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Management of coal mining wastewater in the Tisihu coal field, West Papua, Indonesia

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Abstract
The wastewater generated from coal mining activities if not handled properly will become a major source of environmental pollution for either water resources or aquatic species and humans. Metal elements released by wastewater into the environment cause water pollution, thus adversely impacting biodiversity. The purpose of this study is to identify and describe the potential for liquid waste pollution from coal mining activities and methods for treating polluted water in coal mining in the Tisihu coal field. From this research, we can conclude that choosing the Active Treatment Technologies for wastewater method is the right method for coal mining sites in Tisihu. The built wastewater treatment plant (WWTP) comprises four compartments; wherein Compartment I the process of coagulation with fast stirring took place, in Compartment II there was a process of flocculation with slow stirring, the process of sedimentation took place in Compartment III, whereas the last process in Compartment IV was in the form of a neutralization process using lime. The effectiveness of Coal Mine Wastewater Treatment shows a very effective reduction in TSS, Fe, and Mn parameters above 80%.

Keywords: coal, waste water mining, active treatment, West Papua.

1. Introduction

The role of coal assumes great significance and determines the sustainability of the energy industry and the metallurgical industry around the world [1,2,3]. Various types and grades of coal have been utilized to support ongoing industrial activities; for example, for energy industry activities more use of thermal coal; different to support the steel processing metallurgical industry using coking coal. In addition to their positive impact on economic development, coal mining activities also inflict damage on the environment. One of the negative impacts that arise is the production of solid waste, as well as air and water pollution; which plays a major role in environmental pollution [4,5,6].

Coal mining activities consist of several stages: Mining activities commence from the stage of (1) clearing the land from trees and plants (land clearing), (2) stripping and managing topsoil (topsoil), (3) breaking or blowing up hard seams with explosives, (4) removing the material being blown up, opening the coal seams, and cleaning the top of the coal seams, (5) excavating overburden, (6) unloading coal, and loading and transporting coal to the stockpile, (7) coal processing [7, 8, 9]. Various stages of these activities can be a source of liquid waste. The wastewater source from mining activities comes from runoff water affected/leached in the mining area. Runoff water flowing from overburden, land clearing, topsoil removal, and sump pit will flow to the Settling Pond (S/P) for physical and chemical treatment before being distributed to the receiving water bodies (Muturi river and Wasian river).

Acid mine drainage (AMD) is a type of hazardous liquid waste that can result from coal mining operations. When not properly managed, AMD can degrade the quality of surface water in the surrounding area. The open pit mining method planned for use in West Papua's coal mining industry has the potential to create AMD in two locations: the mine pit, overburden disposal, and the stockpile location where coal processing occurs. In simple terms, AMD forms when sulfide minerals, exposed during excavation and stockpiling, come into contact with oxygen and water (such as rainwater) and leach, causing the water's acidity to increase. This acidity increase can also result in higher concentrations of dissolved metals in the affected water body. AMD is characterized by a low pH (1.5-4), high concentrations of dissolved metals (such as iron, aluminum, manganese, cadmium, copper, lead, zinc, arsenic, and mercury), high acidity values (50-1500 mg/L $CaCO_2$), high sulfate values (500-10,000 md/L), high salinity values (1-20 mS/cm) and low dissolved oxygen concentrations [10, 11, 12]. In addition to liquid waste generated by the main activities of coal mining, sources of liquid waste can also come from supporting activities such as bathrooms, laundry, and kitchens. This liquid waste is referred to as domestic liquid waste. The domestic liquid waste consists of gray water (bathroom, kitchen, and washing waste) and black water (waste from toilet/toilet).

