# Oil palm empty fruit bunch as the selected organic matter in developing the Swampy forest system for passive treatment of acid mine drainage

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# Oil palm empty fruit bunch as the selected organic matter in developing the Swampy forest system for passive treatment of acid mine drainage

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**ABSTRACT**

Coal mining in Indonesia commonly faces expensive and uncertain costs during the operational and mine closure stages from the management of acid mine drainage (AMD). The most expensive method to actively raise the pH of this wastewater is the use of chemical additives. An alternative method is passive treatment, which is acidity treatment with lower costs but limited efficacy. We present the development of passive treatment with Swampy Forest (SF) system as a new natural and sustainable method with lower costs, and greater environmental sustainability. The SF system consists of selecting organic matter and combining it with the planting of selected grass and tree species in the form of a forest constructed wetland. As a preliminary to the construction of the SF wetland, a batch reactor system was used to carry out experiments to find the best organic matter for passive treatment of AMD. Oil palm empty fruit bunches (EFB) were shown to increase the low pH of AMD, which generally has the pH < 4, to be pH between 6 to 9, thus achieving the threshold parameter to comply with applicable regulations for managing mine waste water.

***Key words :** AMD, EFB, Organic matter, Swampy Forest system.*

## Introduction

Coal mining is an industry that generates significant and important revenue in Indonesia, however several environmental consequences are associated with it (Roy *et al.*, 2015). Acid mine drainage (AMD), a global environmental issue in coal mining, is common in Indonesian mines. AMD can present a substantial risk of incurring significant costs if it is not identified early and managed appropriately. In order to attain sustainable mining rehabilitation, managing environmental aspects throughout the duration of the active mining operation is critical (Naidu *et al.*, 2019). Importantly better AMD management will also lead to successful revegetation levels on post mining reclamation (Noor *et al.*, 2019).

Hence, implementations of effective manage-

**Abbreviations** : SF: Swampy forest; EFB: Oil palm empty fruit bunch; RSW: Residual of *Cymbopogon nardus* distilled; CSP: *Albiziachinensis* pruning cut chip; CMF: Cow Manure Fertilizer ment practices, both during operation and post-mining, are necessary to control AMD pollution (Naidu *et al.*, 2019). There are two major categories in AMD treatment technologies, namely prevention and remediation. Prevention techniques mainly focus on inhibiting AMD formation reactions by controlling the source. Remediation techniques focus on the treatment of already produced AMD before their discharge into water bodies (Roy *et al.*, 2015). In terms of AMD remediation, active treatments are generally considered expensive compared to passive treatments, especially when the mining operation has ceased (Jallath *et al.*, 2018).

Passive treatment methods generally achieve precipitation of metal sulfide by creating reducing conditions and utilizing organic substances as alkaline agents including aerobic wetlands and compost reactors (Taylor *et al.*, 2005). A secondary stage of treatment is therefore necessary as neutralization and precipitation through pH change alone is not enough. Constructed Wetlands are a promising passive treatment option as they are relatively self-sustaining once established and are deemed to be cost effective (Roy *et al.*, 2015).

We have developed the Swampy Forest (SF) system as a new natural and sustainable passive treatment method with lower costs, and greater environmental sustainability. The SF system consists of selecting organic matter and combining it with the planting of selected grass and trees species in the form of a forest constructed wetland (Noor *et al.*, 2020). As a preliminary to the SF concepts, a batch reactor system was used to carry out experiments to find the best organic matter for AMD treatment. The aim of the present study was to rapidly decide the best organic matter that would then be combined in the next experiment in developing of passive treatment as an early step of increasing the pH of AMD as a short-term stage and it will combine with another media those have been selected for developing passive treatment of AMD by SF.

## Materials and Methods

### Experimental Design

Laboratory experiments were carried out to compare the ability of several sources of organic matter to raise the pH of AMD in a batch reactor system (Halverson, 2004; Liu, 2017; Poltak, 2005). The results of this organic matter selection experiment will be then used in next experiment. The next experiment will be a combination of the main ingredients in the development of passive treatment by SF system. This experiment was carried out in the reclamation land ex pit of a coal mining company in South Kalimantan, Indonesia. The experiment was designed using a completely randomized design method consisting of five treatments with three replications in 15 batch reactors, each: length: 150cm x width: 50cm x height: 60cm and the height of the layer of treatment material and AMD was y: 50cm for each reactor (Bendoricchio *et al.*, 2000; Halverson, 2004; Trepel *et al.*, 2000).

