Analysis of Iron (Fe), Manganese (Mn), and pH of Coal Mine Acidic Water in Aceh Province

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Abstract. One of the coal mining corporations is in charge of environmental management, which includes managing water resources One of the coal mining corporations is in charge of environmental management, which includes managing water resources. The management of coal mine water that has the potential to become polluted water can be processed into fresh water in a sustainable manner. This indicates that acidic water from coal mines is still handled as waste that must be addressed once more. According Ministry of Health Regulation No. 416 1990 on Water Quality Requirements and Monitoring (Indonesian Government Regulation Ministry of Health related to water quality requirements and water quality monitoring), the purpose of this study is to evaluate the viability of coal mine acidic water quality in comparison to Fe (iron), Mn (manganese) ions, and pH parameters as fresh water. According to the findings of this study into acid mine drainage, the pH of the water in nine study areas in Pucok Reudeup Village, a former coal mining region, is low. The findings of this study on acid mine drainage demonstrate that the pH of the water at nine research sites in Pucok Reudeup a village near a disused coal mine. In nine research locations in Pucok Reudeup Village, a former coal mining area, the pH of the water did not exceed the established freshwater quality requirements (pH water below 6.5 - 9), according to the findings of this acid mine drainage study. Fe parameters that fulfilled the quality requirements were only present at five research sites. High iron concentrations result from Fe^{2+} or Fe^{3+} ions that cannot obtain oxygen from the environment as well as from the stripping of soil and rocks that are predominately composed of iron minerals, necessitating further management such as aeration. All study sites' Mn (manganese) parameters continue to fall short of the quality requirements outlined in No. Minister of Health Regulation 416 of 1990 Requirements on water quality No. Minister of Health Regulation 416 of 1990 Requirements on water quality and monitoring, that is, always exceeding the quality standard by 0.5 mg/L, except for stations 4, 5 and 6 There are 3 locations of Mn (manganese). In general, it can be concluded that the Fe and pH parameters of the study area still do not meet the freshwater quality standards. While

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Mn partially meets freshwater quality standards atstations (4, 5 and 6). Stations 1, 2, 3, 7, 9 are always higher than fresh water quality standards. The problem of acid mine drainage requires environmentally friendly water treatment.
Keywords: coal mine acidic water, Fe, Mn, pH, freshwater.

1 Introduction

Western Aceh is the only district of Aceh Province with significant coal reserves. According to data from Ministry of Energy and Mineral Resources (2012), West Aceh has potential coal resources reserves of 1.7 billion tons with known coal resources of 600 million tons and total coal reserves of 400 million ton [1].

As economic foreign exchange increases, the negative impacts of mining are also inevitable, especially the impact on the surrounding environment [2, 3]. Communities around PT Mifa Bersaudara's concession area have complained about pollution to the environment and river water that has recently become murky. Coal mining causes direct water pollution through coal washing waste, which separates coal from sulfur. Washing waste pollutes river water, making it cloudy and acidic, and coal washing sediment causes river siltation [4, 5].

Coal mining activities in the village of Sumber Batu, Meureubo sub-district, Western Aceh district affects the surface water of the river. Concentrations heavy metals iron (Fe), manganese (Mn) heavy metals iron (Fe), manganese (Mn) and cadmium (Cd) in the river body exceed the limits permitted by PP No. 82 2001. Fe 0.3 ppm, Mn 0.0440 ppm, Cd 0.1195 ppm. High concentrations of Fe, Mn, and Cd metals do not exclude the possibility of other metals [6, 7]

The measured pH value in the input sample is 4.5. Acidic pH values are caused by excessive rock removal, coal mining and waste that expose soil/rock containing sulfide minerals including pyrite and marcasite. In rainy and hot weather conditions, the concentration of Mn metal in river surface water around the coal mine does not exceed the threshold value of water quality standards. The results of the analysis of Fe metal content at the entrance to the West Asse coal basin reached 8.24 mg/L [1]. This shows that the Fe metal content exceeds the allowable limit of the quality standard for coal mine wastewater Pursuant to Decree-Regulation of the Minister of Environment and Forestry No. 5 in 2022 on wastewater treatment to mine companies and/or Operations.

