Implementation of swampy forest system for acid mine drainage treatment to meet threshold value

Ihsan Noor[1,3,4*], *Yudi Firmanul* Arifin[2,3,4], *Bambang Joko* Priatmadi[5], and *Ahmad Rizalli* Saidy[5]

[1] Mining Engineering Study Program, Faculty of Engineering, Lambung Mangkurat University, Jalan Jenderal Ahmad Yani KM-35.5, Banjarbaru, South Kalimantan, Indonesia (70714).
[2] Forestry Science Study Program, Faculty of Forestry, Lambung Mangkurat University, Banjarbaru, South Kalimantan, Indonesia (70714).
[3] Center of Excellence for Innovation, Technology, Commercialization, Management: Forest and Wetland of Lambung Mangkurat University, Banjarbaru, South Kalimantan, Indonesia (70714).
[4] Sustainable Development Goals (SDGs) Center, Lambung Mangkurat University, Banjarmasin, Banjarmasin, South Kalimantan, Indonesia (70736).
[5] Soil Science Study Program, Faculty of Agriculture, Lambung Mangkurat University, Banjarbaru, South Kalimantan, Indonesia (70714).

Abstract. Coal mining with the area of the potential acid-forming category can generate acid mine drainage. Acid mine drainage (AMD) that has been formed must be appropriately managed. There are two techniques to treat AMD by the challenge specificity, including the prohibitive cost of the conventional active treatment with an uncertain process and the passive treatment, which faces time constraints and a wider area for preparation. A novel swampy forest system is a development to overcome the weaknesses of conventional processing by naturally responsive mitigation, reducing cost and speed, which results in greater capacity in AMD treatment. The swampy forest system implemented in coal mining relies on three main components: empty fruit bunches as organic matter, grass, and selected tree species planted in the treatment pond. The system effectively changes the non-compliance parameters of wastewater when entered at the system's inlet to meet the threshold value after processing. It allows for flowing to the public bodies references with the applicable regulation.

1 Introduction

Coal mining activities create positive economic activity, especially for national income and communities around the mine [1]. The coal mining operation in Indonesia applies the open-pit mining method by land clearing and removing overburden to extract the coal. The overburden (OB) in coal mining activities identified consists of two material categories: Potential acid forming (PAF) and non-acid forming (NAF) material. In some areas, there is more OB material in the PAF category than NAF, so there is potential for forming acid mine

* Corresponding author: ihsan.noor@ulm.ac.id

drainage (AMD) [2][3]. The AMD formed during operation must be managed appropriately to reduce the negative impact on the environment. AMD is a wastewater characterized by high acidity levels and heavy metal content. The wastewater from coal mining activities must be treated first to meet the water quality standard according to applicable regulations before being released into public water bodies [4].

The Indonesian government, through Law Number 3 of the year 2020 concerning Mineral and Coal Mining, requires that every Mining Business Permit (IUP) holder must implement a good mining practice by carrying out environmental management and monitoring that may occur, including the formation of AMD which is further described in the Minister's decision of Energy and Mineral Resources 1827. K of 2018 to prevent the formation of AMD and carry out the mitigation to the AMD has been generated [4].

1.1. AMD management

The wastewater generated from coal mining activities is managed by active and passive AMD treatment techniques [5][6]. Active treatment is the application of chemicals directly to AMD with the aim of the neutralization process to raise the low pH to a neutral pH between pH 6 and 9 according to the threshold values. The active treatment is carried out in the settling ponds, which are designed to be placed ahead of the compliance point where we release the successfully treated wastewater [7]. One coal mining operation may have more than one settling pond, and the compliance point depends on the water flow from each catchment area. In areas with high rainfall, especially between 2500 and 4000 mm per year, more wastewaters will force active treatment by Quicklime, and the operation costs are costly. On the other hand, passive treatment, identified as a lower cost relying on the phytoremediation process of plants planted, requires a larger area, considering lots of water comes during high rainfall and creates high acidity levels of AMD. Construction also requires quite a long preparation time and limited capacity to prepare the area of treatment.

