*Eco. Env. & Cons. 26 (2) : 2020; pp. (901-909)*
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*ISSN 0971–765X*

# Development of the Swampy forest system for passive treatment of acid mine drainage during post mining land reclamation: A new concept review

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(Received 1 January, 2020; accepted 25 February, 2020)

## ABSTRACT

One of the big challenges in coal mining is how to improve the treatment of acid mine drainage (AMD) where the outflow water is acid and usually has a high concentration of heavy metals. Commonly costs of around USD 0.04 per $m^3$ acid water of AMD to comply with legislative regulations when active treatments are used for the neutralizing process. We have developed a new concept of passive treatment to treat the AMD at a lower cost compared with active treatment and with much greater capacity to treat significantly more volume of AMD compared with the conventional passive treatment systems. Experiments to determine the role of a combination of organic matter, grass and trees species selected in one system of passive treatment, named Swampy Forest (SF) system, to treat the AMD are described in this article. SF system was shown to be an effective, efficient, and environmentally friendlier process in transforming mine wastewater that was incompliant value at inlet (before treatment) to become compliant at outlet from the treatment system before being released.

***Key words:*** *AMD, Swampy forest system, EFB.*

## Introduction

Utilization of coal mining as natural resources has a positive impact on economic and energy development but can also have a negative impact of environmental pollution in land, water and air if not managed properly (Setiawan *et al.,* 2018). 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 (Dwiki *et al*., 2015; Gautama *et al.,* 2014). The AMD can be formed on the area that have been identified as having higher potential acid forming (PAF) material in overburden that are not well managed in the mining process. It has an impact on successful rate of revegetation process and the runoff water quality (Noor *et al.,* 2019).

The existence of sulfide mineral reaction process in PAF material which eventually enters the pit lake provides an important contribution to increase the acidity of water in the voids (Castro and Moore, 2000). The AMD with its low pH and high concentration of heavy metal must be handled properly so that acceptable water quality levels meet the applicable regulations (Geller *et al.,* 2013). In Indonesia, the threshold parameters reference with Minister of Environment Decree Number 113 of 2003 concerning Wastewater Quality Standards for Mining Activities for releasing the water into the surrounding environment.

In term of AMD treatment, the two major technologies are prevention and remediation. Prevention techniques mainly focus on controlling the source to avoid new AMD formation. Remediation techniques focus on the treatment of the AMD, which has already occurred during mining, before the water is discharged into water bodies (Roy *et al.,* 2015). Remediation usually is either active or passive. Active remediation methods by adding CaO or $CaCO_3$ into it with the aim of the neutralization process (Nurisman *et al.*, 2012).

Gautama *et al.* (2014) have studied using lime for neutralizing the acidity of one of pit lake at Jorong coal mining (JBG) namely $M_{23}E$ pit lake with total capacity of acid water is around 8.2 million $m^3$. The study to review of another method of active treatment, name is In Pit Treatment method that has been implemented in this pit lake using a lime mixing facility in JBG. The treatment of field scale experiment using a lime ($Ca(OH)_2$) to neutralize approximately 460,000 $m^3$ of acidic water with average pH of 2.8 to achieve pH of 7 in three months before discharge to public bodies. It may cost around USD 0.04 per $m^3$ acid water of AMD for neutralizing process to comply with the regulation. The pit lake sampling point as Figure 1.

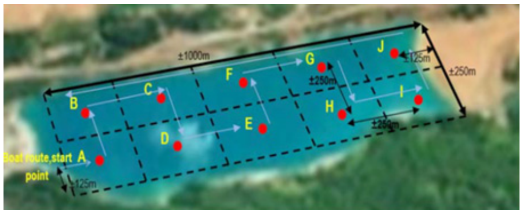

**Fig. 1.** Sampling Point of Treatment (Gautama *et al.,* 2014)

We have developed a new strategy of passive treatment of AMD that can be integrated with reclamation activities on post-mining land, namely "Swampy Forest" system(SF) which can be defined as post-mining reclamation with a combination of the selected organic matter, planting of the undergrowth of grass species and certain woody plants which are able to tolerate the low pH conditions. SF system is aligned with wetland concepts asthe AMD treatment from coal mining activities and the implementation of reclamation in the context of replanting post-mining area can be carried out jointly. SF system is designed by adding selected organic waste from oil palm plantations, namely oil palm empty fruit bunches (EFB) as an initial step in raising the pH of AMD for short-term stages, then proceeding with grass planting of *Typha angustifolia* (typha grass) and *Eleocharis dulcis* (purun grass) species as a medium-term stage efforts in controlling the level of acidity of water and heavy metal removal, then continuing planting with trees species selected which are included in the category of woody and long-cycle by selecting *Nauclea orientalis* (longkida trees) and *Nauclea subdita* (bangkal trees) as the long-term stage, the process thus giving AMD management in a measurable manner to meet the threshold parameter of applicable regulations. This paper will discuss and review this new concept of SF system for future widespread implementation.