The treatment protocol was to place a layer of overburden soil (OB) in the bottom layer in each of the reactors, then a layer of organic matter treatment and then covered with another layer of OB in the form of a sandwich. Sources of organic matter used in this experiment were oil palm empty fruit bunches (EFB), residual of *Cymbopogon nardus* distilled (RSW), *Albiziachinensis* pruning cut chip (CSP) and cow manure fertilizer (CMF) as mentioned in Table 1. These four sources of organic matter were chosen considering they would normally exist in large quantities around the mining area either as waste from the results of the community development program activities or from reclamation activities of coal mining itself.

**Table 1**. Laboratory experimental design and source of organic matter treatment

| Organic Matter Treatment | |
|---|---|
| A.0 : OB + Control | + AMD |
| A.1 : OB + Oil palm empty fruit bunches (EFB) | + OB + AMD |
| A.2 : OB + Residual of *Cymbopogon nardus* distilled (RSW) | + OB + AMD |
| A.3 : OB + *Albizia chinensis* pruning cut chip (CSP) | + OB + AMD |
| A.4 : OB + Cow manure fertilizer (CMF) | + OB + AMD |

### Experimental Procedure

The 15 reactor experiments are layer systems that were arranged randomly according to the treatment code. As a first step, all reactors were filled with the first OB layer of 136 kg each, then placed on top of it in the form of a second layer, the treatment organic matter of either EFB, RSW, CSP or CMF, each 25 kg. Then the third layer of OB, 24 kg each, to keep the organic matter from floating and to reduce contact with oxygen (Liu, 2017; Poltak, 2005). The control reactors were only filled with OB.

Each reactor was then allowed to incubation process for seven days. After the incubation process was completed, each was slowly filled with rain water that has been collected until the water level each reactor was average height 30 cm from the top OB layer and left seven days to acclimatize. Then this process was continued by draining a half of existing water from each reactor via a tap at the bottom and replaced with AMD for the second acclimatization of another seven days. When the total acclimatization period was completed, all the water in the reactors was replaced again with new AMD and monitored over 15 days for treatment (Halverson, 2004).

The measurement of pH in each reactor started on day 1st until day 15th of the treatment period. The pH measurement was carried out in the reactor box with a pH meter. Total Suspended Solid (TSS), and heavy metal content in the form of Fe and Mn were measured on the day 15th of treatment only.

**Data Analysis**

Statistical using analysis of variance test, and Duncan's multiple range test was carried out to determine the effectiveness of the increase of pH and the percentage reduction in Fe, Mn, and TSS concentrations by comparing the concentration day 1st and 15th of treatment. The selected organic matter is the result of treatment which has parameter values that meet with the threshold of applicable regulations, Indonesian Minister of the Environment Decree Number 113 year 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 $L^{-1}$.

## Results and Discussion

### Effect of organic matter on the changes in pH of AMD

Void as a source of AMD has an acid water of average pH < 4 means do not comply to release the water to public water bodies. The AMD treated with some organic matter in laboratory scale experiments showed significant differences on day 15th of treatment. On Figure 1, the treatment of organic matter using EFB on the day 1st of treatment showed an increase in water pH but still has not met the threshold of compliance parameter value but on the day 3rd, the pH value of EFB has been success met the minimum value of threshold. During treatment on day 15th, the pH obtained for the EFB treatment was 7.6, meaning that compared with other treatments the EFB could increase the pH which statistically showed a significant difference where the pH value obtained was able to meet the threshold value.

### Effects of organic matter treatment on changes in TSS, Fe and Mn of AMD

Observation of the value of TSS in each treatment of organic matter used is presented in Figure 2. In all treatments the organic matter used did not show any significant reduction for TSS values. Water from voids has shown a lower TSS value that is average < 37 mg $L^{-1}$ or has met the threshold. All treatments have shown TSS values were increased both on day 1st and 15th of treatment. The TSS of EFB treatment

