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The Effectiveness of Constructed Wetlands in Managing Coal Mining Wastewater

Deden Disa Abdullah, Alifal Hamdan
PT Putra Perkasa Abadi, Indonesia
Email: deden.disa@ppa.co.id
Correspondence: deden.disa@ppa.co.id*

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ABSTRACT
Mining activities, especially coal mining, produce wastewater containing heavy metals such as manganese and iron, which can degrade water quality and harm ecosystems. Effective wastewater management is crucial to meet environmental quality standards and reduce ecological risks. This research aims to evaluate the effectiveness of constructed wetlands in treating coal mine wastewater by assessing critical water quality parameters such as pH, Suspended Solids (TSS), Total Iron (Fe), and Total Manganese (Mn). The research uses a descriptive method involving field sampling and laboratory analysis. Water samples were collected from settling pond BB-18 PPA-BA, both before and after the installation of constructed wetlands. The parameters tested include pH, TSS, Total Iron, and Total Manganese, following standard environmental testing protocols. The implementation of constructed wetlands significantly improved water quality. The measured values after treatment were pH 6.90, TSS 18.20 mg/L, Total Iron 0.31 mg/L, and Total Manganese 2.75 mg/L, all within permissible environmental quality standards. Constructed wetlands effectively reduce pollutants in coal mine wastewater, enabling compliance with environmental quality standards. This approach combines active and passive treatment methods, providing a sustainable and cost-effective wastewater management solution for coal mining operations.

Introduction

One of the problems in coal mining activities is the problem of coal mine wastewater, which has acidic pH levels; besides that, coal mine wastewater also contains heavy metals, namely manganese, and iron, which often contain suspended solid particles with high concentrations. Generally, the process of mining activities carried out using the *strip mine* method of the open pit mining system can cause sulfide minerals to be easily oxidized and dissolved by water, resulting in the formation of acid mine drainage (Kusdarini et al., 2024). Problems arising from acid mine drainage include degradation of water quality, damage to ecosystems and soil due to its toxic nature, obstacles to the growth of living things, and corrosion of objects exposed to the water (Kusdarini et al., 2020; Kusdarini & Budianto, 2022). The presence of heavy metal compounds in wastewater causes the water to smell bad and can cause irritation to the skin and eyes. If consumed regularly and in the long term, this can lead to serious health risks, even death (Soemirat, 2018). Coal mine wastewater not only impacts the mining area but can also impact water sources outside the mining area. Therefore, it must be handled carefully, and it must not be directly discharged into the river because it can have a detrimental impact on the ecosystem (Mamede & Sennahati, 2023). The obligation to conduct mine wastewater management is contained in the Minister of Energy and Mineral Resources Regulation No. 7/2014 on the Implementation of Reclamation and Post-mining in Mineral and Coal Mining Business Activities.

On the basis of these considerations, PT Putra Perkasa Abadi, which is one of the companies engaged in mining, has carried out coal mine wastewater management, one of the locations where mining wastewater management is located at the PT Bukit Asam Tbk *job site*. The coal mine wastewater management process at PT Putra Perkasa Abadi *job site* PT Bukit Asam Tbk (PPA-BA) initially used an active treatment approach; the principle was carried out by adding chemicals continuously into acid mine water (Amin & Kurniasih, 2019), such as by adding quicklime which is known to be effective in neutralizing acid mine water (Iizuka et al., 2022). However, the approach that has been taken through active treatment is considered less effective, and the quality of wastewater produced still does not meet environmental quality standards. Based on measurements that have been made of coal mine wastewater in the BB - 18 PPA-BA *settling pond* area, it is found that there is a test parameter, namely Total Manganese (Mn), which exceeds the maximum level of environmental quality standards, the measurement results of Total Manganese (Mn) levels are 3.70 mg/L. In contrast, the maximum allowable level is Total Manganese (Mn) levels of 3 mg/L. So, based on the results of these measurements, the coal mine wastewater management process carried out by PPA-BA combines an active approach with a passive approach. Management through passive treatment means that mine wastewater is regulated naturally through gravity, biological, and geochemical processes; no routine monitoring and maintenance is required, resulting in more affordable costs (Kusdarini et al., 2024). The passive approach is to use a *constructed wetland* installed in *settling pond* BB-18. *A constructed wetland* is a planned and controlled wastewater treatment system. *Constructed wetland* is designed and built using natural processes, such as using sandy soil and microorganisms to clean wastewater (Sasono & Asmara, 2013). In the view of Hammer (1989), a *constructed wetland* is a natural sewage treatment method consisting of areas that are waterlogged and support aquatic plant life of hydrophytes, have a growing substrate in the form of sandy soil always waterlogged, and water-saturated media. *Constructed wetland* works through the process of adsorption, filtration, sedimentation, microbial decomposition, and natural ion exchange (Ayu & Pangesti, 2021). Based on the effectiveness, efficiency, and benefits of *constructed wetlands*, PPA-BA uses this media as a tool to manage coal mine wastewater, see Figure 1.