## Materials and Methods

### Experimental Design of SF System

The SF system is designed to combine three main media in AMD treatment. The selection media in the SF system will be determined by conducting individual experiments namely experiment 1A for organic matter selection, 1B for grass species selection and 1C for trees species selection.The process of selection is a very important stage and a foundation for determining the next step (Chisti, 2006; Liu, 2017; Trepel *et al.,* 2000).

Second stage experiment is laboratory (lab) simulation. The experiment combined all three selected media to be in lab experiment with surface flow water system reactor. Lab simulation experiment used three reactors and every reactor had overburden (OB) on the bottom of reactor, treatment with organic matter selected and continue planting the grass and trees selected. AMD flowed in with consistent capacity to the reactor and monitoring of the parameters of pH, TSS, Fe and Mn until the quality of water at outlet complies with government regulations (Economopoulou and Tsihrintzis, 2004).

Third stage experiment is pilot project. During lab simulation, we have recorded some data about the volume of reactor, surface flow water capacity and retention time those are a basic reference. On

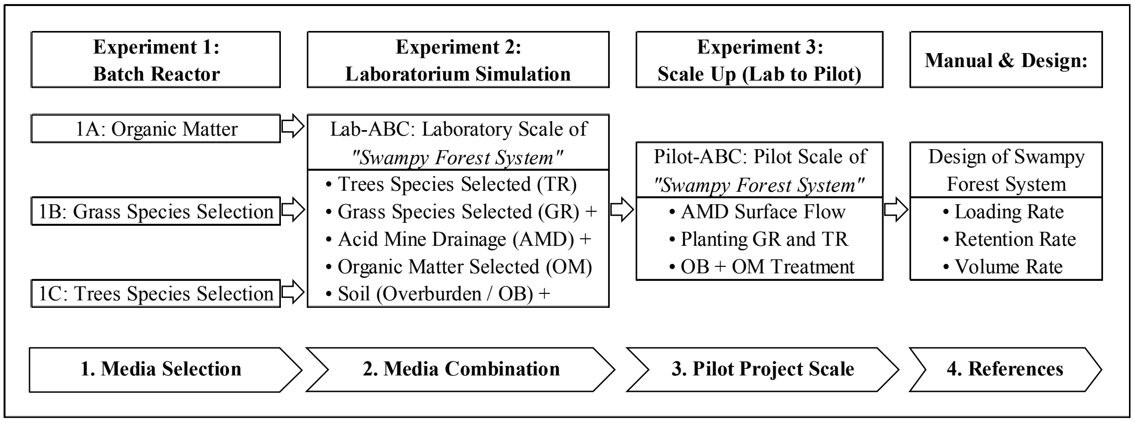

**Fig. 2.** Swampy Forest System Experiment Design

pilot project design, we just scale up the data for more volume of treatment, more water debt flow in and confirm the retention time for validation confirmation data (Arnold *et al.*,2001; Favero *et al.,* 2007). On Figure 2 shown the step of all experiments.

## Methods of Media Selection

The first stage is a preliminary study in the laboratory by conducting a batch reactor system experiment with three replicates of completed sampling design. The experiment was divided into three experiments are 1A, 1B and 1C.

The experiment 1A, 1B, and 1C required the incubation and acclimatization process with total 30 days then continue entering 30 days detention time period (Grybos *et al.,* 2009; Magen *et al.,* 2011). Every reactor will monitor the pH value daily from day 1st until day 15th. Other compliance parameter of TSS, Fe and Mn will be analysis from sampling of water and soil on 15th and 30th days of treatment. The material list of first stage experiment have been mentioned in Table 1.