The high Fe metal content in acidic coal mine wastewater is influenced by Fe metal which is a component of the scrap coal content. Acidic coal mine water is characterized by low pH and high content of several metal compounds such as iron (Fe), manganese (Mn), cadmium (Cd), sulfate and pyrite which are commonly found in coal mine water. found in mines [8, 9]. The high Mn content in the waste is caused by the Mn metal present in the composition of the coal itself with the Mn content value in coal being 46 mg/kg [10, 11], the Mn content measured at the outlet of 0.189 mg/L did not exceed the threshold value determined by the Decree of the Minister of Environment No. 113 in 2003 as 4 mg/l [2, 3].

One of the environmental management responsibilities for coal mining activities in West Aceh in particular and in Indonesia is the aspect of water management [4]. Water management that is not optimal in both quality and quantity will become a serious problem and have a negative impact on the environment. Water from mining operations sourced from groundwater, rainwater, runoff, water from disposal and other sources is water that has been mixed with many impurities that can cause the water to turn into wastewater or often called acid mine drainage. Coal mine water management does not pollute the receiving water of the settling pond. In addition, coal mine acidic water has the potential to be utilized as a sustainable future clean water source [12-14].

In its management and utilization, the condition of coal mine water that has undergone stripping generally has a high solubility of metals. So what happens is that acid mine water that has undergone a chemical reaction that will have a direct effect on the quality of soil and groundwater because the pH of the water and soil in the area drops very sharply [13]. The obstacles faced by coal mine water from stripping open pit mines are generally in water quality with pH, Fe and Mn which tend to increase [7].

From the results of the survey and analysis in the field that the water of the former coal mine pond tends to be acidic and Heavy metal ions such as Fe, Mn are very high, this has a hazardous impact on the surrounding environment [2, 3, 5, 15, 16].

The pH of the water will be affected by the hardness of the iron content in the water, if the pH of the water is low it will lead to a corrosion process that makes iron and other metals can dissolve in the water. Less than 6 metals can be dissolved. At low pH, iron in water is in the form of iron and iron in the form of iron will precipitate and do not dissolve in water, invisible to the naked eye causing water to be colored, foul-smelling and tasteless [9, 12]. From the general description above, there is something interesting to study about Acid water quality from coal mine when opening open pit mine. By determining the overall quality of the acid drainage in the mine, the water quality of the old mining pond can be used to raise fresh fish. Research on the use of acid mine water in clean water has also been carried out [17, 18, 14].

The results of the analysis of used coal mine pond water with known pH content, heavy metal ions in the future. This used acidic water can be processed and utilized as a source of future water reserves as clean water for the needs of the company or the needs of the community around the mine to pay attention to the standard clean water standard according to Regulation No. 416 1990 of the Minister of Health on Water Quality Monitoring and Requirements.

This ex-mining water, if not treated, will become environmental pollution. for this reason, it is necessary to analyse the pH and heavy metals (Fe and Mn) in mining water. This analysis will be used to determine the quality of ex-mining water to determine the concentration of heavy metals and pH of water as a reference in future water treatment as a mining water treatment solution to be used as a future water source.

2 Research methods

This research was conducted in the operational area of PT Mifa Bersaudara Indonesia coal mine in West Aceh Regency, Aceh Province. This research includes two activities, namely activities in the field and in the laboratory. The sampling location is in the open pit mine. Analysis of chemical parameters of coal mine water was carried out at the Integrated Laboratory of Diponegoro University.

This is study coal mine acid water sampling method used the instantaneous method (Grab sample). The instantaneous method describes the test samples taken at one point and at a time or the volume of test samples taken directly from the water body under study.

https://doi.org/10.1051/bioconf/20236902008

Water samples are then prepared according to the parameters to be tested. Materials used in this study both in the field and laboratory include: water samples, polyethylene plastic bottles, mineral-free water, concentrated nitric acid, standard solutions of iron and manganese metals, acetylene gas, HNO_3 diluent solution, HNO_3 washing solution, calcium solution, compressed air.

The equipment used in the field and laboratory includes: Atomic absorption spectrometer (SSA), YSI-556 MPS (meter for pH, temperature, salinity, electrical conductivity, total dissolved solids, oxidation-reduction potential (ORP), GPS, buffer pH, empty cathode lamp with iron and manganese, 100 mL and 250 mL beaker, 10 mL and 50 mL volumetric pipettes, 50 mL, 100 mL and 1000 mL volumetric flasks, 100 mL conical flask, glass funnel, face meter glass, resistor, thermal filter, vacuum, 0.45 µm filter, BASE analysis.