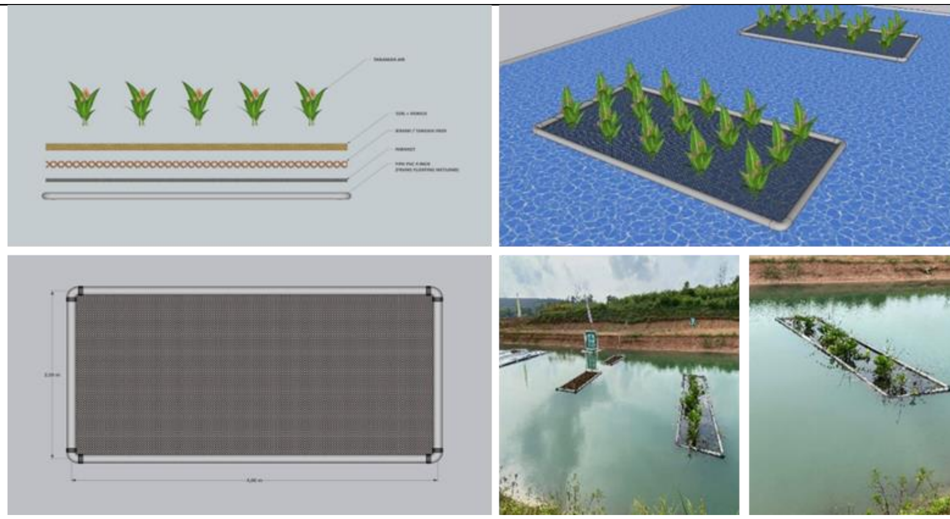

Figure 1. Design and Existing Conditions of Constructed Wetland in Settling Pond BB - 18

Based on the effectiveness, efficiency, and benefits of constructed wetlands, PT Putra Perkasa Abadi uses this method as a tool for managing coal mine wastewater. The constructed wetland system at settling pond BB-18 includes seven compartments, with the constructed wetland installed in compartment 7. Its dimensions are 15 x 70 meters, with eight units constructed using materials such as 4-inch PVC pipes, parent, straw, soil, humus, and aquatic plants. With this setup, it is expected that the treated wastewater will meet the environmental quality standards set by the South Sumatra Governor Regulation Number 8 of 2012 concerning Liquid Waste Quality Standards for Industrial, Hotel, Hospital, Domestic, and Coal Mining Activities.

This research aims to evaluate the effectiveness of constructed wetlands in improving the quality of coal mine wastewater. It will focus on compliance with environmental quality standards for critical parameters, including pH, Suspended Solids (TSS), Total Iron (Fe), and Total Manganese (Mn).

Research Methods

The method used in this research is descriptive, the method is a research approach that aims to produce a description, description, or painting systematically, factually, and accurately about the properties, facts, and relationships between the phenomena being investigated (Nasir, 1998). The population used in this study is water in *settling pond* BB - 18 PPA-BA with test parameters, namely pH (Insitu), Suspended Residue (TSS), Total Iron (Fe), and Total Manganese (Mn). The pH (Insitu) measurement method is based on SNI 6989.11-2019, the suspended residue (TSS) measurement method is based on SNI 6989.3-2019, while the Total Iron (Fe) and Total Manganese (Mn) measurement methods are based on APHA 2012. The fulfillment of wastewater quality standards is based on the Technical Approval for Fulfillment of Wastewater Quality Standards Discharged to Surface Water Bodies of PT Bukit Asam Tbk Tanjung Enim Mining Unit in 2023, while the parameters used are as follows, see Table 1.

Table 1. List of Test Parameters, Maximum Levels of Test Parameters, and Measurement Methods

No.	Test Parameters	Maximum Level	Unit	Measurement Method
1	pH (Insitu)	6 - 9	-	SNI 6989.11-2019
2	Suspended Residue (TSS)	100	mg/L	SNI 6989.3.2019
3	Iron (Fe) Total	4	mg/L	APHA 2012
4	Manganese (Mn) Total	3	mg/L	APHA 2012

Source: Technical Approval for Fulfillment of Quality Standards of Wastewater Discharged to Surface Water Bodies PT Bukit Asam Tbk Tanjung Enim Mining Unit in 2023; SNI 6989.11-2019; SNI 6989.3.2019; APHA (2012)