1.2 Passive treatment development by swampy forest system

Active treatment using chemicals is short-term mitigation, and it will only be effective in the short term considering the uncertainty of the process, especially for coal mining, which will enter the mine closure stage. The AMD treatment must run naturally, considering limited operation and costs when the mining area is abandoned [8].

The limitations of passive processing that exist so far must be developed to reduce the obstacles as an alternative solution due to the inflated cost of active treatment. The swampy forest system is designed as a development of passive processing to improve the capacity of treatment, cut the longer duration of the preparation process itself, and stay with plant phytoremediation processes in the treatment of the acidic water [9][10].

1.3 Swampy forest system design

The swampy forest system is designed using three primary media for AMD treatment. These three materials were selected individually using batch reactor experiments as the first stage of the swampy forest system. The three main ingredients selected are empty fruit bunch (EFB) as a side product of palm oil processing, then the planting of specified types of grass and trees, namely Purun grass (*Eleocharis dulchis*) and Batibati grass (*Cyperus* sp.), which represents the local types of grass combined with Typha grass (*Thypa angustifolia*) and Vetiver grass (*Vetiveria zizaniodes*) which represent non-local types of grass, Galam tree (*Melaleuca leucadendra*) and Bangkal tree (*Nauclea subdita*) representing local tree species combined with Longkida trees (Nauclea orientalis) and Kayuputih trees (*Melaleuca Cajuputi*) representing non-local tree species [11].

Laboratory simulation is the next step (second stage) after we have selected the primary media and combined them as a passive treatment. The three selected media were put into three reactor boxes, which had dimensions of 200cm in length, 100cm in width, and 80cm in height for each box. Put the OB material in the bottom as the first layer, then continue the EFB as a second layer, and plant the grass and trees selected for 30-day incubation period [10]. The flow of AMD to the reactor starts from the inlet of boxes 1, 2, and 3, which have been serially installed until the AMD flows out to the reactor outlet. Close the inlet gate at box-1 and the outlet gate box-3 for the second incubation period of 30 days. Flow in the AMD to the box by surface water capacity averages 1.2 m^3 $hour^{-1}$. Record the retention time when we start to open the water at the inlet until the water at the outlet was between pH 6 and 9, then continue to evaluate total suspended solids (TSS), iron (Fe), and manganese (Mn) content until the quality of water at outlet complies with government regulations. In laboratory simulation experiments, primary data was obtained to change wastewater, which had parameters that did not meet the quality standard values to meet quality standards. Namely, the volume of water was 1.2 m^3, the water discharge used was 1.2 m^3 $hour^{-1}$, and the retention time was 4.04 hours [10].

The third stage of the experiment is a pilot project. A pilot project design refers to primary data obtained in laboratory simulation experiments. Pilot project construction of four treatments based on scale-up volume to 3,600 m^3 or 900 m^3 each pond with dimensions of 60m long, 15m wide, and water height of 1m. Water flow into the system was scaled from 1,2 m^3L^{-1} to 41,67 m^3L^{-1}, and retention time was scaled from 4.04 to 141.40 hours. During the validation process, the correction value meets the actual condition during processing [10]. The swamp forest system preparation step before implementation is shown in Figure 1.