## Methods of Lab Simulation

On lab simulation experiment will treat the combination of the best organic matter, grass, and trees species selection those we have selected, namely Lab-ABC. The experiment aims to determine the role of organic matter, grass species and trees species selected combination in development the passive treatment on AMD. Every box reactor experiment with layer system was consist of OB on the bottom layer then the organic matter selected on second layer. Continue planting *Typha* and purun grass combined with longkida and bangkal trees on serial of three box reactors with size of each reactor are L: 200 cm, W: 100 cm, H: 80 cm and y: 60 cm. Total incubation and acclimatization process is 30 days (Jethwa and Bajpai, 2016; Ong *et al.,* 2010).

Flow in the AMD by plastic pipe (3/4 inch) from AMD tank storage to first reactor and control surface water capacity flow in is average 1.2 $m^3$ $hour^{-1}$ then continue flowing to the second and third reactor (Vymazal, 2011). Record the retention time when we start to open the water at inlet until the water at outlet was between pH 6 to 9. The cross-section of three box reactor for lab simulation illustrated in Figure 3.

## Method of Pilot Project Scale

The third stage experiment is the implementation of

**Table 1.** Treatment Material List of First Stage Experiment

| 1A : Organic Matter Selection | 1B : Grass Species Selection | 1C : Trees Species Selection |
|---|---|---|
| - Control | - Control | - Control |
| - Palm Oil Empty Fruit Bunch (EFB) | - *Typha angustifolia* (typha grass) | - *Nauclea orientalis* (longkida trees) |
| - Residual of *Cymbopogo nardus* Distilled (RSW) | - *Vetiveria zizaniodes* (vetiver grass) | - *Nauclea subdita* (bangkal trees) |
| - *Albizia chinensia* Pruning Cut Chip (CSP) | - *Eleocharis dulcis* (purun grass) | - *Melaleuca leucadendra* (galam trees) |
| - Cow Manure Fertilizer (CMF) | - *Cyperus species* (batibati grass) | - *Melaleuca cajuputi* (kayu putih trees) |

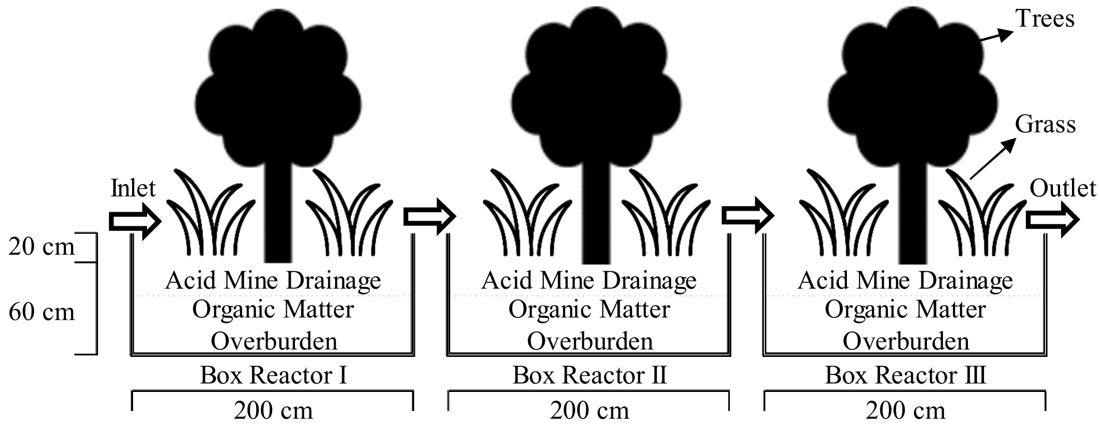

**Fig. 3.** Cross Section of Lab Simulation Reactor

Lab-ABC's research results into the field by applying in construction called "Swampy Forest" system on post-mining reclamation land of 1 ha. Four compartments constructed in a serial system mean the water will flow from pond one to pond two then to pond three and last to pond four. The size of pond reference with ratio of length to width is 4:1 (L: 60 m & W: 15 m) with a total volume of detention time is 900m$^3$ (Coppini *et al.*, 2019; Heal, 2014).

This third stage of the research is an experiment to test the results obtained by validating data that had been obtained in laboratory simulation experiments such as water discharge data, retention time and reactor volume of the compartment. The validation data process determined the correction value of the results obtained in laboratory simulation experiments (Cheng *et al.,* 2018; Su *et al.,* 2009).

## Results and Discussion

### Result of Media Selection

The experiment 1A was selecting the organic matter from some source of organic matter. Result of this experiment has recommended to select EFB is of alternative material can rise the pH of AMD. The experiment 1B was selecting the grass species of typha and purun grass. The experiment 1C was selecting the tress species those are longkida and bangkal trees species. The summary of first stage experiment shown in Table 2.