In this study, there were 9 samples consisting of 9 location points with varying distances of 100 m - 200 m For sampling locations there are three Void locations For sampling locations there are three void locations ; 4 ^{0} 12’23,86” N 96 ^{0} 15’2, 14”E, 4 ^{0} 12’42,25”N 96 ^{0} 14’56, 93”E 4 ^{0} 12’51,37”N 96 ^{0} 14’59, 77”E of the former coal mine water pool. The results of the analysis and the type of data are described in the table below

Table 1. Data Type Analysis

No	Parameter	Reference Method		Measurement	Nature of Data
1.	pH of acid mine drainage	SNI		Insitu	Primary
2.	Total dissolved Fe	SNI 6989.4:2009		Laboratory	Primary
3.	Total Dissolved Mn	SNI 6989.5:2009		Laboratory	Primary
4.	Temperature	SNI		Insitu	Supporting
5.	Salinity	SNI		Insitu	Supporting
6	Conductivity	SNI		Insitu	Supporting
7	Oxidation Reduction Potensial (ORP)	SNI		Insitu	Supporting
8	Total Dissolved Solid (TDS)	SNI		Insitu	Supporting
9	Total Suspended Solid (TSS)	SNI		Insitu	Supporting

Laboratory Analysis. Measurements of pH parameters were carried out in the field using a pH meter, while the methods of measuring Fe and Mn parameters were carried out in the laboratory. While the parameters of pH, TDS, ORP, salinity, conductivity of water are performed by YSI - MPS electrode tool. Descriptive analysis. The resulting data will then be tabulated in a chart with the Permenkes Clean water quality standard No. 416/MENKES/PER/IX/1990 . Statistical analysis was performed to determine the relationship between water quality parameters and water correlation analysis.

3 Results and discussion

In this study, in addition to primary data, namely pH, Fe and Mn, secondary data obtained were temperature, conductivity, total dissolved solid , salinity and oxidation reduction potensial.

Table 2 Secondary data analysis of acid mine drainage parameters

No	Location Sample				Physical/Chemical Properties of Samples			
	Area	Code Sample	Point Sample	Temp (ºC)	Conductivity	TDS	Salinity	ORP
1	South TB1	SP1	ST1	26,5	1	110	0,02	241
2	Sourh TB2	SP2	ST2	26,3	0,934	88,9	0,03	213
3	Sout TB3	SP3	ST3	26,6	0,092	57,6	0,02	216
4	Nort TB1	SP4	ST4	26,2	0,051	87,5	0,01	174
5	Nort TB2	SP5	ST5	27	0,043	40,1	0,11	173
6	Nort TB3	SP6	ST6	27,1	0.039	32,4	0,12	188
7	Central TB 1	SP7	ST7	26,1	0,035	82	0,22	190
8	Central TB2	SP8	ST8	28	0,049	43	0,04	178
9	Central TB3	SP9	ST9	25	0,029	59	0,01	210

3.1 Results of iron (Fe) parameter analysis

Measurement of acid coal mine water quality is carried out at the site of the former open pit mining basin mining pond which is still active in the open pit mine by PT MIFA Bersaudara. The location of measurements and observations in the open pit mine is divided into 3 areas, namely the South Open, Central Open and North Open areas. The location of acid mine drainage observations has a varying distance of 150 m - 250 m.

The table 3 and graph at figure 1 below show the iron content in coal mine acid water. The total dissolved Fe measurement results vary with a range of 1.4 - 8.24 mg/L.

Table 3. Observation Results of Total Dissolved Fe Parameters

No	Research Location		Dissolved Total Fe Measurement Results	Quality Standard Total Dissolved Fe 1 mg/L	Requirements of quality standards according to Permenkes No. 416/Menkes/Per/IX/1990 Re quirements of Quality standards according to Permenkes No. 416/Menkes/Per/IX/1990
	Sample Code	Sample Point			
1	SP1	ST1	8,24	1	have not met the requirements
2	SP2	ST2	4,7	1	have not met the requirements
3	SP3	ST3	3,03	1	have not met the requirements
4	SP4	ST4	5,3	1	have not met the requirements
5	SP5	ST5	2,76	1	have not met the requirements
6 7 8 9	SP6 SP7 SP8 SP9	ST6 ST7 ST8 ST9	2,1 2,0 1,8 1,4	1 1 1 1	have not met the requirements have not met the requirements have not met the requirements have not met the requirements