The mine wastewater management system aims to avoid the impact of rock acid water not only on the quality of nearby surface water bodies but also on the quality of the soil. Surface water from various locations of coal mining and processing activities is channeled into a control system in the form of multilevel settling ponds to be processed and monitored before being released into water bodies. Treatment, treatment, and rehabilitation processes are applied routinely to settling ponds to increase the pH value of the water or routine pond maintenance. Water quality standards are taken by taking daily samples. These samples will later be analyzed to ensure that the water quality standards in settling ponds comply with the specified standards. If the existing water quality standards meet the set standards, then they will be channeled into public water bodies. Before the process of channeling the company's wastewater into public water bodies such as rivers or seas, it is ensured that the output of the wastewater produced meets the quality standards stipulated through the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.68/MenLHK/Setjen/Kum.1/8/2016 concerning Quality Standards of Domestic Activities Wastewater; and Regulation of the Minister of Environment of the Republic of Indonesia No 113 of 2003 concerning Wastewater Quality Standards for Coal Mining Businesses and or Activities.

This study aims to identify and describe the potential for liquid waste pollution from coal mining activities and methods for treating polluted water in coal mining in the Tisihu coalfield, West Papua

2. Materials and methods

2.1. Location

The research was conducted in the coal concession area in the following regions: Isim District, Dataran Beimes District, and Tahota Distrik, Province of West Papua, Indonesia. The coordinates are East Longitude (BT) coordinates 133^0 34' 00.69" in the west to 133^0 46' 60.00" in the east, and South Latitude (LS) 01^0 37' 30.00" in the North, and 01^0 43' 07.21" in the South).

Water quality test samples were taken at upstream and downstream locations of the receiving water bodies (Muturi River and Wasian River). Water sampling from the wastewater treatment plant (WWTP) was performed at the location of the inlet and outlet wastewater. Wastewater samples were taken at three WWTP locations (Table 1).

Table 1: Location of waste water sampling at WWTP.

Sampling Point	Coordinates	
	Longitude	Latitude
WWTP-1	117°53'65.258" E	2°16'20.556" S
WWTP-2	$117^0$55'10.326" E	2°17'04.274" S
WWTP-3	117°54'28.725" E	2°17'58.503" S

2.2. Materials and Laboratory Measurements

Six samples of water were taken from upstream and downstream of Muturi River and Wasian River; while six samples of wastewater from WWTP. The water quality analysis was carried out at the Laboratory of Productivity and Aquatic Environment (ProLing), Department of Aquatic Resources Management, Bogor Agricultural Institute. The parameters of mining, domestic and water waste water in receiving water bodies that are examined are: pH, Total Iron (Fe), Total Manganese (Mn); Cadmium (Cd), Copper (Cu), Zinc (Zn), TSS, COD, BOD.

3. Results & Discussion

3.1. Result of Laboratory Measurement

The results of the water quality analysis are tabulated in Table 2 (Result of wastewater quality from WPTP), and Table 3 (Result of water quality from Muturi River)

Table 2: Result of wastewater quality from WPTP.

No	Parameters	ESQ*	Inlet		
			WWTP-1	WWTP- 2	WWTP- 3
1	TSS (mg/L)	400	3,137.60	3,281.20	3,528.76
2	pH	7 - 9	5.90	5.80	6.05
3	Fe	7	0.84	0.45	0,75
4	Mn	4	0.056	0,058	0,046

*ESQ: **Environmental Quality Standard**, Government Regulation Number 113, 2003 Concerning Wastewater Quality Standards for Coal Mining Businesses and Activities

Table 3: Result of water quality from Muturi River and Wasian River.

No	Parameters	Muturi River			Wasian River		
		MR 1	MR 2	MR 3	WR 1	WR 2	WR 3
A	Physics						
1	TSS (mg/L)	37	11	16	23	< 8	16
2	TDS (mg/L)	90	144	96	50	98	122
3	Temperature (^{0})						
B	Chemical						
1	BOD (mg/L)	14	6	8	7.60	9.50	8.50
2	COD (mg/L)	67.94	30.75	39.06	36.8	4.29	40.74
3	Fe (mg/L)	0.105	0.249	0.281	0.086	0.156	0.082
4	Mn (mg/L)	0.022	0.032	0.021	0.062	0.028	0.030
5	Cd (mg/L)	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
6	Zn (mg/L)	0.036	0.028	0.020	0.018	0.020	0.016
7	Cu (mg/L)	<0.005	<0.005	<0.002	<0.011	<0.005	<0.005
8	pH	7.40	7.30	7.60	7.50	7.70	7.60
9	DO (mg/L)	7.85	7.40	6.20	6.91	8.21	6.80