**Table 2.** Summary of First Stage Experiment Result.

| Experiment 1A | | Experiment 1B | | Experiment 1C | |
|---|---|---|---|---|---|
| Treatment | Selected | Treatment | Selected | Treatment | Selected |
| EFB | Yes | Typha Grass | Yes | Longkida Tree | Yes |
| RSW | No | Vertiver Grass | No | Bangkal Tree | Yes |
| CSP | No | Purun Grass | Yes | Galam Tree | No |
| CMF | No | Batibati Grass | No | Kayu Putih Tree | No |

### Result of Lab Simulation

Result of first stage experiment has shown the individual's and their respective roles of each media. It is not enough the constructed wetland planted with the species of grasses only but also need to combine with other trees species those planted in the postmining area to achieve revegetation process in forestry land. Lab simulation (Lab-ABC) have three reactor and each reactor those have been treated with EFB combine with typha grass, purun grass, longkida trees and bangkal trees as a simulation of SF system experiment in laboratory scale with the summary result mention of Table 3.

**Table 3.** Summary Result of Second Experiment

| Description | Result |
|---|---|
| pH at Inlet | Not Comply |
| pH at Outlet | Comply |
| Volume of Capacity (m$^3$) | 3.6 |
| Average of Water Flow in (m$^3$ hour$^{-1}$) | 1.2 |
| Average of Retention Time (hour) | 4.04 |

All threshold parameters have been recorded during experiment with surface flow system. There was some parameter are not compliance value when the AMD flowing at inlet to the first box with an average of surface flow water capacity to control average 1.2 $m^3$ $hour^{-1}$ by considering the size of the reactor is 1.2 $m^3$ each. Finally, the average of retention time was 4.04 hours until the quality of water at outlet is comply with the applicable regulation standard between pH 6 to 9.

### Result of Pilot Scale Experiment

Pilot-scale experiment (Pilot-ABC) is the project to implement all data those recorded during a lab simulation. Pilot project scale was lab simulation data x 750 with surface flow water capacity assumption 900 $m^3$ $hour^{-1}$ and was having 4.04 x k hours of retention time as shown in Figure 4.

There was having a construction of four compartment and flow in the AMD to inlet and continue entering the treatment pond until flow out at Outlet of SF system. We monitored the pH of this treatment by comparing the pH value at inlet and outlet shown in Figure 5. On Figure 5 can tell the confirmation that the SF system can treat the AMD with parameter of water are not comply at inlet to be comply at outlet of the system.

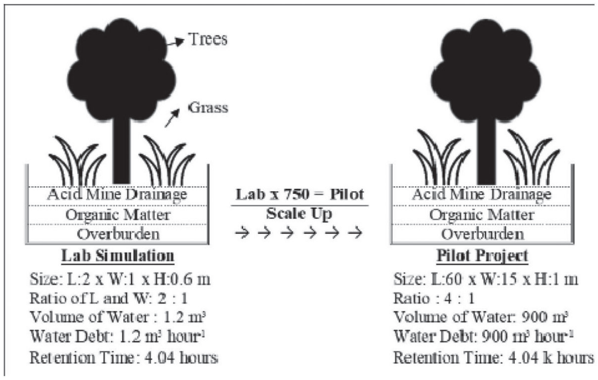

**Fig. 4.** Scale up from Lab Simulation to Pilot Project

## Discussion

### Individual Role of Media Selected

First stage experiment was one of the parts to find better planning. Better planning is a prediction with appropriate and accurate assumption considering the failure in AMD management leads to long-term impacts on ecosystems and human health, in addition to the financial consequences that were not small and damage to the company's reputation (Parbhakar-Fox and Lottermoser, 2015).