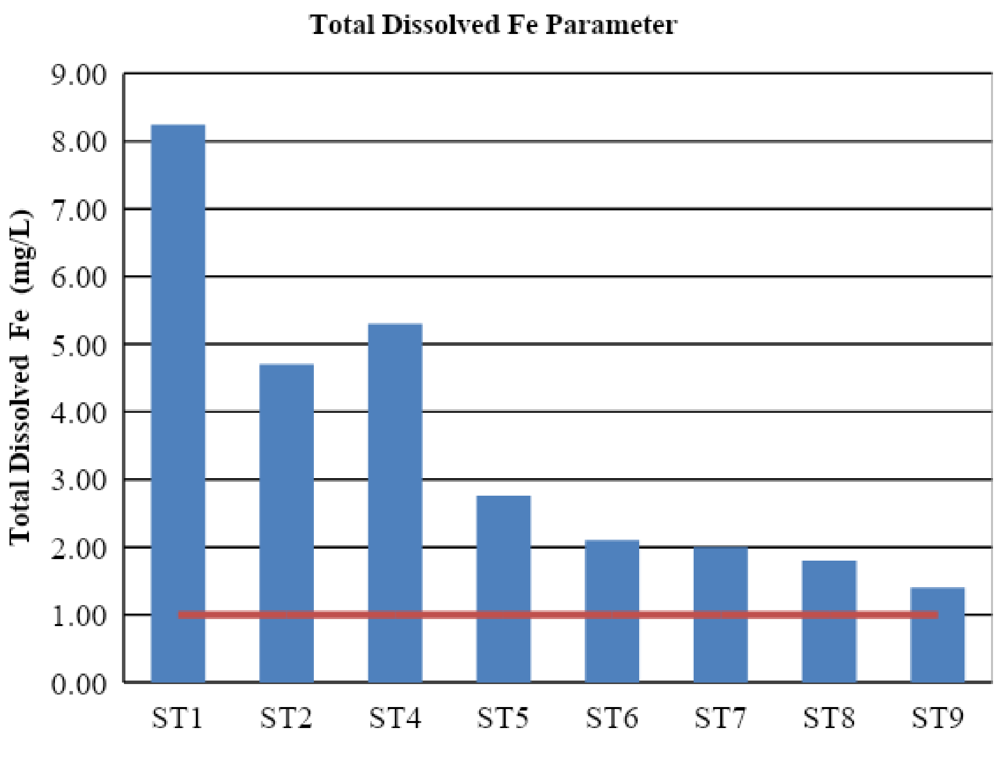

Fig 1 Results of Iron (Fe) Parameter Analysis of coal mine acid water

Measurement of the total dissolved Fe parameter was carried out at the Integrated Laboratory of Diponegoro University. The variation of results that do not meet the eligibility as clean water can be seen in the graph below. In the graph, the results of Fe metal analysis contained in the 9 (Nine) locations above do not meet the quality standards of Permenkes No. 416 of 1990 because they are still above 1 mg/L, namely ST1, ST2, ST3, ST4, ST5, ST6, ST7, ST8 and ST9 with a range of values from 1.40 mg/L - 8.24 mg/L. From the results of the Fe analysis at the former coal mine site, the Fe content is still high. From the results of Fe analysis at the former coal mine site, the Fe content is still high. This is in accordance with the research of Kiswanto, (2020) that coal mines have high Fe levels for new coal mining.

3.2 Manganese (Mn) parameter analysis results

The next analysis result besides water pH and Fe is total dissolved Mn. The measurement results on 9 samples show that the value of Mn has a range of 0.18 - 2.27 mg/L. observation of the value of Mn is also the same as Fe conducted at the Integrated Laboratory of Diponegoro University. In addition, the quality standard of mining water will refer to the criteria for clean water according to Permen Kes No. 416 of 1990. The results of the Manganese parameter analysis state that all locations or 9 samples have not met the Permenkes quality standard number 416 1990, that is below 0.5 mg/L.