3.2. Discussion

The two approaches in AMD treatment technologies are known as either passive or active, in which the two technological approaches combine physical, biological, and chemical aspects [13]. The two approaches aim to increase the pH and often lowers sulfate concentration and salinity; they also reduce the concentration of toxic metals. The use of active treatment requires the addition of solvents/reagents regularly and routine maintenance. Knowledge about the characteristics of mine waste water is required to determine the use of active or passive technology, which is why information about the potential of coal mining itself is necessary. The composition of AMD depends on the coal, local rock mineralogy, and availability of water and oxygen, and thus each mine has its unique potential to produce AMD.

The main source of the formation of AMD in coal mining concessions in the District of Isim, Dataran Beimes, and Tahota are coal in stockpiles, overburden rock piles, leach piles, mine adits, and pit walls, shafts, and floors [14]. Coal characteristics of the Steenkool formation in coal mining concessions in the Isim District and its surroundings have a low content of water, ash, sulfur, high volatile matter, and high calories, thus being classified into high volatile bituminous coal [15]. The potential for AMD formation remains although the total sulfur content is quite low (.1.0%). This is related to the formation of AMD that occurs when iron sulfide minerals react with oxygen (either from the air or dissolved in water) and the presence of water dissolving it [12,16]. The reaction of AMD is as follows:

$$FeS2 + 3½ O2 + H2O \Leftrightarrow Fe2+ + 2SO42- + 2H+ \quad (1)$$

$$Fe2+ + ¼ O2 + H+ \Leftrightarrow Fe3+ + ½ H2O \quad (2)$$

$$Fe3+ + 3H2O \Leftrightarrow Fe(OH)3 + 3H+ \quad (3)$$

As shown in reaction 1, when air and water come into contact with pyrite minerals, pyrite will decompose and dissolve in water in the form of ferrous iron (Fe2+) and sulfate (SO42-); 2 moles of acid (H+). Reaction 1 will continue as an oxidation reaction forming the elements ferric iron (Fe3+) and water; 1 mole of acid (H+) (reaction 2). Reaction 2 proceeds slowly, especially under acidic conditions (pH 2-3); however, this reaction can be accelerated by using certain Fe-oxidizing bacteria. On the other hand, reaction 3 exhibits that the process of forming ferric iron (Fe3+) in water will result in a hydrolysis reaction of iron to form the ferric hydroxide, Fe (OH)3 and 3 moles of acid (H+).

Based on research conducted by Helman et al [15], at Tisihu Coalfield, West Papua. Notably, most of the overburden and interburden rocks have the potential to become acid-forming rocks (Figure 1)

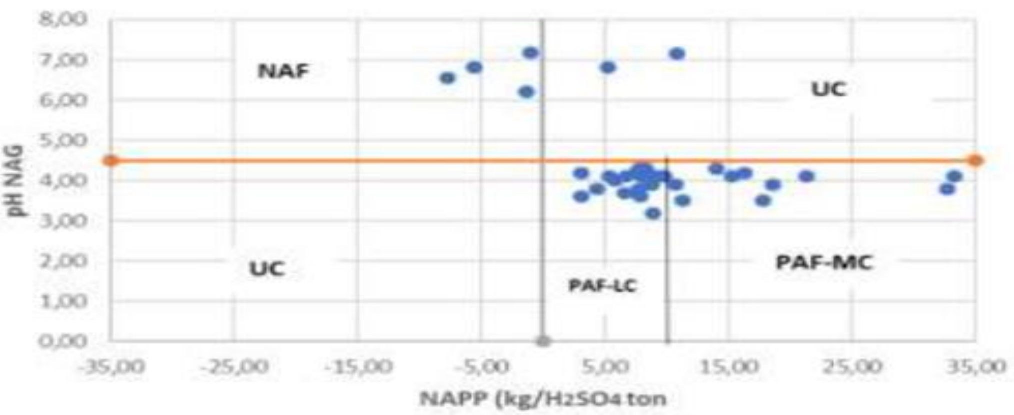

Fig. 1: Geochemical classification plot of overburden samples in Horna coalmines. (NAF: Non-Forming Acid; PAF -LC: Low-Capacity Potential Acid Former; PAF-MC: Moderately Capacity Potential Acid Former; UC: uncertainty) (Source: Helman et al., 2017).