AMD has low concentrations of organic carbon and need addition of electron donor (molecular hydrogen or organic compounds) to enhance microbial activity. It may carry out oxidation reactions using inorganic carbon, while the reduction processes are stimulated by organic carbon as carbon source and electron donor (Hallberg and Johnson, 2005; Sánchez-Andrea *et al.*, 2014). The treatment process can be applied in situ or ex-situ. In situ technique involves the use of anaerobic constructed wetlands and compost bioreactors or sulfidogenic reactors. In situ technologies are durable, clean, and cheap and are considered the preferable option to

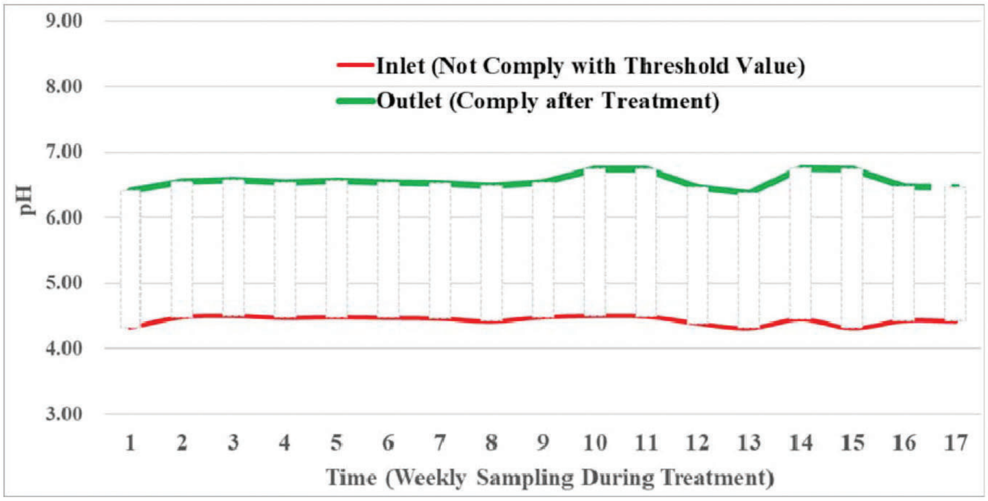

**Fig. 5.** pH Performance of Swampy Forest Pilot Project

ex-situ techniques (Sánchez-Andrea *et al.*, 2014). One primary objective from a biotechnological point of view is selecting a suitable organic substrate to have the process efficient and economically feasible. The raw organic materials assessed in earlier research cover a wide range of agricultural and food processing wastes (Cong Manh *et al.*, 2019). The EFB is a by-product of oil palm plantations which weight up to 23% of the weight of fresh oil palm bunches. EFB is a solid waste generated from the sterilizer and stripper processes. The compost produced in the form of EFB is a source of organic fertilizer and contains elements needed by the soil and plants as organic material. The addition of EFB compost can significantly increase soil pH from 5.26 to 6.22 where 25 grams of EFB compost is equivalent to five-ton ha$^{-1}$ which is also followed by an increase in leaf chlorophyll content (Hayat and Andayani, 2014). Process of sorption, coprecipitation, and exchange to precipitated Fe and Mn, organic materials, and soil-like materials are additional mechanisms for metal removal to reduce concentration in AMD (Jeff Skousen *et al.*, 2017).

Experiment 1B to select grass species that can adapt to the acid condition and high metal concentration of AMD. *Typha* grass is one of the grass species actively adapted with the high metal condition in soil (Dhir, 2013). Aquatic plants like *Typha* grass will add fresh organic material to the media and translocation of oxygen to the media through plant roots (Skousen *et al.*, 2019). *Typha* grass often forms dense colonies, survival in shallow water conditions or grow in wet, upright stem and flowering. The leaves are in two lines, mostly at the base, with a straight leaf (Irhamni *et al.*, 2018). Another experiment also reported on 15 species of grass selected from coal mining area that *Typha* grass and purun grass are the species that can survive and grow better on acid condition of pH around 2.8 and high concentration of Fe & Mn by showing their better biomass production and higher Fe removal efficiency of AMD in wetland treatment (Munawar *et al.*, 2011). The selection of grass criteria to overcome metal contamination must be based on tolerance to metals and the surface area of the metal's bioaccumulation potential (Karathanasis and Johnson, 2003). It was found that many wetlands were overgrown with *Typha* grass, purun grass and other species of grass growing by themselves. To enrichment of grass and trees species are also important for AMD remediation (Dhir, 2013; Hlihor *et al.*, 2017).

Experiment 1C of trees selection is the way to determine which trees species can adapt well to stagnant soils, low water pH and metal contamination as an effort to enrich and fulfil trees species in reclamation land focusing in returning process of forestry land. Most of the coal mining lands are loan use from forestry land and need to return to the government with compliance of the criteria of forestry revegetation. The mechanism of plants that can grow on the land are plants that are categorized also tolerant if they can grow without being disturbed growth. Longkida is one example of a tolerant species and combined with bangkal trees as a local species those can grow on postmining area (Tuheteru *et al.*, 2016). The role of plants in absorbing high heavy metals can be categorized as phytoremediation processes. Phytoremediation using plants will involve microbes and other processes to remove, extract or reduce the contaminants in nature (Kumar *et al.*, 2019; Wong, 2003).