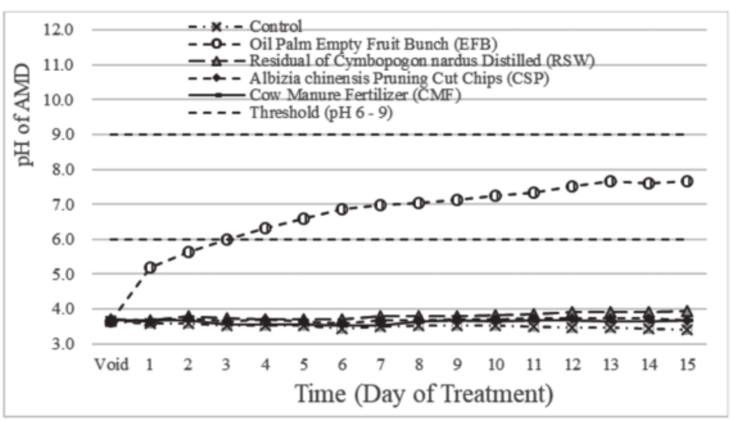


**Fig. 1.** pH trend of EFB compare with other organic matter start on day 1st until day 15th of treatment

showed the highest and significant different when compared with other treatment but the TSS values of all treatment are under the threshold value of maximum 400 $mgL^{-1}$.

The content of heavy metals such as Fe and Mn is commonly raised in AMD, which means it exceeds the threshold parameter so that these two heavy metals require treatment in order that the values of Fe and Mn can be reduced to meet the threshold value. Water to be released into public bodies must have a value of Fe < 7 mg $L^{-1}$ and Mn < 4 mg $L^{-1}$. Based on the results obtained, all organic matter treatments showed a decrease in Fe value when compared water in void with day 1st and day 15th of treatment. On day 15th of treatment, all organic matter treatment showed the value of Fe < 7 $mgL^{-1}$as presented in Figure 3 means comply with the threshold value.

The results of water sampling on void shows that the Mn above the threshold value, so Mn must be lowered also to meet the value of Mn < 4 mg $L^{-1}$. Figure 4 shows all treatments increase when compared water in void with water in day 1st treatment but when compared the day 1st with day 15th for all treatment indicate a decrease. Only the EFB and CSP treatment meet with Mn value of threshold (Mn < 4 mg $L^{-1}$).

**Effectiveness of organic matter treatment for AMD**

The results of the treatment on all parameter shown in Table 2. The highest effective value of increasing the pH was found in the EFB treatment on day 15th by 47.44% compared to other treatments. Meanwhile, the effectiveness of TSS did not show a significant difference because all treatments varied and tended to increase compared to the TSS values on voids. It was concluded that the batch type experiment where OB is used above and below the or-

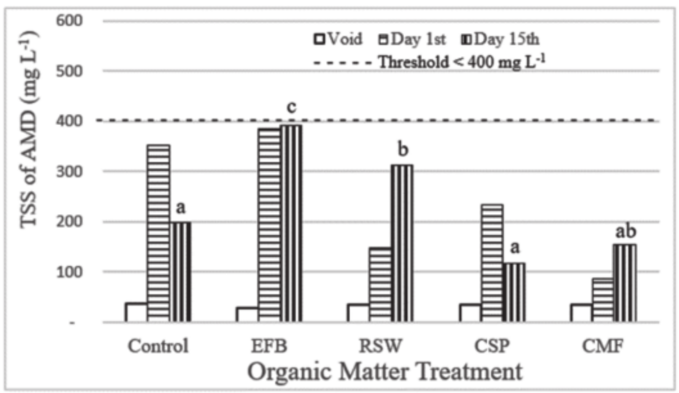


**Fig. 2.** Comparison of TSS on void, day1st and 15th of organic matter treatment and the different lowercase letter above the columns indicate significant differences between the treatment (day 15th)

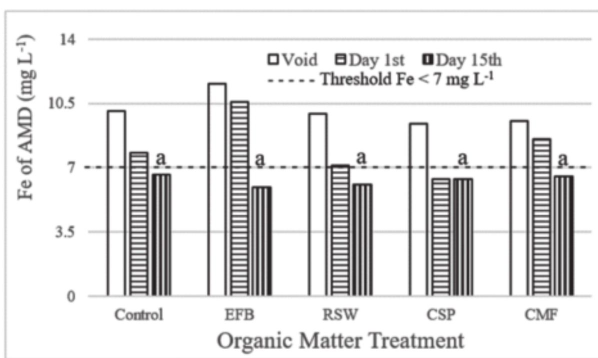


**Fig. 3**. Comparison of Feon void, day 1st and 15th of organic matter treatment and the same lowercase letter above the columns indicate non-significant differences between the treatment (day 15th)

ganic matter is not relevant to investigating TSS as the OB itself releases significant suspended solids. The highest decrease was only obtained in CSP when compared day 15th with day 1st of treatment was 49.60%. Although there is a decrease, but it cannot be lower than the previous value in voids. On day 15th, all treatments have met or comply with the threshold value of TSS < 400 mg $L^{-1}$.