Both of these have the potential to act as acid-forming rocks, the active treatment was chosen as a technological treatment for processing mining wastewater before being released to the wastewater receiving river to avoid polluting the environment. This was done after taking the characteristics of coal and overburden and interburden rocks into account. As seen in table 2, the pH and TSS parameters do not meet the environmental standards as stipulated in Government Regulation No. 103 of 2003, while the Fe and Mn do meet the environmental requirements. Referring to the water quality data of the Muturi and Wasian Rivers (Table 3). This indicates that both rivers will receive mining wastewater; based on the Republic of Indonesia Government Regulation No. 22 of 2021, concerning the Management of Water Quality and Control of Water Pollution. The water of the Muturi and Wasian rivers can be grouped into Class II-III, which can then be utilized for fish farming, agriculture, and plantations. A wastewater treatment plant (WWTP) plan was designed consisting of four compartments with approximate dimensions of 30 m in length, 30 m in width, and 3 m in depth based on average rainy-day data and calculation of rainfall intensity, characteristics of wastewater from coal mining (Figure 2).

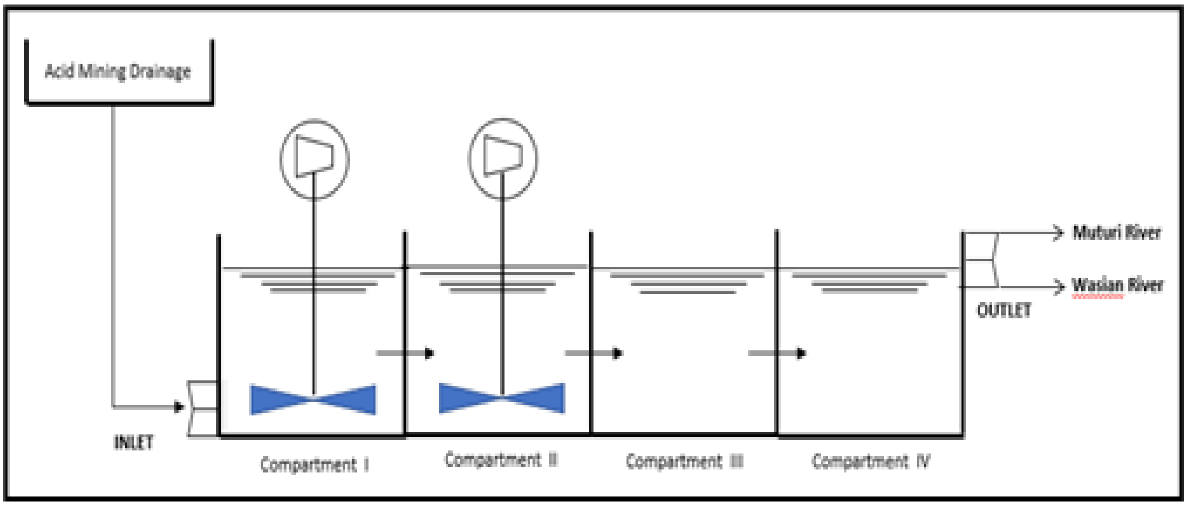

Fig. 2: Scheme of WWTP in coal mining (unscaled)