Results and Discussion

The method used for pH measurement (Insitu) is based on SNI 6989.11-2019, using the principle of potentiometric hydrogen ion activity using a pH meter. The equipment needed includes a pH meter, glass stirrer, 1,000 mL volumetric flask, 250 mL goblet, semport flask, and analytical balance with a readability of 0.1 mg. After the tools and materials are prepared, the next step is the testing step, which is the steps taken to calibrate the pH meter with at least 2 buffer solutions that match the desired measurement range each time. The next step is to take measurements in the right way. First, rinse the electrode using mineral-free water, then dry it with fine tissue paper. Second, immerse the electrode into the test sample until the pH meter shows a consistent reading. The third involves recording the results of the scale or numbers that appear on the pH meter screen. Fourth, the temperature should be recorded when measuring pH and inform the results. Fifth, the electrode should be rinsed using mineral-free water after completing the measurement. The measurement results show that the in situ pH value in settling pond BB - 18 PPA-BA is 6.90, which means it is in accordance with the standard.

The next measurement is Suspended Residue (TSS). The method applied to measure Suspended Residue (TSS) follows SNI 6989. 3-2019 by filtering a homogeneous test sample through a filter media that has been weighed first. The residue still attached to the filter media is dried at around 103°C until it reaches a constant weight. The increase in filter weight reflects the Total Suspended Solids (TSS). The necessary equipment includes a desiccator containing desiccant, an oven operating at a temperature range of 103°C to 105°C, an analytical balance with a precision of 0.1 mg, volumetric pipettes or measuring cups, media for weighing, a vacuum filter system, tweezers, and a vacuum system. The first step in the measurement process is to filter using filter equipment and moisturize the filter media with a little water without minerals. Second, stir the test until it is homogeneous, then take it quantitatively with the specified volume, pour it into the filter medium, and turn on the vacuum. Third, rinse the filter medium three times using 10 mL of mineral-free water, then continue the filtration process using the vacuum system until it is completely drained. Fourth, gently transfer the filter media (glass fiber cloth) from the filter device to the weighing container. The fifth step is to place the weighing medium or Gooch cup filled with the filter medium in the oven for at least one hour at a temperature between 103°C and 105°C, cool in a desiccator, and weigh. The sixth step is to repeat the fifth step until a constant weight is obtained (recorded as W_1). Seventh, calculate TSS using the formula (SNI 6989.3-2019):

$$TSS\ (\frac{mg}{l}) = \frac{(W_1 - W_0)\ x\ 1000}{V}$$

Description:

W_0 : weight of the weighing medium containing the initial filter medium (mg);

W_1 : weight of weighing media containing filter media and dry residue (mg);

V : test sample volume, (mL);

1000 : milliliter to liter conversion.

The measurement results show that the value of Suspended Residue (TSS) in the BB - 18 PPA-BA *settling pond* is 18.20 mg/L, which means it meets the standard. The next step is to measure Total Iron (Fe) in sediment samples, which refers to the APHA (2012) method. First, the samples were oven-dried at 105°C, after which they were pulverized and sieved. Second, 5g of the sample was weighed and transferred to an Erlenmeyer with a capacity of 250 mL, after which the sample was added with 5 mL of HNO3 and 50 mL of distilled water, then heated to a clear solution until it reached 10 mL. Third, the sample was filtered using Whatman No. 41 filter paper, and the screening results were diluted to 50 mL. Fourth, a 10 mL sample was used to measure Iron (Fe) metal levels using an Atomic Absorption Spectrophotometer at a resonance wave of 248.3 nm. The measurement results show that the total Iron (Fe) value in the BB - 18 PPA-BA *settling pond* is 0.31 mg/L, which means it meets the standard.

Finally, we measured the total manganese (Mn) in the sediment samples using the APHA (2012) method. First, the water to be tested is mixed evenly in a glass cup before being taken as much as 100 mL. Second, add 5 mL of Nitric Acid and heat the test solution in a flask using an electric heater until it is almost dry. Fourth, pour 50 mL of distilled water into the flask and stir gently with filter paper to drain into a 100 mL flask. Fifth, carefully put 10 mL of Manganese (Mn) metal parent solution, which has a concentration of 1000 mg/L, into a 100 mL flask, then dissolve it completely using a dilution solution until it reaches the predetermined mark. The measurement results show that the total Manganese (Mn) value in *settling pond* BB - 18 PPA-BA is 2.75 mg/L, which means it is in accordance with the standard.