The value of Fe and Mn of AMD in void area are higher than the threshold of compliance parameters. The treatment of AMD with organic matter showed that: the effectiveness of Fe reduction in the EFB treatment was the greatest on day 15th of treatment (44.10%) compare with other organic matter treatment. The effectiveness of Mn reduction in all treatments showed the greatest both on the EFB of 78.48% and the CSP of 79.18% on the day 15th of treatment.

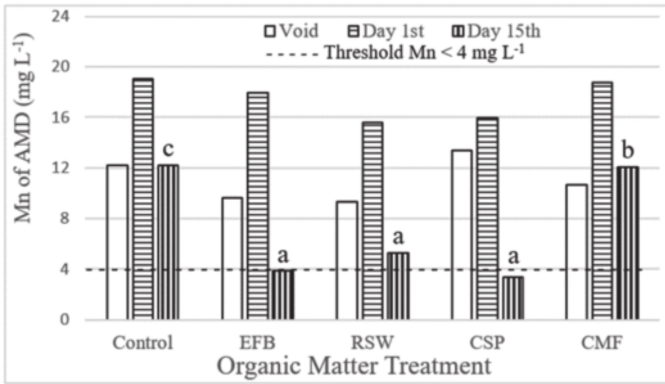


**Fig. 4**. Comparison of Mn on void, day 1st and 15th of organic matter treatment, and the different lowercase letter above the columns indicate significant differences between the treatment (day 15th)

**Table 2**. Effectiveness of organic matter treatments on compliance threshold parameters.

| Treatment | Threshold | Treatment | | Efficiency | | Summary | |
|---|---|---|---|---|---|---|---|
| | | Day 1st | Day 15th | Change | % | Fulfillment | Change |
| Control | | 3.60 | 3.40 | -0.20 | -5.56% | - | - |
| EFB | | 5.20 | 7.67 | 2.47 | 47.44% | Comply | Higher |
| RSW | pH 6-9 | 3.67 | 3.93 | 0.26 | 7.09% | - | - |
| CSP | | 3.63 | 3.67 | 0.04 | 1.10% | - | |
| CMF | | 3.67 | 3.67 | 0.00 | 0.00% | - | - |
| Control | | 352 | 198 | 154 | 43.75% | Comply | - |
| EFB | | 385 | 392 | -7 | -1.89% | - | - |
| RSW | TSS < 400 $mgL^{-1}$ | 147 | 312 | -165 | -111.68% | - | - |
| CSP | | 234 | 118 | 116 | 49.60% | Comply | Higher |
| CMF | | 87 | 156 | -69 | -79.75 | Comply | |
| Control | | 7.81 | 6.61 | 1.20 | 15.40% | Comply | - |
| EFB | | 10.59 | 5.92 | 4.67 | 44.10% | Comply | Higher |
| RSW | Fe, mg $L^{-1}$ | 7.10 | 6.08 | 1.02 | 14.41% | Comply | - |
| CSP | | 6.38 | 6.39 | -0.01 | -0.16% | Comply | - |
| CMF | | 8.55 | 6.54 | 2.01 | 23.52% | Comply | - |
| Control | | 19.08 | 12.23 | 6.85 | 35.88% | - | - |
| EFB | | 17.95 | 3.86 | 14.09 | 78.48% | Comply | Higher |
| RSW | Mn < 4 mg L-1 | 15.58 | 5.27 | 10.31 | 66.20% | Comply | - |
| CSP | | 15.98 | 3.33 | 12.65 | 79.18% | Comply | Higher |
| CMF | | 18.78 | 12.03 | 6.75 | 35.92% | - | - |

*Note:* Comply with the threshold parameter of applicablel regulation

## Discussion

### Organic matter raises the pH of AMD

AMD must be treated because the water to be released into public water bodies must meet the threshold of compliance parameter efficiently and effectively. Treatment of AMD with chemicals such as quicklime is expensive, costing on the average USD 0.04 per $m^3$ of AMD before it can be released to public rivers (Gautama *et al*., 2014). There is an urgent need to find an alternative material and methodology to replace the use of quicklime to neutralize the low pH of AMD (Santos *et al*., 2018).

Our preliminary work has shown that the use of waste organic matter from around mining activities can replace chemicals and thus reduce AMD's processing costs. The selection of the best organic matter is the first step to determine which selected organic matter will then be combined with other treatments in the next experiment. Organic matter can be used to remediate AMD making use of the oxygen and enriched carbon source produces (Hilson and Murck, 2000; Johnson and Hallberg, 2005). The organic matter during the reduction process creates a terminal electron acceptor and generates alkalinity then metal recovery is achieved by regulating the concentration of the reactant sulfate through pH control in the bioreactor (Johnson and Hallberg, 2005).