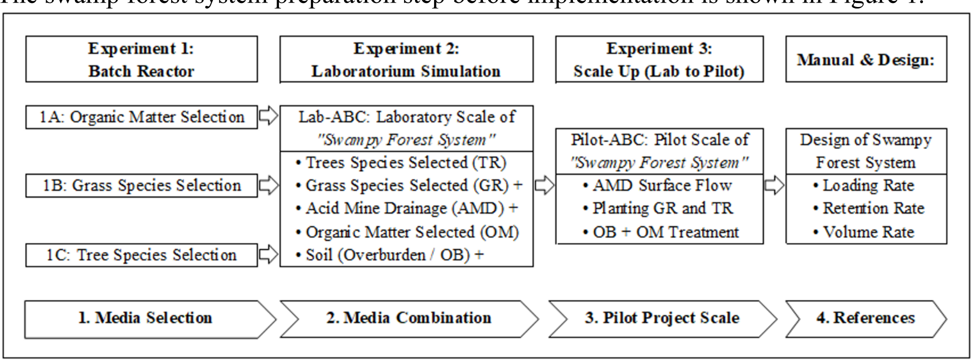

Fig.1. Swampy forest system process step before field implementation

2 Materials and methods

2.1 Construction of swampy forest system

The swampy forest system is a constructed wetland (CW) designed to manage surface water runoff from the void of the ex-mining site that accommodates AMD. The swampy forest system has vital components: an inlet, a mud trap pond, a sediment pond, a central processing pond consisting of four compartments, a lime mixer machine to anticipate certain situations if needed as a backup process to continue to obtain compliant processing results, then enter to the outlet as the last point of the processing process then flow into the compliance point before being released into public waters [4]. The process flow on every critical component is illustrated in Figure 2.

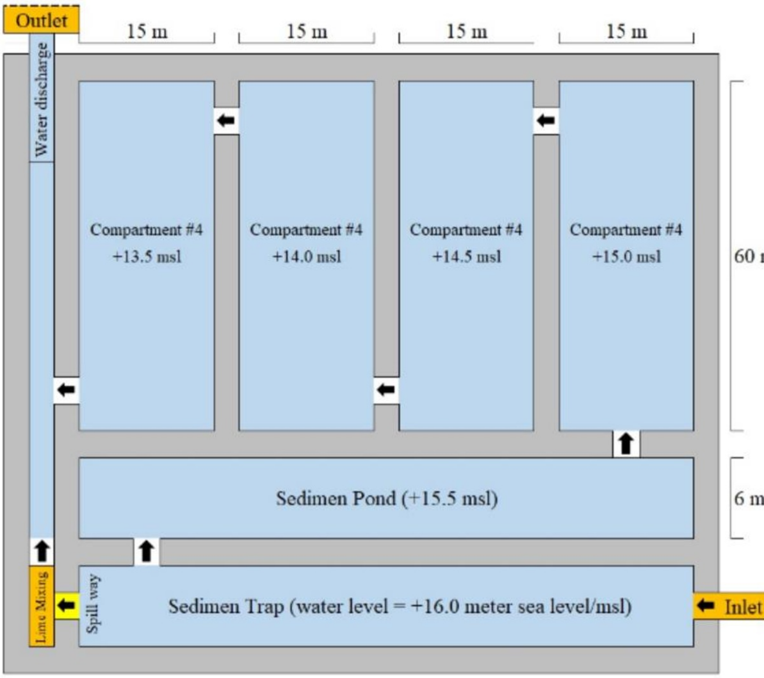

Fig. 2. Layout of swampy forest system design

2.2 Media application protocol of swampy forest system

After the swampy forest construction is complete, the next step is filled with three primary materials that have been determined: EFB, grass, and selected tree species. The first step is to put 2,000 kg of EFB on the floor of each pond. Followed by planting grass and trees on every 1 m^2 are two clumps of grass and one tree each. They were planting grass and trees, as illustrated in Figure 3.

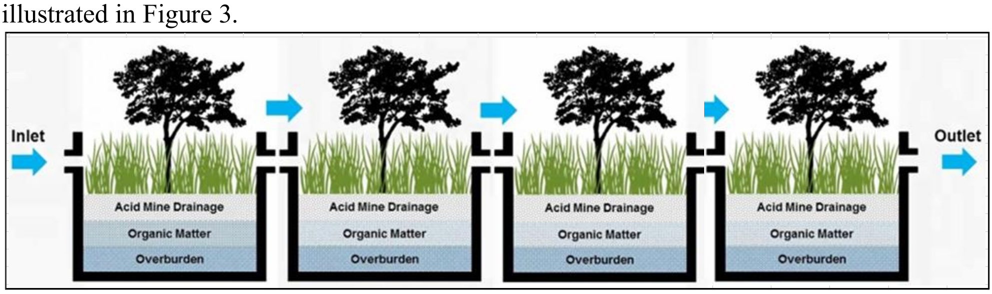

Fig. 3. Illustration of wastewater surface flow, grass, and tree planting at swampy forest system

