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Role of the Tree Species Selected in Developing Swampy Forest System for Passive Treatment of Acid Mine Drainage

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Abstract. Coal mining is one of economic sector that requires forestry area in Indonesia. Most of coal mining concession are forestry area loan use from the government and during mining operation facing with acid mine drainage (AMD). AMD passive treatment can be integrated with revegetation process that related with better handling of overburden (OB) with potential acid forming (PAF) during reclamation processed. The most expensive methods and uncertainty process are the use of quick lime in treatment of AMD. During operation and preparing mine closure stage need to create the effective one to comply with the regulation. "Swampy Forest (SF) system" is an alternative method of sustainable and naturally process. Selecting the appropriate tree species as a preliminary process to develop a better SF system by batch experiment in the form of a forest constructed wetland. The tree species selected are *Nauclea orientalis* (*lonkida* tree) and *Melaleuca cajuputi* (*kayuputih* tree) as non-local species then *Nauclea subdita* (*bangkal* tree) and *Melaleuca leucadendron* (*galam* tree) as local species have been selected. Local species higher in Fe and Mn adsorption in pH of AMD <4 then nonlocal species higher in Fe and Mn adsorption on pH of AMD >4 condition.

1. Introduction

Coal mining is one of economic sector that requires forestry area in Indonesia. Most of coal mining concession are under forestry land (Pratiwi et al., 2021). During operation and postmining stage, coal mining facing with AMD issue (Beauclair et al., 2021) and lower successful level of post mining revegetation (Noor et al., 2019). AMD is one such major issue that occurs in many coal mines with the low pH value of water in voids of former mining pits (Geller et al., 2013; McCullough & Schultze, 2018).

Generally, coal mining companies face an AMD expensive treatment if not handling properly. To apply open cut mining methods has a consequence of environmental impact and requires an integrated process both acid mine drainage treatment and successful revegetated. Sustainable AMD treatment is a critical process that can be integrated during mining and reclamation process of post mining (Ulrich et al., 2012). Reclamation on post mining is revegetated the area with tree species selected reference with forestry procedure (Permenhut P.60, 2009).

We have developed the SF system consists of selecting organic matter, grass and tree species (Noor et al., 2020). The aim of the present study was to rapidly decides the best tree species to apply of passive treatment in developing the SF system.

2. Experimental Design

Batch reactor system applied to carried out the ability of tree species (Liu, 2017; Trepel et al., 2000). This experiment was carried out in the reclamation land ex pit of a coal mining company (PT JBG) in South Kalimantan, Indonesia. The experiment was designed using five treatments with three replications in 15 experiment reactors of 1.2 m^3 of acid water each boxes of y: 50 cm for each reactor (Trepel et al., 2000).

The treatment protocol was to place a layer of overburden soil (OB) in the bottom in each reactor, then treatment with a manure (MN) as an organic fertilizer to support the tree planting process. Then continued drainage of AMD to the reactor. For control was only filled with OB, MN and AMD. Species of tree used in this experiment are *Nauclea orientalis* (*lonkida* tree), *Nauclea subdita* (*bangkal* tree), *Melaleuca leucadendra* (*galam* tree), *Melaleuca cajuputi* (*kayuputih* tree). These tree species were considered as a higher hyperaccumulator species and growing *better* in wet condition, low pH and higher concentration of Fe and Mn as well (Adiloğlu, 2018; Holland et al., 2018).

3. Experimental Procedure

The 15 reactors experiments are design of randomly plot according to the treatment code. The batch reactor were filled with the first OB layer of 160 kg each, then placed on top of it in the form of a second layer, the treatment of organic fertilizer then planted with tree species of treatment, each nine tree (Liu, 2017; Trepel et al., 2000). Each reactor was then allowed to incubation process for seven days. After the incubation process completed will be continued by slowly filling with surface water until the water level each reactor was average height 16 cm from the top OB layer and let it seven days acclimated process. Then continue by draining all existing water on each reactor via a tap at the bottom and replace with AMD for second acclimation of another seven days process. When the total acclimatization period was completed, all the water in the reactor was replaced again with full of AMD to start entering treatment period (Liu, 2017).

