Phytoremediation of Fe and Mn Metal in Acid Mine Drainage Using *Typha Angustifolia*

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**Abstract.** Coal mining activities in Indonesia are quite high and generally use the open-pit method. The problem that arises due to open mining is the presence of acid mine drainage (AMD) containing heavy metals such as Fe and Mn. The existence of heavy metals can cause water pollution and cause the death of aquatic organisms. Active processing methods that are widely used to process AMD have shortcomings, including high costs and can produce large amounts of sludge. One of the passive processing methods, namely phytoremediation method using constructed wetland system, is an alternative processing method which has advantages such as easy design, low cost of financing, and does not require expert operations, but has a fairly good ability to reduce pollutants, including heavy metals. The purpose of this study was to examine the effectiveness of a constructed wetland system in reducing Iron metal (Fe) and manganese metal (Mn) in AMD. This study was designed in a laboratory-scale research experiment by flowing AMD into a reactor that has regulated discharge and growing media. In addition to these two variables, the success of the constructed wetland system in this study was also influenced by the presence of *Typha angustifolia* which functions as a phytoremediation agent in reducing the concentration of Fe and Mn metals. The analysis showed that the best treatment in this study was Q1M2 which had the highest removal efficiency of Fe and Mn respectively 94.35% and 85.21%.

**1. Introduction**

Indonesia is one of the countries with quite high coal mining activities in the world. In general, coal mining uses the open-pit mine method. The problem caused by open mining is acid mine drainage (AMD). AMD is water that is formed due to oxidation of exposed or exposed sulphide minerals in the air in the presence of water catalysed by iron oxide and sulphur bacteria [1].

AMD has a low pH and contains dangerous heavy metals such as Fe, Al, Mn, Cu, Zn, Cd, Pb, As and usually also contains high sulphate, so it is a source of environmental contamination [2-5]. The existence of heavy metals can cause water pollution so that the water contained in the vicinity of the mining site cannot be consumed and supports people's lives. Besides, it can also cause the death of aquatic organisms. The content of heavy metals that accumulate in seawater and sediments will enter the food chain system and affect the life of the organism [6].

There are two methods for processing AMD, which are active treatment technology and passive treatment technology. One of the active processing technologies that are widely used is neutralisation which serves to neutralise the pH of AMD so that the iron removal process in water can run well.
Active processing generally uses chemicals containing lime, in the form of $\text{CaCO}_3$, $\text{Ca(OH)}_2$, $\text{CaO}$ or the addition of caustic soda ($\text{NaOH}$) and ammonia ($\text{NH}_3$). The weakness of this method is that it is expensive and can cause sludge to be drained regularly [7].

Passive treatment method with phytoremediation method using constructed wetland system is an alternative treatment to reduce the concentration of AMD heavy metals. Phytoremediation is a technique that uses plants to reduce or reduce levels of pollutants in the environment so that they are no longer dangerous [8]. Categories in phytoremediation consist of phytoextraction, *phytofiltration*, *phytostabilisation*, phytovolatilization and phytodegradation depending on the mechanism of remediation [9]. Phytoextraction involves the use of plants to remove contaminants in the soil. *Phytofiltration* is the process of removing metals from water that is polluted by roots or saplings of plants. Whereas *phytostabilisation* involves roots to absorb pollutants from the soil and store them in the rhizosphere, and reduce the spread of pollutants. *Phytovolatilization* involves the use of plants to remove pollutants through the evaporation process in leaf foliage, such as Se and Hg pollutants. *Phytodegradation* is the use of plants to associate with microorganisms in reducing levels of pollutants [10]. The use of plants in the constructed wetland system contributes to the increase in the content of organic matter through substances produced by secretions and decomposition of plant residues, helps stabilise the substrate, helps maintain microbial populations, and provides aesthetic quality for wetlands [11].

This study was designed to analyse the removal efficiency of Fe and Mn metals through a constructed wetland system using *Typha angustifolia*, which was adjusted to East Kalimantan Regional Regulation No. 02 of 2011 concerning Water Quality Standards from the Coal Industry [12].

2. Methods
This research is an experimental pilot project by conducting a research experiment to see the effect of the studied variables on the content of ferrous metals and acid mine manganese before and after being constructed wetland.

2.1. Research Design
This study consisted of two independent variables, namely flowrate and growth media composition. The plant used is a type of aquatic plant that is *Typha angustifolia* with the number of plants meeting the reactor with a spacing of 15 cm (30 plant clumps). Water discharge is divided into two variations namely $Q_1 = 0.00125$ l/s with HRT 5 days and $Q_2 = 0.00200$ l/s with HRT 3 days. The composition of the planting media also consists of two variations namely $M_1 =$ consisting of gravel; limestone; compost and soil with a height of 5 cm: 15 cm: 30 cm and $M_2 =$ consist of the same planting medium with a height of 10 cm :20 cm :20 cm.