It is ensured that grass and tree species can grow well to cope with the AMD that flows from the voids through open channels into the sediment trap and then into four swampy forest compartment units in sequence. The water in the swampy forest compartment was incubated for 30 days. During the incubation process, the swampy forest is subjected to a reduction process. Under reduction conditions, the low pH will increase and become stable at 6 to 7, and replanting is needed [4][10].

2.3 Wastewater protocol treatment

The wastewater of AMD from the voids of the former mining area by gravity enters the swampy forest system and flows into the inlet, which has a water gate installed to control the water flow that will enter. The wastewater will first enter the sediment trap, then the sediment pond, before entering the main compartment, namely pond-1, and continue to flow to pond-2, pond-3,and pond-4 until it reaches the outlet of the swampy forest system. Close the sluice gate at the inlet after all parts of the swampy forest system are filled with wastewater. Allow the wastewater to fill all parts of the swampy forest system for up to 30 days of incubation. Reopening the water gate at the inlet after the incubation period is complete with an average water flow capacity of 1,000 m^3 day^{-1}, as illustrated in Figure 4.

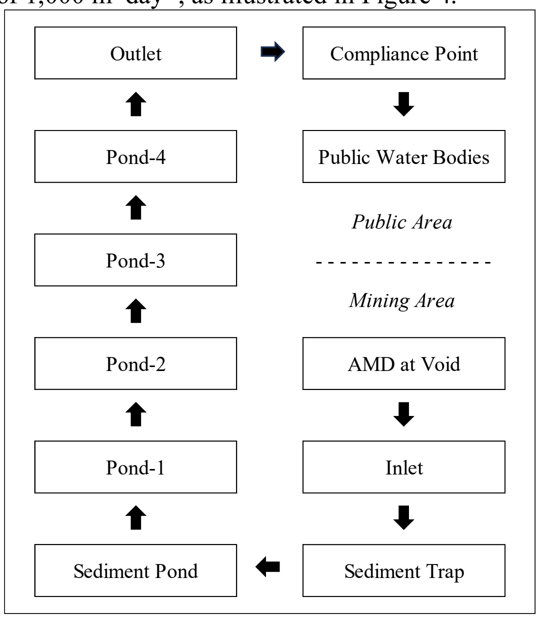

Fig. 4. Water flow chart from void to swampy forest system

3 Sampling and data analysis

They are monitoring the pH of the water by observing the online monitoring system at the inlet and outlet so that a comparison of the data before and after treatment is obtained. Data observations were conducted for up to 30 days while maintaining the flow of flowing water at a constant level of 1,000 m^3 day^{-1}. Then, the wastewater is sampled to monitor the pH level, TSS and water metal contents of Fe, Mn and Cd concerning the Environmental Ministry Regulation Number 113, Year 2003 (pH 6–9, TSS < 400 mg L^{-1}, Fe < 7.0 mg L^{-1}, and Mn < 4.0 mg L^{-1}) and the Regulation of South Kalimantan Governor Number 036, Year 2008 (pH 6–9, TSS < 200 mg L^{-1}, Fe < 7.0 mg L^{-1}, Mn < 4.0 mg L^{-1}, and Cd < 0.05 mg L^{-1}).