Table 2 shows the effectiveness of the compliance parameters with the treatment given. The optimization of these mixtures is important to achieve water acidity reduction and maximum metal and sulfate removal. Heavy metal ions present then react with the hydrogen sulfide gas produced to form insoluble metal sulfide precipitates and the metals are removed through sulfide precipitation (Kefeni *et al*., 2017). The TSS is suspended materials and is not soluble in water (Heal, 2014). Suspended solids consist of particles which are smaller in size and weight than sediments. TSS may include mud, clay, metal oxides, sulfides, algae, bacteria, fungi, and inorganic particles. TSS contributes to turbidity by limiting light penetration for photosynthesis and visibility in water. TSS concentrations can be removed by sedimentation and by the activity of microorganisms and plants (Gargallo *et al*., 2017). During treatment, TSS higher when compare with the water on void are caused by the reaction between AMD and OB which have higher loose particles and the material condition of the organic matter used especially the EFB.

The decrease in Fe and Mn values by organic matter are due to organic matter releasing electrons to bind metals (Gibert *et al*., 2004; Kalin *et al*., 2006), Other studies have shown that AMD treated with organic matter was colonized by bacteria could reduce the availability of Fe and Mn metals in water (Coppini *et al*., 2019; Lazareva *et al*., 2019; Sahinkaya *et al*., 2015). Some condition the Fe value increase, it is likely that the EFB has reached the saturation point in terms of absorption or decomposition process (Jayalath *et al*., 2016; Kadir *et al*., 2004).

### Organic matter selected for Swampy Forest system

SF system is the development of AMD passive treatment which is defined as post-mining reclamation by combination of organic matter treatment, planting of under growth 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). Concepts of forest constructed wetlands are green and engineered wastewater treatment systems, which are designed and constructed to utilize the natural purification processes involving wetland plants, substrates, and the associated microbes (Cheng *et al*., 2018).

The results of the selection of organic matter, namely EFB in a experiment showed that the EFB treatment into AMD can raise the pH of AMD in just a few days to raise the pH to the level of compliance value as shown in Figure 1. So it is a short-term solution to overcome the low pH of AMD but this provision of organic matter cannot be the sole solution, so it needs to be combined with planting grass plants in wet conditions for medium-term purposes and continued with planting of woody tree species to meet the criteria for replanting post-mining land considering most of coal mining land are forest area. The planting of woody tree species is a long-term stage so that it becomes AMD management and sustainable reclamation (Noor *et al*., 2020). In anaerobic wetland systems, matrix compositions used such as compost can be added to stimulate the growth of sulfate reducing bacteria to increase the alkalinity which can increase the pH of AMD (Gibert *et al*., 2004). EFB is a by-product of oil palm plantations which weight up to 23% of weight of fresh oil palm bunches (Vakili *et al*., 2015). Sorption, coprecipitation, and exchange to precipitated Fe and

Mn, organic matter, and soil-like materials are additional mechanisms for metal removal to reduce concentration in AMD (Skousen *et al*., 2017).

The key drivers for enabling water reuse and valuable resource recovery are innovative treatment technologies of SF system as well as the integration of conventional and alternative processes. The conclusions from the experiments described below revealed that oil palm empty fruit bunch (EFB) was the organic matter selected as one of the media combination that apply in SF system which can increase the low pH of AMD to pH level of compliance standard pH 6 until 9 before release to public water bodies.

## Conclusion

The treatment of AMD by means of a passive remediation system involves the selection of an appropriate organic substrate of EFB was shown to increase pH of AMD from day 1st and then compliance levels were reached on day 3rd of treatment. This selection of EFB is one of the critical steps in the development of the SF passive treatment system, as this depends to a great extent on the degradability of the organic substrate.

In a short-term stage to adjust the pH, the EFB is the alternative organic matter selected in developing AMD treatment as the EFB can raise the pH < 4 to be compliance with threshold parameter pH 6 – 9 if we compare with other source of organic matter around mining area. Thus, a prior characterization of the organic substrate predicting its biodegradability would be desirable before embarking on an extensive large-scale application. This method is an appealing alternative to conventional methods because of its cost effectiveness, maintaining ecological balance and aids in reestablishing polluted environments.

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