The measurement of water of pH in each reactor started on day1^{st} until day15^{th}. The pH measurement is carried out in the reactor box with a pH meter. Another parameters measurement is Total Suspended Solid (TSS), Fe, and Mn on the day15^{th} of treatment period (Kepmen LH 113, 2003)

4. Data Analysis

To determine the ability of each parameter in each treatment that was tested by statistical analysis of variance, Duncan's multiple range test and the effectiveness of the percentage of increasing of pH and reduction in Fe, Mn, and TSS concentrations by comparing the concentration day15^{th} to day1^{st}. The selected of tree species is the result of treatment which has parameter values that meet the threshold value according to regulations (Indonesian Minister of the Environment Decree Number 113 of 2003 concerning Wastewater Quality Standards for Mining Activities) that the pH 6-9, TSS <400 mg L^{-1}, Fe <7 mg L^{-1} and Mn <4 mg L^{-1} (Kepmen

LH 113, 2003). To compare Fe and Mn of plant to at soil, determine the bioaccumulation factor (BAF) of Fe or Mn (Anning & Akoto, 2018; Takarina & Pin, 2017). The BAF is Fe or Mn concentration in plants / concentration in soil.

$$BAF = \frac{concentration\ of\ Fe\ or\ Mn\ in\ plants}{Concentration\ of\ Fe\ or\ Mn\ in\ soil}$$

The removal efficiency of each parameter was calculated to determine the potential of Fe and Mn uptake of tree species based on following equation (Anning & Akoto, 2018; Takarina & Pin, 2017).

$$\%\ Removal\ efficiency = \frac{(C\ ini - C\ fin)}{C\ ini}\ x\ 100$$

where C *ini* represent the initial concentration of metal content, while C *fin* signify the final concentration of metal content.

5. Result and Discussion

Effect of tree species the changes in pH of AMD

Void as a source of AMD had an acid water of average pH <4. The AMD treated with tree species laboratory scale experiments showed the four tree species are significant differences with the control on day15th as showed on Figure 1.

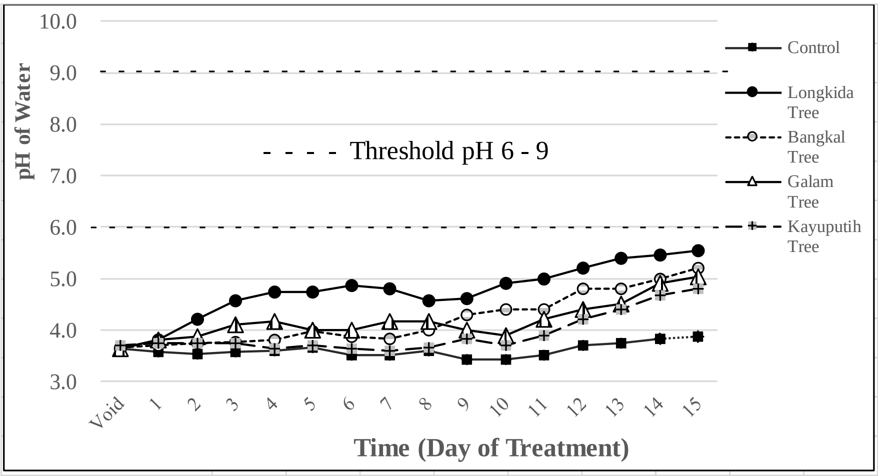

Figure 1. pH trend of tree species treatment on batch reactor experiment starts on day 1st until day 15th.

All tree species treatment showed the pH of water reduce on day1st and started increasing from day 2nd to day 15th. On the day 15th, the *lonkida* tree showed the highest of pH was 5.53 that was not significant difference with other tree species of *bangkal* tree with pH was 5.20, *galam* tree was 5.03 and *kayuputih* tree was 4.80. All tree species are significant difference with control showed almost meet with the pH threshold of compliance parameter value. The result still was not complying with the threshold, but they had potential to reach it on the other day of treatment considering the trend of their increasing. Applying manure during the tree planting process can reduce the acidity as on the same time the tree uptake the heavy metal from the soil or water (Jayalath et al., 2016; Lee et al., 2014).