Table 4. Observation Results of Total Dissolved Mn Parameters

No	Research Location		Dissolved Total Mn Measurement Results	Quality Standard Total Dissolved Mn 0.5 mg/L	Quality Standard Requirements According to Permenkes No. 416/Menkes/Per/IX/1990
	Sample Code	Sample Point			
1	SP1	ST1	1,1	0,5	have not met the requirements
2	SP2	ST2	1,01	0,5	have not met the requirements
3	SP3	ST3	2,27	0,5	have not met the requirements
4	SP4	ST4	0,18	0,5	meets the requirements
5	SP5	ST5	0,19	0,5	meets the requirements
6	SP6	ST6	0,22	0,5	meets the requirements
7	SP7	ST7	1,17	0,5	have not met the requirements
8	SP8	ST8	1,25	0,5	have not met the requirements
9	SP9	ST9	0,81	0,5	have not met the requirements

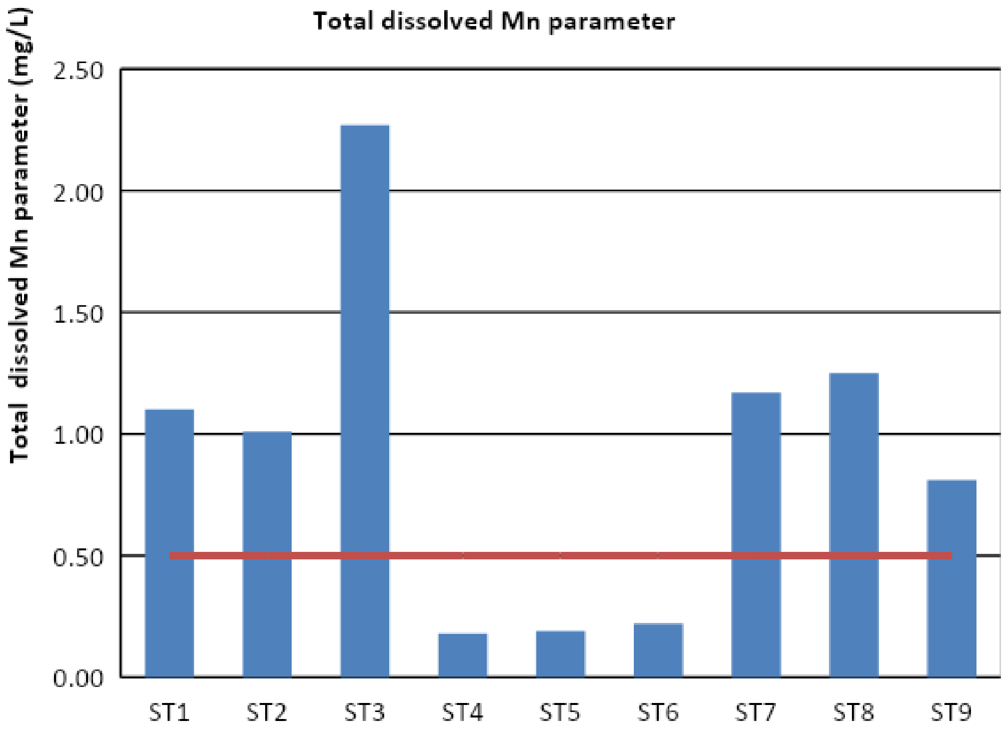

Fig 2. Results of manganese (Mn) parameter analysis of coal mine acid water

From the graph above, it can be seen that at all stations for Mn content is still high above the quality standard except for stations 4, 5 and 6. which are still below the quality standard. .Measurement of the total dissolved Mn parameter has a variety of results that do not meet the feasibility as clean water can be seen in the graph below. In the graph, the results of the Mn metal analysis contained in the 9 (Nine) locations above do not meet the quality standards of Permenkes No. 416 of 1990 because they are still above 1 mg /L, namely ST1, ST2, ST3, ST4, ST5, ST6, ST7, ST8 and ST9 with a range of values from 0.18 mg/L to 2.27 mg/L From the results of the Mn analysis at the former coal mine site which is still below the quality standards, it is found in ST4, ST5, and ST6. While for ST1, ST2, ST3, ST7, ST8, and ST9 are still above the quality standards.

3.3 Water pH parameter

The results of groundwater quality measurements for the pH parameter of water show that the pH of the water is not yet suitable according to the requirements of clean water quality from 9 research locations.