2.2. Research Implementation
2.2.1. Reactor Preparation. This study uses a constructed wetland reactor made of box-shaped fibre with dimensions of 100 cm x 100 cm x 100 cm. Reactor provided as many as four pieces that are adjusted to the specified treatment variations. The treatment variations are presented in the following Table 1:

| Water discharge | Growing media composition |
|-----------------|---------------------------|
|                 | M1 | M2 |
| $Q_1$           | Q1M1 | Q1M2 |
| $Q_2$           | Q2M1 | Q2M2 |
2.2.2. Acclimatisations of Typha Angustifolia. Acclimatisation of plants to the environment has only been carried out for 15 days after planting. After the plant adaptation period ends, the process of plant acclimation to the water to be treated is carried out using groundwater with a characteristic pH of 6.94, Fe content of 0.05 mg/L and Mn content of 0.7 mg/L. The ability of plant adaptation is characterised by the visual appearance of fresh / not withered leaves.

2.2.3. Research Experiment. The acid mine water used in this study is collected in a water tank, then flowed into each of the available reactors. Filling wastewater up to the reactor height, then flowing out of the reactor through a tap and collected in a plastic container. The discharge of wastewater flowed from the water tank to the reactor is regulated so that it is balanced with the discharge of wastewater coming out of the reactor. Then the water sample is processed and placed in a plastic bottle. Laboratory analysis of wastewater parameters according to SNI standards.

3. Result and Discussion
3.1. Characteristics of Acid Mine Drainage
The characteristics of acid mine drainage used in this study can be determined based on the water quality parameters listed in Table 2.

| Parameter | Unit | Value | Quality standards |
|-----------|------|-------|-------------------|
| pH        |      | 2.9   | 6 - 9             |
| Iron (Fe) | mg/L | 11.32 | 7                 |
| Manganese (Mn) | mg/L | 16.9  | 4                 |
| TSS       | mg/L | 326   | 300               |

Data from the laboratory analysis results of AMD sample parameters indicate that the pH, Fe, Mn and TSS values exceed the required standards based on East Kalimantan Regional Regulation No. 02 of 2011 concerning Water Quality Standards from the Coal Industry.

3.2. pH Value of Acid Mine Drainage
PH measurements for all effluent reactors constructed wetland carried out five times. The measurement result data is in Table 3. Then the data is compared with the required quality standards.

| Treatment variations | Observation time (day) | Quality standards |
|----------------------|------------------------|-------------------|
|                      | 2          | 6       | 10      | 14      | 18      | 8         |
| Q1M1                 | 6.82       | 7.10    | 6.55    | .670    | 7.56    | 6 - 9     |
| Q1M2                 | 6.86       | 7.04    | 6.58    | 6.58    | 7.16    |           |
| Q2M1                 | 3.47       | 3.48    | 3.21    | 3.97    | 3.05    |           |
| Q2M2                 | 3.42       | 6.04    | 4.82    | 6.08    | 5.40    |           |

The data presented in Table 3 shows that all effluents of reactors constructed wetland with different treatments have increased pH. However, variations in the treatment of Q1M1 and Q1M2 showed an increase in pH that was higher than the treatments of Q2M1 and Q2M2 and had met the required quality standards of 6-9. The Q1 treatment with HRT of 5 days was seen to have a positive influence on the increase in pH of AMD because the contact time with lime was longer than the Q2 treatment. Water discharge affects AMD retention times in artificial swamp systems [13]. The use of lime in each reactor is intended as an active treatment to increase the pH due to an increase in alkalinity in both the
limestone layer and the organic/compost layer. In anaerobic wetland systems with the composition of growing media such as compost and soil added with active lime can stimulate the growth of sulphate reducing bacteria to increase the alkalinity that can increase the pH of AMD [14, 15].

3.3. The concentration of Iron Metals (Fe) Effluent Constructed Wetland

Data from laboratory analysis results for the Fe concentration of water samples through the constructed wetland reactor carried out five times are presented in the following Table 4.

| Treatment variations (mg/L) | Observation time (day) | Highest removal efficiency (%) | Quality standards |
|-----------------------------|------------------------|-------------------------------|-------------------|
|                             | 2   | 6   | 10  | 14  | 18  |                     |
| Q1M1                        | 7.92| 4.18| 4.16| 5.64| 0.75| 93.37              |
| Q1M2                        | 2.25| 4.23| 3.14| 3.16| 0.64| 94.35              |
| Q2M1                        | 11.25| 4.49| 11.52| 5.02| 11  | 60.34              |
| Q2M2                        | 3.60| 4.86| 9.81| 3.26| 6.48| 68.20              |

The data presented in Table 4 and Figure 1 shows that all constructed wetland reactors with different treatment variations can reduce the concentration of Fe contained in acid mine drainage. Wetlands function to absorb and bind heavy metals and slowly precipitate them as sedimentary deposits to become part of the geological cycle [16]. The reactor with Q1M2 treatment has a higher ability than other treatments because it is proven that the concentration of Fe effluent is lower, ranging from 0.64 to 4.23 mg/L with the highest removal efficiency of 94.35%. The level of Fe effluent produced has met the required quality standards of 7 mg/L.