Effects of tree species treatment on changes in TSS, Fe, and Mn of AMD

TSS is one of threshold parameter. The results of the TSS observations are presented in Figure 2. The TSS observations on day 1st showed higher than in voids and day 15th higher than day 1st. Mostly the value is compliance with the national regulation but reference with the regional one is some not compliance. If compared day15th to day1st, only *kayuputih* tree show reduction efficiency is 20.1% and other tree species treatment show the TSS value is increase. Compared with threshold value, all tree species treatment meets with compliance value of National level is TSS <400 mg L^{-1} but if compare with regional level of South Kalimantan compliance of threshold, only *bangkal* tree and *kayuputih* tree are the TSS <200 mg L^{-1}.

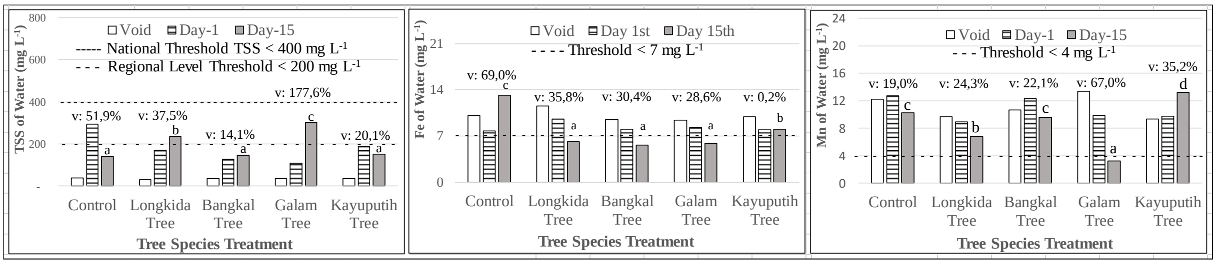

Figure 2. Comparison of TSS, Fe and Mn on void, day1st and 15th of tree species treatment. The different lowercase letter above the columns indicate significant differences between the treatment and variance (v) is TSS, Fe and Mn reduction efficiency on day15th.

AMD generally has high Fe and Mn content in coal mining sites (Herniwanti et al., 2014). Higher Fe and Mn values contribute to non-fulfillment of predetermined water quality standards. Values that exceed the quality standard must be treated so that the value of Fe < 7 mg L^{-1} and Mn < 4 mg L^{-1}. Figure 2 shows that all tree species treatments showed a decrease in Fe value on day 15th of water compared to the conditions in the voids or on the day 1st. On the day 15th of treatment, all types of treatment trees showed Fe values < 7 mg L-1 except for *kayuputih* trees. The highest efficiency of Fe reduction on the day 15th was shown by l*onkida* tree by 35.8% then *bangkal* tree by 30.4%, *galam* trees by 28.6% and *kayuputi*h tree by 0.2%.

Content of Mn in water is also higher of Mn or not compliance. The water treatment also needs to reduce content of Mn. Figure 2 shows the increase of Mn content if compare day 1st to void condition but if compare the day15th to day 1st indicated the trending decrease. Only the *galam* tree treatment meets with Mn value of threshold. The highest efficiency reduction of Mn on day15th showed by *galam* tree is 67.0% then *lonkida* tree is 24.3%, *bangkal* tree is 22.1%, but *kayuputih* tree increased 35.2%.

Fe and Mn uptake by tree species

The four species of tree showed their role to uptake the Fe and Mn from the soil that contaminated AMD. On Table 1 showed the result of plant uptake the heavy metal of Fe and Mn figured by the accumulation factor for soil contaminated by heavy metal which all trees species have BAF ratio >1. The highest BAF ratio for Fe is *bangkal* tree and for Mn is *lonkida* tree. The highest of Fe uptake showed on *bangkal* tree species is 23.56 g kg^{-1} and the lowest one is *kayuputih* tree. For Mn, the highest showed by *lonkida* tree is 8.03 g kg^{-1} and the lowest one is *bangkal* tree. Lonkida and kayuputih as not local tree species higher to uptake Fe and Mn in pH >4 while bangkal and galam as local tree species higher to uptake the Fe and Mn in pH < 4 condition.