Table 5 Observation Result of pH Parameter of Coal mine acid water

No	Research Location		Measurement Results	Water pH Quality Standard		Quality Standard Requirements According to Permenkes No. 416/Menkes/Per/IX/1990
	Sample Code	Sample Point		min 6,5	max 9,0	
1	SP1	ST1	4,2	6.5	9	have not met the requirements
2	SP2	ST2	5.2	6,5	9	have not met the requirements
3	SP3	ST3	6,1	6,5	9	have not met the requirements
4	SP4	ST4	5,3	6,5	9	have not met the requirements
5	SP5	ST5	4,4	6,5	9	have not met the requirements
6	SP6	ST6	6,0	6,5	9	have not met the requirements
7	SP7	ST7	4,0	6,5	9	have not met the requirements
8	SP8	ST8	4,7	6,5	9	have not met the requirements
9	SP9	ST9	4,5	6,5	9	have not met the requirements

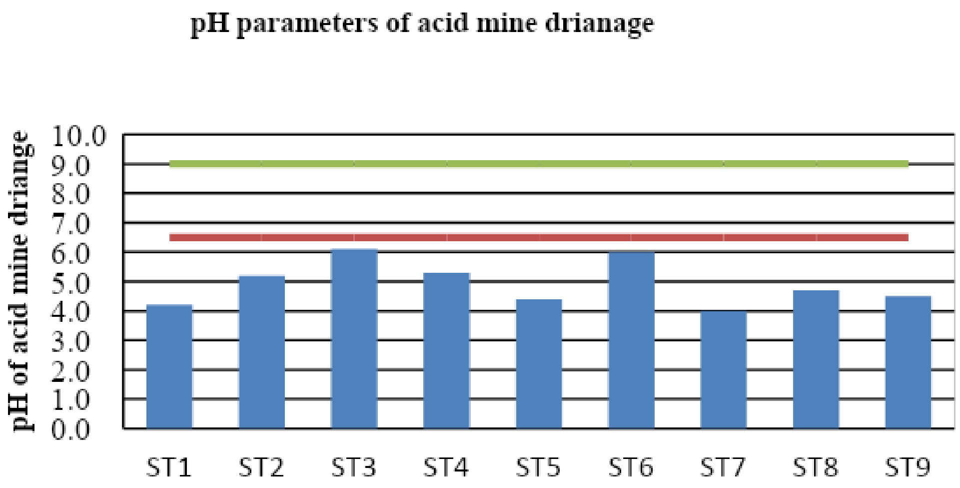

Fig 3. Results of pH Parameter Analysis of Acidic Coal Mine Water

From the graph above, the results of direct field measurements for the pH parameter of acid coal mine water state that all acid coal mine water sampling locations have a pH ranging from 4.2 - 6.1. Sampling locations in ST 6 and ST3, have a pH above 5 while ST1, ST2, ST 4, ST5, ST7, ST8, and ST9 have pH values below 5.0. In general, the pH value of water in the South Open area in the acid mine drainage void and in the North Open area in Acid mine drainage voids have a pH less than 5.

3.4 Fe content in coal acid mine water

Analytical results of iron metal in coal mine acid water with 3 positions (ST1, ST2, ST3, ST4, ST5, ST6, ST7, ST8 and ST9) that are still above the dissolved iron quality standard of 1 mg/L. This is because soil stripping activities and the groundwater hydrological cycle also indirectly contribute to the Fe fluctuations of acid mine drainage. If stripping is carried out continuously, the Fe content will naturally increase, as well as during the rainy season, the Fe content will increase[4, 6]. The Fe element of acid coal mine water in the other 9 locations (ST1,ST2,ST3,ST4,ST5,ST6,ST7,ST8 and ST9) has not met the feasibility because it has a value above 1 mg/L. This is due to the rock lithology, especially the large volume of coal that can contribute high iron elements to the rock. This study also states that there is no significant correlation between pH and Fe. This is because the laboratory analysis carried out is total dissolved Fe or 2+ valence while the iron content has changed to Fe3+ (ferric).

This change is due to iron that exists in the form of iron and iron, where iron will precipitate and be insoluble in water and be visible to the naked eye resulting in a yellowish color, odor and taste. Many conditions in the field are found to form yellow deposits derived from 3-valence iron or ferric.

3.5 Mn content in coal mine acidic water

The Mn parameter indicates that all locations meet the prescribed quality standard of 0.5 mg/L. Analyzes of manganese metal in acidic coal water at three sites that still fall below water quality standards are ST4, ST5, and ST6. On the other hand, ST1, ST2, ST3, ST7, ST8 and ST9 still exceed quality standards. The Mn parameter indicates that all locations meet the required quality standard of 0.5 mg/L. Analyzes of manganese metal in acidic coal water at three sites that still fall below water quality standards are ST4, ST5, and ST6. On the other hand, ST1, ST2, ST3, ST7, ST8 and ST9 still exceed quality standards.