4 Result

4.1 Effect of swampy forest system the changes in pH of AMD

Monitoring water pH is the first crucial step to evaluate AMD treatment. The Indonesian government has issued regulations requiring all coal mining operations to install online pH monitoring tools at every compliance point in the operational area. The AMD stored in the void then flows into the swampy forest system. The average water quality at the inlet was pH < 4, which means it does not meet the quality standard value according to applicable regulations. Pond-1 and pond-2 observations have increased pH > 4 but do not meet the quality standard value. Then, in pond-3, pond-4 has reached pH > 6, and finally, the wastewater comes out at the pH outlet > 7, as presented in Figure 5.

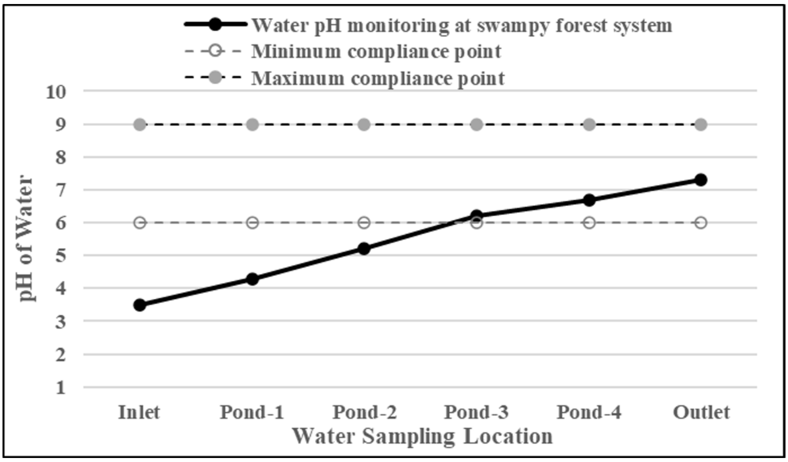

Fig. 5. Data of pH monitoring at the inlet, pond-1, 2, 3, 4, and outlet of the swampy forest system

The observation results showed that the swampy forest system changes the quality standard parameter values of pH to comply, and it may conclude that this system is worked during debt water has set 1,000 m^3 day^{--1} and continued to monitor and compare the pH at inlet and outlet with the result average increase was 2.42 as mentioned on Table 1. The monitoring period of pH tools was installed for 12 months, and the observations were made that an increase in pH levels varying between 2.07 and 3.01; thus, an increase in the pH of the wastewater was obtained to approximately 2.36, changing the pH values to be ranging from pH=6 to pH=9.

Table 1. Data of pH monitoring at outlet compared to inlet from week-1 to week-48

Week	1	2	3	4	8	16	24	32	48
Inlet	4.33	4.48	4.50	4.47	4.46	4.25	4.45	3.96	3.96
Outler	6.41	6.55	6.57	6.54	6.52	6.89	7.19	6.97	6.45
Increase	2.08	2.07	2.07	2.07	2.06	2.64	2.74	3.01	2.49

4.2 Effects of the swampy forest system on changes in TSS, Fe, and Mn of AMD

Total suspended solids (TSS) observations showed a low value, namely TSS was 15 mgL^{-1} at the inlet, then increased to 354 mgL^{-1} in the pond-2 and continued to increase in the pond-3 was 376, but then decreased the value of TSS was 187 mgL^{-1} in the pond-4, and at the outlet is 154 mg L^{-1}. If we compare the TSS value at the inlet, it meets the quality standard and then increases at the outlet. However, according to applicable regulations, it is still below the quality standard, as shown in Figure 6.