1. **Compartment 1 (Coagulation zone)**
   Compartment I is a coagulation zone (inlet zone). This zone serves as the entry point for water mixed with solids (in the form of mud) carried by water into the WWTP. A coagulation process occurs in this compartment. Mining wastewater entering the compartment I zone contains suspended particles. Particles suspended in water can be in the form of free and colloidal particles with very small sizes between 0.001 microns (10-6 mm) to 1 micron (10-3 mm). The particles found comprised inorganic particles (silt, clay, and asbestos fiber), coagulant precipitates, and organic particles (humate, viruses, bacteria, and plankton). These suspended particles are very difficult to settle naturally for a size of 0.001micron colloidal particles only settle after 200 years, differing from sand particles in only 10 seconds. This is attributed to the stability of colloid suspension; due to Van de Walls forces, electrostatic forces, and Brownian motion. A coagulant is added (in this case ferric hydroxide to accelerate the process of precipitation and chemical dispersion; Fe (Cl)3), and fast stirring. Owing to rapid stirring, stable colloids and particles become unstable by decomposing into particles with positive and negative charges; for example, the formation of bonds between positive ions from coagulants (e.g. (Fe3+) and negative ions from coagulants such as Cl-, which, in turn, causes the formation of floc nuclei (precipitate).
2. **Compartment II (Flocculation Zone)**
   The flocculation process occurs in Compartment II. As soon as the floc core is formed, it is followed by the flocculation process in compartment II. The flocculation process is the merging of floc cores into larger flocs – caused by collisions between flocs - which allows the particles to settle. The occurrence of the collision between flocs occurs is ascribed to slow stirring.
3. **Compartment III (Sedimentation Zone)**
   This zone is where solid material mixed with water will settle. The sludge slurry will be dredged when the sludge volume has reached 60% of the capacity of the sediment pond. This pertains to the decreased function of the sedimentation pond in case the sludge slurry is not dredged. Then, the dredged sludge will be taken to the waste dump area using a truck.
4. **Compartment IV (Neutralization Zone)**
   After the sedimentation process takes place in compartment III, the liquid waste is channeled to compartment IV for the neutralization process. It is necessary to add alkaline chemicals to increase the pH value so that it is at the specified quality standard, namely at a pH value of 6 - 9, because the pH of the waste solution before treatment is still low, Therefore, the addition of lime can be done for the neutralization process. Finally, the treated effluent disposal is channeled to the Wasian River and Muturi River with quality that meets the standards set by the government (Table 4)

Table 4: The quality of wastewater before and after treatment.

No	Parameters	ESQ*	Before Treatment			After Treatment		
			WWTP-1	WWTP- 2	WWTP- 3	WWTP-1	WWTP- 2	WWTP- 3
1	TSS (mg/L)	400	3,137.60	3,281.20	3,528.76	41.15	38.25	45.30
2	pH	7 - 9	5.90	5.80	6.05	6.75	7.01	7.15
3	Fe	7	0.84	0.45	0,75	0.05	0.04	0.05
4	Mn	4	0.056	0,058	0,046	0.005	0.008	0.002

*ESQ: **Environmental Quality Standard**, Government Regulation Number 113, 2003 Concerning Wastewater Quality Standards for Coal Mining Businesses and Activities

The effectiveness of Coal Mine Wastewater Treatment showed a decrease in the parameters of TSS by 98.7-98.8%, Fe by 91.1 – 94.3%.75%, and Mn by 86.2-95.1 % (Table 5)

Table 5: The effectiveness of Coal Mine Wastewater Treatment.

No	Location	TSS			Fe			Mn		
		In	Out	Eff (%)	In	Out	Eff (%)	In	Out	Eff (%)
1	**WWTP-1**	3,137.60	41.15	98.7	0.84	0.05	94.3	0.056	0.005	91.1
2	**WWTP- 2**	3,281.20	38.25	98.8	0.45	0.04	91.1	0.058	0.008	86.2
3	**WWTP- 3**	3,528.76	45.30	98.7	0,75	0.05	93.4	0.046	0.002	95.6

4. Conclusions

The process of managing wastewater from coal mining activities in Tisihu Coalfield, Isim District, West Papua Regency, Indonesia, occurs across four stages: coagulation with fast stirring, flocculation with slow stirring, and sedimentation. Meanwhile, it ends with a neutralization process using lime.

The wastewater treatment from coal mining activities shows results ensure compliance with the wastewater quality standards determined by Government Regulation Number 113, 2003 Concerning Wastewater Quality Standards for Coal Mining Businesses and Activities.

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