The decrease in Fe effluent concentration after passing through the constructed wetland reactor with Q1M2 treatment was due to the longer HRT and the composition of the planting medium with higher gravel and limestone layers than other treatments. HRT 5 days gives sufficient time for contact between AMD and the planting media and plants to occur in the process of reducing Fe metals. The process of reducing metal Fe occurs because of the activity of microorganisms that live on plant roots that produce oxygen so that aerobic conditions that support the decomposition of metals are created.

Plants also have a role in the process of reducing Fe metals. Fe metal is absorbed by plants because this metal element is a micronutrient needed in the process of forming proteins, as a catalyst for the

![Figure 1](#)
formation of chlorophyll. The element Fe is important in the synthesis of chlorophyll which is a place for plant photosynthesis [17]. Some plants identified can be used in the phytoremediation process because of their ability to accumulate heavy metals, one of which is Typha angustifolia [18]. Plants that can accumulate heavy metals in their organ tissues are known as hyperaccumulators. The properties possessed by hyperaccumulator plants include fast-growing, being able to consume large amounts of water in a short time, being able to remediate more than one pollutant, and high tolerance to pollutants [19].

Another factor that influences the high efficiency of the reactor removal by Q1M2 treatment is the height of the limestone media. The presence of a sufficient amount of limestone causes an increase in pH value to the neutral pH range. At neutral pH and the presence of sufficient dissolved oxygen, soluble ferrous ions can be ionized into ferrous and subsequently form ferrous hydroxide deposits which are difficult to dissolve, in the form of crystals (precipitates) which are usually brownish yellow, due to acidic and aerobic conditions the ferrous form soluble in water [20].

3.4. The concentration of Manganese Metals (Mn) Effluent Constructed Wetland

Laboratory analysis data for the Mn concentration of water samples through the constructed wetland reactor conducted five times are presented in the following Table 5.

Table 5. The concentration of manganese metals (Mn) effluent constructed wetland

| Treatment variation (mg/L) | Observation time (day) | Highest removal efficiency (%) | Quality standards |
|---------------------------|------------------------|-------------------------------|------------------|
|                           | 2   | 6   | 10  | 14  | 18  |                        |                  |
| Q1M1                      | 7.70| 6.70| 6.90| 6.90| 5.90| 65.09                   |                  |
| Q1M2                      | 2.50| 8.30| 6.80| 6.90| 5.90| 85.21                   | 4                |
| Q2M1                      | 13.40| 9.20| 17.00| 3.26| 6.48| 80.71                   |                  |
| Q2M2                      | 8.60| 6.80| 11.10| 7.40| 7.30| 59.76                   |                  |

Figure 2. The concentration of manganese metals (Mn) effluent constructed wetland

The data presented in Table 3 and Figure 2 show that all reactors constructed wetland with different treatment variations can reduce the concentration of Mn in acid mine drainage. However, the reactor with Q1M2 treatment has a higher ability than other treatments because it is proven because the Mn concentration of the effluent is lower which ranges from 2.50 - 8.30 mg/L with the highest removal efficiency of 85.21%. The resulting effluent concentration has met the required quality standard of 4
mg/L, but only at one observation time. Likewise, the reactor with Q2M1 treatment, there is only one time of observation that shows the ability to reduce levels of Mn in acid mine drainage to meet quality standards. The effluent of the reactor with the treatment of Q1M1 and Q2M2 on each observation does not show the ability to reduce the levels of Mn metals that meet the required quality standards.

The decrease in Mn effluent levels after passing through the constructed wetland reactor is due to HRT and the composition of the planting media. Similar to the reduction process of Fe metals in acid mine drainage, the reduction of Mn metals also occurs because of the activity of microorganisms that live on plant roots and absorption by plant roots. Several types of microbes can oxidise and reduce manganese, among others, Leptothrix pseudoochraceae, Arthrobacter siderocapsulatus and Metallogenium significantly play a role in the oxidation process of Mn divalent ions and Mn-oxide reduction [21]. Mn metal is one of the microelements needed by plants. Mn is an essential element in photosynthesis reactions, especially the process of breaking down water fractions into free hydrogen ions and oxygen [22]. Mn functions as an activator in the oxidoreduction system in the photosynthetic electron transport system [23].

Mn metal processing is not as easy as Fe metal processing. In Mn processing, preliminary treatment needs to be carried out before entering in a constructed wetland. AMD with acidity level > 4 can be channelled into the settling pond first to reduce the heavy metal content. Besides, the optimisation of reduction of Mn metal is done by aeration.

4. Conclusion
All reactors constructed wetland with different treatment variations showed the ability to remove Fe and Mn metals. The highest removal efficiency of Fe and Mn metals was shown by the Q1M2 reactor at 94.35% and 85.21%, respectively and had met the required quality standards.

Acknowledgement
Thanks to the Faculty of Engineering Hasanuddin University for funding the 2019 LBE research activities.

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