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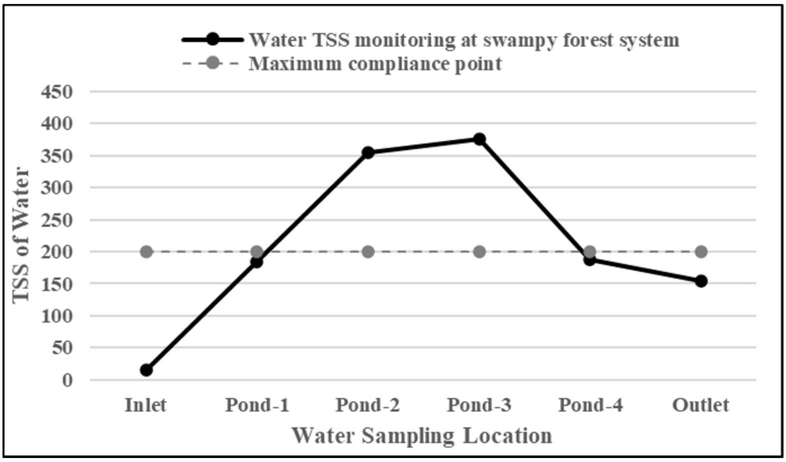

Fig. 6. Data of TSS monitoring at the inlet, pond-1, 2, 3, and 4 and outlet of the swampy forest system

The content of Fe in water is one of the critical parameters that must be monitored. At the inlet, it showed Fe of 9.85 mgL^{-1} or did not meet the quality standard value, then decreased in pond-2 to 7,92 mgL^{-1}, continued to decline to 6.54 mgL^{-1} in pond-4, then continued to decrease to 5.72 mgL^{-1} at the outlet or has met the quality standard value. If we compare the Fe values at the inlet and outlet, there is an average decrease of 4.13 mgL^{-1} or 41,93%, as shown in Figure 7.

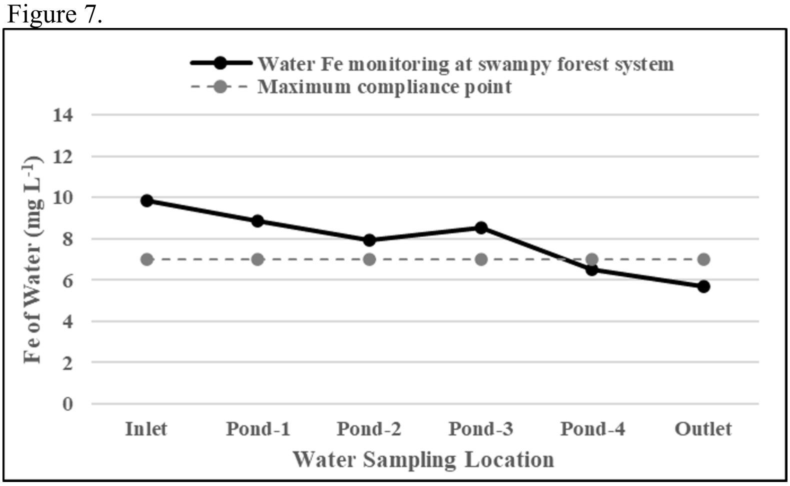

Fig. 7. Data of Fe monitoring at the inlet, pond-1, 2, 3, and 4 and outlet of the swampy forest system

The Mn content in water is another parameter that must be monitored. At the inlet, it shows Mn of 11.91 or has not met the quality standard value, then continues to increase to 16.81 mgL^{-1} in pond-2, then decreases to 14.32 in pond-3, and continues to decrease to 3.86 mgL^{-1} in pond-4 and at the outlet was 3.29 mgL^{-1} or has met the quality standard value. If we compare the Mn values at the inlet and outlet, there is an average decrease of 8.62 mg L^{-1} or 72.38%, as shown in Figure 8.

