| A | 630.8 | m ² |
| RT | 24.0 | hr |
| Set | 2 | ea |

SS concentration: 270.4 mg/L
Max. sludge generation: 45069 kg/day
Annual sludge generation: 6580.0 t/yr

Available area : 50,000.0 m² Required area : 1,312.4 m²

Figure 2 Developed software for mine water treatment, showing a design example of (a) an active treatment system and (b) a semi-active treatment system.

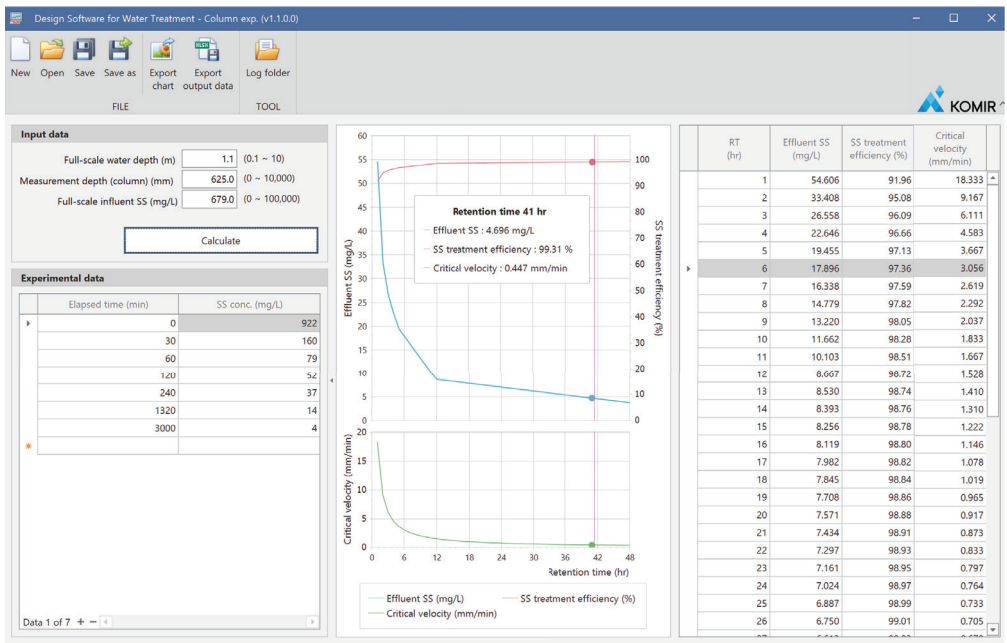


Figure 3 Prediction module for settling efficiency in mine water treatment facilities based on column experiments

Results and discussion

Passive Treatment

The chemical composition of adit drainage from the ET mine, Peru, was used as the input data for the software (Table 1). The modeled treatment system consisted of two sequential SAPS and oxidation–settling pond units, followed by a slag reactor and an aerobic wetland (Figure 1). A single SAPS and oxidation–settling pond sequence was insufficient to neutralize the calculated acidity (Table 2); therefore, two sequential units were recommended. In addition, because the influent pH was sufficiently low (4.7), less than 2 mg/L of Fe(III) was predicted to be generated through Fe(II) oxidation, resulting in only 11.6 mg/L of sludge accumulation in the SAPS over 2 days. Consequently, an oxidation–settling pond was not recommended prior to the first SAPS.

With an influent Mn concentration of 7.7 mg/L, the conventional treatment sequence consisting of SAPS – oxidation–settling pond – SAPS – oxidation–settling pond – aerobic wetland was predicted to

reduce Mn concentration only to 6.7 mg/L, which exceeded the target concentration of 2 mg/L. Therefore, a slag reactor was additionally recommended, with a predicted hydraulic retention time (HRT) of 3.0 h based on the Mn concentration (Table 2). Subsequently, an aerobic wetland was included to reduce the effluent pH following the slag reactor. The resulting treatment train was identical to that of the pilot-scale ET mine drainage treatment facility reported by Kim *et al.* (2025), except for the As adsorption pond which was not included in the software.

(Semi-)Active Treatment

The same adit drainage from the ET mine was also used to design active and semi-active treatment facilities (Figure 2). The target treatment pH was recommended as 8.4 based on the Fe and Mn concentrations (Table 3). The required dosages of hydrated lime and flocculant (anionic PAM) were estimated to be 212 mg/L and 1.0 mg/L, respectively. Sludge generation was predicted to be 270 mg/L (Table 3).



Table 1 Chemical composition of adit drainage from the ET mine, Peru, used for model prediction (Kim et al. 2025).

| pH | Al | Fe(III) | Fe(II) | Mn | Zn |
|------|--------|---------|--------|------|-------|
| (-) | (mg/L) | | | | |
| 4.70 | 7.93 | 12.6 | 80.0 | 7.73 | 19.00 |

Table 2 Major design parameters for the passive treatment system modeled using adit drainage from the ET mine, Peru.

| Influent acidity | Fe(III) generated on SAPS (2 d) | Total Fe(III) on SAPS (2 d) | Sludge generation on SAPS (2 d) | HRT of slag reactor |
|------------------------------|---------------------------------|-----------------------------|---------------------------------|---------------------|
| (mg/L as CaCO ₃) | | (mg/L) | | (h) |
| 259.3 | 1.99 | 14.59 | 11.61 | 3.0 |

Table 3 Major design parameters for the (semi-)active treatment system modeled using adit drainage from the ET mine, Peru.

| Target pH | Dosage of Ca(OH) ₂ | Dosage of flocculant (PAM) | Sludge generation |
|-----------|-------------------------------|----------------------------|-------------------|
| (-) | | (mg/L) | |
| 8.4 | 212 | 1.0 | 270 |

Additionally, Kim et al. (2026) investigated the prediction of settling efficiency based on column experiments by comparing predicted and measured settling efficiencies in several mine drainage treatment facilities.

Conclusions

While AMDTreat provides a range of functions, including cost estimation, the present software additionally predicts Mn concentrations based on co-precipitation and sorption by Fe and incorporates a dedicated module for settling analysis. It also integrates recently published models for Fe oxidation and slag reactor performance. This software is non-commercial and will be freely distributed. It can be applied to the practical design of mine water treatment facilities worldwide. The developed framework is expected to contribute to improving both the efficiency and the design quality of mine drainage treatment systems.

Acknowledgements

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