Another research has been evaluated the reclamation project at JBG summarized that the area has better revegetation will have better water quality on surface flow identification (Noor *et al.*, 2019). The potential of longkida trees for phytoremediation in AMD wetlands shows that 90th day age of seedlings has high (100%) adaptation (Tuheteru *et al.*, 2017). To achieve sustainable vegetation on metal-contaminated postmining reclamation land, selecting the right type of plant is a must (Sucahyo *et al.*, 2018).

In constructed wetland, the *Typha* grass could absorb up to 40% of Fe and that the metal was largely accumulated in the roots of *Typha* plants (Zubair *et al.*, 2020). For purun grass also can absorb Fe and Mn effectively during the sapling phase with 15 cm planting distance (Prihatini *et al.*, 2016).

## Combination Role in Lab Simulation

Lab-scale experiment obtains the basic data for the next implementation stage on the field. All recorded data will be an important reference for the next construction of pilot scale. Especially on reclamation land which is an integrated process of water management and revegetation activities. Combination of grass and trees species selected will be able to increase soil fertility and a succession of environmental improvements. The use of hyperaccumulator plants is the most effective plant to overcome metal-contaminated soils from mild to moderate concentrations (Wong, 2003). To obtain potential results, plant growth is expected as much as possible to overcome contamination by facilitating bacterial growth for phytoremediation processes (Glick, 2003).

### Implementation to Pilot Project

Construction of SF system in pilot project scale is divided into three phases. The first phase is to construct the sediment trap to control and reduce the flow rate of incoming AMD water to settle the large particles or mud before entering the treatment process. The second phase is to construct the main compartment where the combination treatment process of organic matter, planted grass and trees species selected will occur. This will consist of four serially connected cell from the total pond. The last phase is the construction of the compliance point compartment with settling pond and exit channel to release the wastewater to public water bodies.

The AMD water flows in from void and enters to sediment trap to have sedimentation process then continues to inlet of the first cell of the main compartment. The pH value is monitored at the inlet flow from the first cell to the second cell, then on to the third cell and then entering the fourth cell, and finally flowing out at outlet of the fourth cell where the pH value is measured. Data in Figure 5 shows that the SF system successfully processes AMD naturally and in an environmental friendlier over the first week until 17 weeks of treatment operation successfully meeting compliance parameters.

## Conclusion

Swampy Forest system is a new concepts of passive treatment development of AMD as the integrated of water management and reclamation system with combination of organic matter selected with planting grass and trees species to improve water quality from not meet with compliance parameter (before treatment) to be meet with the threshold standard parameter (after treatment). SF system offer a successful solution to mining operations facing acidity of wastewater.

Whilst further experiments are recommended to understand the best way of using the selected organic matter, EFB, to absorb the heavy metal itself, we have shown that the swampy forest system to be a viable and natural alternative to reduce costs when compared to the conventional treatment of neutralizing AMD.

## Acknowledgements

This research is part of Swampy Forest Project lead by the author and thanks for:

1. PT Jorong Barutama Greston, Coal Mining Company in South Kalimantan, Indonesia for research area facility.
2. Banpu Public Company Limited (Banpu) for Silver Medal (USD 3,000 Award) on 6thBanpu Innovation Convention in Bangkok on 2 March 2018 for Presentation of Passive Treatment of Mine Water Through Swampy Forest Concept.
3. Banpu for Gold Medal (USD 5,000 Award) on 7thBanpu Innovation Convention in Bangkok on5 April 2019 for Presentation of Zero Quicklime by Swampy Forest, The Implementation Project.
4. The University of New Castle, Australia for Oral Presentation of Zero Quicklime by Swampy Forest in 9thAnnual Best Practice Ecological Rehabilitation of Mined Land Conference in Newcastle, Australia at 19-21 June 2019.
5. Dr. Ir. Irdika Mansur, M.For.Sc. from Bogor Agriculture Institute (IPB)/ Seameo Biotrop Indonesia for Project Advise.
6. Professor Tim Robert from the University of Newcastle, Australia for Paper Review Contribution.

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