This means that coal mine acid water needs to be treated. The small manganese (Mn) content is due to the lithology/rock constituent in the mine Low elemental content. The manganese content enters the water due to biological reactions under reducing or anaerobic conditions (without oxygen). When manganese-containing water comes into contact with air or oxygen, the manganese oxidation reaction takes place slowly, forming unexpected manganese oxide scales and colloidal lumps. In groundwater systems, manganese compounds change depending on the acidity (pH) of the water. Changes in natural manganese compounds due to divalent pH conditions are generally water soluble. Therefore, we will switch from a water treatment system that uses the oxidation of manganese compounds to compounds that are insoluble in water and are easy to physically separate, using a high-order oxidation method. Although Mn in the compound $MnCO_3$, $Mn(OH)_2$ has a valence of two, the substance is relatively difficult to dissolve in water but for compounds such as $MnCl_2$, $MnSO_4$ has a large solubility in water [3, 6].

3.6 Acidity level in acidic water from coal mines

The research results show that the pH value of the coal mine acid water sampling from 9 sites is still above the water quality standard and below the value of 6.1. This is caused by dissolved metals, especially iron ions in the form of Fe2 + or Fe3 + ions. The solubility comes from acid coal mine water that does not get oxygen from the atmosphere (air) but comes from microbial activities that break down organic matter. The decrease in pH also

 https://doi.org/10.1051/bioconf/20236902008

comes from lithology/rock constituents, one of which is rock dominated by iron minerals[19]. While in the water in the void of mine pool water, the pH value is stated to be below 6, but it has not met the quality standards because the water sourced from coal mine acid water has not been treated so that the pH water does not meet Permenkes standard number 416 of 1990.

The pH of acidic coal water is also affected by the redox potential where the correlation value r is -0.75 (strong negative relationship). This means that when water conditions lack oxygen/reduction increases, the pH of the water will decrease/acidic. This is caused by groundwater that does not contain much oxygen O2, then the solubility of iron will increase [19]

4 Conclusion

The element of iron (Fe) heavy metal content of acid coal mine water is not suitable as clean water at locations ST1,ST2,ST3,ST4,ST5,ST6,ST7,ST8 and ST9 has a content above 1 mg/L because of the typical lithology and volume of coal that is not suitable as clean water (> 1 mg/L) this is because the area is dominated by lithology / coal which has a high iron mineral source.

Manganese (Mn) parameters at the research site that still meet the Permenkes Quality Standard No. 416 1990 which is still below 0.5 mg/L, are found at stations ST4, ST5, and ST6. Meanwhile, the Manganese (Mn) parameter contained in acid coal mine water at stations ST1, ST2, ST3, ST7, ST8 and ST9 is still above the quality standard. The reduction in manganese concentration is caused by mineral rocks that are low in the element manganese.

The pH of acidic coal mine water for 3 locations with 9 stations still Not yet meet Clean Water Permenkes quality standards Not yet meet Permenkes clean water quality standard No. 416 1990 so that it cannot be categorized as clean water. The low/acidic degree of pH acidity is caused by the contribution of Fe elements and the potential of minerals that form coal mine acid water. So that further research is needed on the quality parameters of coal mine acidic water related to minerals in open rock layers.

Reference

[1] Kiswanto and W., "Pengolahan Air Kolam Tambang Batubara Menggunakan Membran Untuk Budidaya Perikanan," Jurnal Teknik Lingkungan (JTL), vol. 29, no. 3, pp. 1–13, 2023.

[2] H. Susanto, Sudarno, and Kiswanto, "Characterization Of Coal Acid Water In Void Pools Of Coal Mining In South Kalimantan," E3s Web Of Conferences, vol. 73, pp. 305030, 2018. DOI: 10.1051/e3sconf/20187305030.

[3] H. Susanto, Sudarno, and Kiswanto, "Karakteristik Air Asam Batubara Di Kolam Bekas Tambang Batubara Pt. Bukit Asam (PTBA)," Seminar Dan Konferensi Nasional Idec, pp. 7–8, Surakarta, 2018.

[4] H. Susanto, Sudarno, Wintah, and Kiswanto, "NF270 Membrane Technology: New-Product From Acid Mine Drainage," Journal Of Green Engineering, vol. 11, no. 1, pp. 807–823, 2021.

[5] Y. Yildirim, A. K. Topaloğlu, M. Ince, and M. N. Kajama, "The use of NF and RO membrane system for reclamation and recycling of wastewaters generated from a hard coal mining," Nigerian Journal of Technology, vol. 38, no. 4, pp. 1048-1055, 2019.