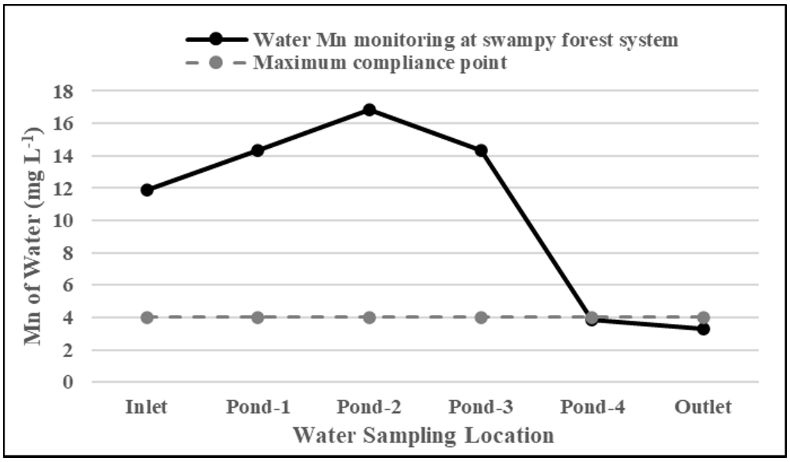

Fig. 8. Data of Mn monitoring at the inlet, pond-1, 2, 3, and 4 and outlet of the swampy forest system

The AMD channeled into the swampy forest system, entered the sediment pond to trap the particles carried in the wastewater flow, and then flowed into the main pond of the swampy forest system. The system treats the wastewater and changes the water quality from pH < 4 to pH 6–9 to meet the quality standards reported by applicable regulations. Organic material from oil palm waste in empty palm oil bunches may replace lime to increase the pH of wastewater. Reusing palm oil waste materials reduces the use of more expensive chemicals. Wastewater quality is improved by providing organic matter at a lower cost and in a more environmentally friendly manner; organic matter increases the absorption, precipitation, and binding of heavy metals, such as Fe and Mn [12][13][14][15][16].

5 Discussion

AMD is wastewater with low pH and low organic carbon concentration values; thus, it requires electron donors in hydrogen and organic compounds to increase bacterial activity. Oxidation reactions in the soil use inorganic carbon; however, the reduction is stimulated by organic carbon as a carbon source and electron donor [17][18][19]. The use of organic materials shows different results due to various conditions, especially in decomposition and the supporting conditions. For example, an aerobic process makes contributions, namely, sulfate-reducing bacteria that thrive in conditions without oxygen; the process of decomposing organic matter occurs in aerobic conditions that require a large amount of oxygen [20][21][22].

The use of appropriate grass species results in the absorption of heavy metals; Typha grass types reduce the Fe content by 25% in water [23], and Purun grass effectively reduces Fe and Mn [24][25]. Plants have their respective roles in their growth, especially their abilities to adapt to and tolerate acidic conditions and high metal concentrations. Typha grass transfers oxygen to media through plant roots [26][27]. Types of vetivers and batibati grass formed land colonies that survive flooding [28]. Some root exudates change the root area's pH levels, facilitating heavy metal deposition, limiting their availability, and thus reducing their toxicity levels to plants [27].

Selecting suitable tree species assists growth in stagnant and acidic conditions. Longkida and eucalyptus tree species are tolerant to these conditions [29], which is combined with local species that survive in various situations, such as Bangkal and Galam trees; these tree species adapt through remediation [30][31][32]. For example, returning reclaimed land refers to the forest reclamation criteria [33][34][35]. The development of tree species that are adaptable and tolerant to acidic conditions and flooding helps achieve success criteria to return reclamation land that originates from forestry land [36][37].

The results obtained by online recording prove that the stability of the swampy forest system is caused by the function of organic matter, playing a role in the short term; the role of grass species is essential in the medium term, and the type of tree plays a role in the long term for sustainable systems. Organic matter of empty bunches can improve plant growth over time in line with the weathering of the organic matter process. The organic matter has significant effect on C-organic, N-total, K-exchangeable, and CEC of the soil. Better condition of soil to support plan growth considering the soil nutrient availability is increase [38][39][15].

6 Conclusion

Passive treatment development by the swampy forest system is a new concept of AMD treatment to meet the threshold value. The system is very dependent on the three media selected: EFB for short-term mitigation to improve the water pH, planting the grass selected for the mid-term phytoremediation process, and planting trees for the long-term revegetation process of reclamation. The swampy forest system could change the non-compliant wastewater to water quality compliant with the threshold value of application regulations.

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