Table 1. Total Fe and Mn uptake on day15th. BAF ratio showed in plant higher than in soil.

Tree Species Treatment	Fe (g kg^{-1})		Mn (g kg^{-1})		BAF Ratio		Condition	
	Plant	Soil	Plant	Soil	Fe	Mn	pH <4	pH >4
Longkida	20.63	9.60	8.03	0.17	2.15	46.99	-	Higher
Bangkal	23.56	9.59	0.95	0.12	2.46	7.95	Higher	-
Galam	16.71	7.07	1.14	0.07	2.36	17.21	Higher	-
Kayuputih	12.43	9.86	3.05	0.23	1.26	13.49	-	Higher

Role of Tree Species on AMD Treatment

On this experiment, each tree species has been shown their performance to increase the pH and reducing the TSS, Fe and Mn of AMD. Each tree species has role to reduce the Fe and Mn mostly higher in AMD. The reducing of Fe and Mn on tree species treatment to confirm the previous research of constructed wetland that *longida* tree and *kayuputih* tree can adsorb Fe and Mn (Rahmatia et al., 2019) (Tuheteru *et al*., 2016). Tree species have ability to adapt or to tolerate the heavy metal (Dhir, 2013; Ford, 2003) to transfer oxygen to media by root (Skousen *et al*,. 2019) and the tree species can survival in wet condition (Irhamni *et al*., 2018). The tree species adapted by showing better biomass production and efficiency to reduce the Fe and Mn (Tuheteru *et al*., 2016) that can be indicated by the grass and tree species accumulate potential (Karathanasis & Johnson, 2003).

Phytoremediation is a process that helps the absorption of metals by plants which depends on the ability of roots to limit the mobility of contaminants and their availability in the soil through binding, deposition, or reduction of complexity (Glick, 2003). Types of tree can hold metal at the root or collect and localize metal on cell vacuoles (Prihatini et al., 2015). Tree species of hyperaccumulator are widely used in Phyto stabilization which is part of the phytoremediation process considering its rapid growth and extensive root system (Dhir, 2013; Yan *et al*., 2020). Tree species can absorb heavy metals through their roots and shoot through a fairly high transpiration process in the rooting area which ultimately has the role of limiting the movement of heavy metals in the soil (Skousen *et al*., 2019). The pH rooting areas are changed by some root exudates and help the process of deposition of heavy metals, limit their availability and reduce the level of poisoning (Dhir, 2013; Hidayati, 2013).

Tree species selected for Swampy Forest System

"Swampy Forest (SF) system" is a new concept of passive treatment which is defined as post-mining reclamation by combination of organic matter treatment, planting of undergrowth of certain types of grass and woody trees that are able to live in wet conditions, low pH and high heavy metal concentrations with constructed wetland reference concept (Noor et al., 2020). The tree species selected will be combined with organic matter and grass species those selected on the other experiment as the basic media of SF system. Concepts of forest constructed wetlands are naturally for wastewater treatment systems, which are designed to utilize the natural purification processes involving wetland plants, substrates, and the associated microbes

(Cheng *et al*., 2018; Hlihor *et al*., 2017). *Bangkal* tree and *galam* tree can adsorb higher Fe and Mn in condition pH <4 and *lonkida* tree and *kayuputih* higher to adsorb Fe and Mn in pH >4 (Kumar *et al*., 2019).

6. Conclusion

This study provides evidence of the tree species selected have ability to adsorb the Fe and Mn from the soil by phytoremediation process. The tree species has roles to comply with the threshold both individually and together with others. The conclusions from the experiments described revealed that the four tress species selected of *lonkida* tree, *bangkal* tree, *galam* tree, *kayuputih* tree have role to adsorb Fe and Mn in different condition. All tree species will be applied in SF system to treat the water parameter that mostly are not comply and change it to be comply parameter before releasing to public water bodies.

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