Based on the measurement of 4 test parameters, it is known that all measurement results of the test parameters meet the standards in accordance with the Technical Approval for Fulfillment of Wastewater Quality Standards Discharged to Surface Water Bodies of PT Bukit Asam Tbk Tanjung Enim Mining Unit in 2023. These results are better than the measurements taken before the *constructed wetland* was used in *settling pond* BB—18 PPA-BA. The measurement results before and after the installation of the *constructed wetland* can be seen in Table 2.

Table 2. Test Parameter Results Before and After the Use of *Constructed Wetlands*

No.	Test Parameters	Before the Use of *Constructed Wetlands*	After the Use of *Constructed Wetlands*	Maximum Level	Unit	Measurement Method
1	pH (Insitu)	6,70	6,90	6 - 9	-	SNI 6989.11-2019
2	Suspended Residue (TSS)	10,80	18,20	100	mg/L	SNI 6989.3.2019

No.	Test Parameters	Before the Use of *Constructed Wetlands*	After the Use of *Constructed Wetlands*	Maximum Level	Unit	Measurement Method
3	Iron (Fe) Total	0.05	0,31	4	mg/L	APHA 2012
4	Manganese (Mn) Total	3,70	2,75	3	mg/L	APHA 2012

Source: Results of Analysis; Technical Approval for Fulfillment of Quality Standards for Wastewater Discharged to Surface Water Bodies PT Bukit Asam Tbk Tanjung Enim Mining Unit in 2023; SNI 6989.11-2019; SNI 6989.3.2019; APHA (2012)

In Table 2, it is known that the total manganese (Mn) value in the BB - 18 PPA-BA *settling pond* before the use of *constructed wetland* is 3.70 mg/L, which means it is below the maximum standard set, while after the use of constructed wetland, the total manganese (Mn) value in the BB - 18 PPA-BA settling pond is 2.75 mg/L, which means it is in accordance with the maximum standard set. These results show that the use of constructed wetlands can be effectively used in the management of coal mine wastewater; as stated by Vyamazal and Kröpfelová (2008), a constructed wetland is proven to effectively remove organic pollutants, suspended solids, and nutrients from wastewater.

The findings demonstrate that constructed wetlands play a vital role in improving the quality of coal mine wastewater by reducing the concentrations of heavy metals and improving pH stability. The system's effectiveness aligns with the principles of passive water treatment, which combines physical, chemical, and biological processes to filter and neutralize pollutants.

The decrease in Total Manganese levels can be attributed to adsorption, sedimentation, and microbial activity within the wetland. The slight increase in Total Iron levels may result from residual iron deposits from previous treatments, requiring further optimization.

The improvement in pH levels underscores the effectiveness of lime application and natural buffering in constructed wetlands. These results are consistent with the findings of Vyamazal and Kropfelova (2008), who highlighted the efficiency of constructed wetlands in treating wastewater containing heavy metals and organic pollutants.

Relevant theories and prior research substantiate the study's findings. Hammer (1989) described constructed wetlands as engineered systems designed to treat contaminated water using natural processes. Ayu and Pangesti (2021) emphasized that wetlands provide cost-effective and sustainable solutions for wastewater management. According to Kusdarini et al. (2024), combining active and passive treatment methods maximizes wastewater treatment efficiency. Studies by Iizuka et al. (2022) showed that chemical treatments alone could not maintain long-term water quality stability, reinforcing the need for an integrated approach.

Overall, the literature supports the current research, indicating that constructed wetlands effectively treat coal mine wastewater while reducing operational costs and environmental risks. Future studies should explore long-term monitoring and system optimization to enhance performance further.

Conclusion

The process of managing coal mine wastewater in *settling pond* BB - 18 PPA-BA, which previously only used an active approach, is now combined with a passive approach, namely through the use of *constructed wetland*. *Constructed wetland* can be effectively used to carry out coal mine wastewater management so that the test parameters can meet the environmental quality standards set by the Technical Approval for Fulfillment of Wastewater Quality Standards Discharged to Surface Water Bodies of PT Bukit Asam Tbk Tanjung Enim Mining Unit in 2023. The results of the test parameters before the use of *constructed wetland* in *settling pond* BB - 18 PPA-BA are pH (Insitu) 6.70, Suspended Residue (TSS) 10.80 mg/L, Iron (Fe) Total 0.05 mg/L, and Manganese (Mn) Total 3.70 mg/L. The results of the Manganese (Mn Total) measurement exceeded the predetermined maximum level of 3 mg/L. While the results of test parameters after the use of *constructed wetland* in *settling pond* BB - 18 PPA-BA are pH (Insitu) 6.90, Suspended Residue (TSS) 18.20 mg/L, Iron (Fe) Total 0.31 mg/L, and Manganese (Mn) Total 2.75 mg/L, which means that all test parameters have met the established environmental quality standards.

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