[6] H. Susanto, Sudarno, and Kiswanto, "Treatment Of Coal Mine Acid Water Using Nf270 Membrane As Environmentally Friendly Technology," Jurnal Pendidikan IPA Indonesia, vol. 9, no. 3, pp. 439–450, 2020. DOI: 10.15294/jpii.v9i3.23310.

[7] Kiswanto, Wintah, and N. L. Rahayu, "Analisis Logam Berat (Mn, Fe, Cd), Sianida Dan Nitrit Pada Air Asam Tambang Batu Bara," Jurnal Litbang Kota Pekalongan, vol. 18, pp. 20–26, 2020.

[8] E. Nurisman, "Studi Terhadap Dosis Penggunaan Kapur Tohor (CaO) Pada Proses Pengolahan Air Asam Tambang Pada Kolam Pengendap Lumpur Tambang Air Laya Pt. Bukit Asam (Persero), Tbk," 2012.

[9] S. Nasir, M. Purba, and O. S., "Pengolahan Air Asam Tambang Dengan Menggunakan Membran Keramik Berbahan Tanah Liat, Tepung Jagung Dan Serbuk Besi," Jurnal Teknik Kimia, no. 3, vol. 20, Agustus 2014.

[10] Kiswanto, Wintah, S. Sriwahyuni, and Nurdin, "Post-Mining Pond Water Suitability For Fisheries Culture In West Aceh, Indonesia," AACL Bioflux, vol. 15, no. 1, pp. 436–445, 2022.

[11] A. Kuriata-Potasznik, S. Szymczyk, A. Skwierawski, K. Glińska-Lewczuk, and I. Cymes, "Heavy Metal Contamination In The Surface Layer Of Bottom Sediments In A Flow-Through Lake: A Case Study Of Lake Symsar In Northern Poland," Water (Switzerland), vol. 8, no. 8, 2016. [Online]. Available: https://doi.org/10.3390/w8080358

[12] N. I. Said and S. Yudo, "Status Kualitas Air Di Kolam Bekas Tambang Batubara Di Tambang Satui, Kabupaten Tanah Laut, Kalimantan Selatan," Jurnal Teknologi Lingkungan, vol. 22, no. 1, pp. 48–57, 2021. [Online]. Available: https://doi.org/10.29122/jtl.v22i1.3900

[13] Ashari, D. Budianta, and D. S. "Efektivitas Elektroda Pada Proses Elektrokoagulasi Untuk Pengolahan Air Asam Tambang," vol. 17, pp. 45–50, 2015.

[14] A. Meyzilia, "Pemanfaatan Air Kolong Bekas Tambang Timah Sebagai Penambah Sumber Air Tanah Menggunakan Lubang Kompos Di Bangka Belitung," Jurnal Pendidikan Ilmu Sosial, vol. 27, no. 1, pp. 22–30, 2018.

[15] H. Kyllönen, E. Järvelä, J. Heikkinen, M. Urpanen, and A. Grönroos, "Emergent Membrane Technologies For Mine Water Purification," pp. 36–42, 2017.

[16] M. Sivakumar and M. Ramezanianpour, "Mine Water Treatment Using A Vacuum Membrane Distillation System," ICESD, Dubai UAE 5, pp. 157–162, 2013. [Online]. Available: https://doi.org/10.1016/J.Apcbee.2013.05.028

[17] E. Y. Suroso, M. Said, and S. J. Priatna, "River Water Pollution Control Strategy Due To Coal Mining Activities (Case Study In Kungkilan River West Merapi District, Lahat)," Sriwijaya Journal Of Environment, vol. 2, no. 2, pp. 50–57, 2017. [Online]. Available: https://doi.org/10.22135/sje.2017.2.2.-50-57

[18] A. Meyzilia and D. "Pemanfaatan Kolong Bekas Galian Tambang Timah," Jurnal Pendidikan Geografi, vol. 17, no. 2, pp. 153–158, 2017.

[19] S. Asmadi, Khayan, S. Kasjono, and Heru, Teknologi Pengolahan Air Minum. Penerbit Gosyen Publishing. Yogjakarta, 2011.

[20] S. Asmawi and Suhaili, Kualitas Air Untuk Perikanan - Bahan Kuliah Pengelolaan Perairan. Fakultas Perikanan Universitas Lambung Mangkurat, Banjarbaru. 40 halaman, 1994.