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Optimizing Acid Mine Drainage Treatment Using Fly Ash and Bottom Ash

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ABSTRACT

Acid mine drainage (AMD), characterized by high acidity and elevated concentrations of heavy metals, poses a significant threat to aquatic ecosystems. This study aims (1) to analyze and optimize the effects of fly ash (FA) and bottom ash (BA) on the reduction of pH, Fe, Mn, and total suspended solids (TSS) through adsorption processes, and (2) to evaluate the impact of varying adsorbent mass ratios in determining optimal treatment efficiency. Adsorption experiments were conducted using 10, 20, and 30 g of FA, BA, and their combinations, with surface morphology characterized via scanning electron microscopy (SEM). The results demonstrated that 30 g of BA achieved the highest removal efficiency, increasing pH from 2.8 to 7.5, reducing Fe from 12.2 mg/L to 1.6 mg/L, Mn from 7.9 mg/L to 0.9 mg/L, and TSS from 40 mg/L to 5 mg/L. SEM analysis revealed that BA possesses a higher pore density and carbon content than FA, offering a greater number of active sites for adsorption. The t-test indicated that the individual and combined effects of FA (X1), BA (X2), and their mixture (X3) significantly influenced treatment performance. An adjusted R^2 value of 83.9% confirmed a strong correlation between adsorbent variables and improvements in AMD quality.

Keywords: adsorption, acid mine drainage, BA, FA

INTRODUCTION

Human activities generate both solid and liquid waste; while minimal quantities may be manageable, large-scale waste can disrupt ecosystem balance (Oktaviansyah & Rully Masriatini, 2024). Coal, though cost-effective as an energy source, poses environmental risks near mining sites and coal-fired power plants (M. Arifin et al., 2021). Coal combustion in steam power plants produces gaseous and solid by-products, collectively known as coal ash, which consists of fly ash (FA) and bottom ash (BA)—a mixture of metal oxides. FA and BA have been applied as coagulants in produced water treatment (Redy, 2022). Their properties vary depending on coal type, combustion conditions, and handling methods (Naellis et al., 2023). BA typically contains Si, Al, Fe, Ca, Mg, S, and Na (Kinasti et al., 2018). Although economically viable, coal mining and combustion generate environmental waste, notably coal ash and mine wastewater, which require effective management.

Mine wastewater primarily consists of sludge and acid mine drainage (AMD), which is typically acidic and contains dissolved metals such as iron (Fe) and manganese (Mn). If discharged untreated, it can significantly pollute nearby water bodies. AMD is a major environmental concern associated with mining activities due to its potential to degrade water quality. It is commonly generated when sulfide-containing waste rocks are exposed to air and water during excavation, transport, or storage processes (Siregar et al., 2021).

Oxidation of sulfide minerals, especially pyrite (FeS_2), during mining exposes water and oxygen, producing acid mine drainage (AMD) (Perala et al., 2022). This process increases acidity and mobilizes metals, posing environmental risks if untreated. Proper AMD management is essential to prevent contamination (Amsya et al., 2021).

Acid mine drainage (AMD) is one of the most significant environmental impacts of coal mining, particularly due to its long-term effects if poorly managed during post-mining stages (Meriestica et al., 2021). AMD formation is primarily influenced by the presence of water, oxygen, and sulfide-bearing minerals. Open-pit mining increases AMD potential due to direct exposure to air (Kiswanto et al., 2018). Additional factors such as sulfide mineral concentration, mineralogy, particle size, rainfall, temperature, neutralizing agents, microbial activity, and oxygen transport mechanisms (advection and diffusion) also play critical roles in AMD generation (Nugraha et al., 2021). AMD negatively affects the environment by contaminating soil and water, inhibiting plant growth, killing aquatic life, accelerating equipment corrosion, and reducing mine productivity (Yudiantoro et al., 2018).

According to Yao et al. (2015), fly ash and bottom ash (FABA) are widely utilized across various countries for multiple applications. Several studies have indicated that FABA possesses alkaline chemical properties, making it a potential neutralizing agent for acid mine drainage (AMD) (Damayanti et al., 2015; Said et al., 2019), including in former mining pits. Additionally, the physical properties of FABA allow it to be used as a cover material for acid-generating rock piles, thereby limiting AMD formation by reducing exposure to air and water (Syaefudin et al., 2020).

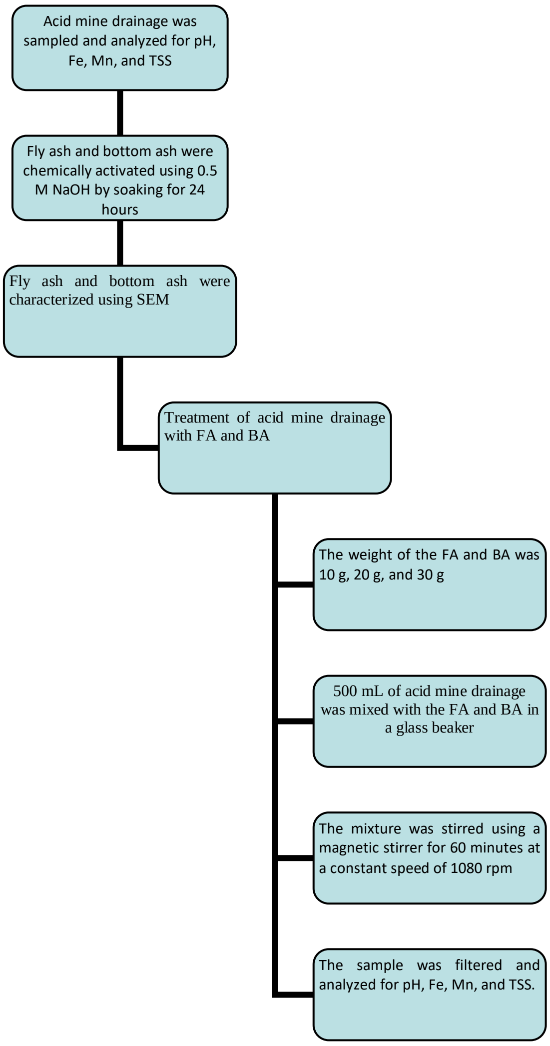
Adsorption is a surface phenomenon in which molecules from a fluid phase adhere to the surface of a solid material known as an adsorbent (Martini et al., 2020). This process is widely used for pollutant removal due to its simplicity, cost-effectiveness, and efficiency (Gobel et al., 2018). Adsorption mechanisms are generally classified into two types: physical adsorption (physisorption), driven by Van der Waals forces, and chemical adsorption (chemisorption), which involves the formation of chemical bonds between the adsorbate and the adsorbent surface (Botahala, 2022). Physisorption occurs at lower temperatures without activation energy and typically forms multilayers, whereas chemisorption involves higher temperatures, requires activation energy, and results in monolayer adsorption. Adsorption plays a key role in wastewater treatment by attracting contaminants to the outer and inner surfaces of the adsorbent (Oktaviansyah, 2024)

Adsorption is a widely used method for treating acid mine drainage (AMD) due to its effectiveness, simplicity, and low operational cost (Patel et al., 2022). It involves the adhesion of molecules, ions, or particles from a fluid phase onto the surface of a solid adsorbent. Adsorbents may include solids such as activated carbon, liquids like liquid zeolites, or gases interacting with solid surfaces. Among various wastewater treatment techniques, adsorption is considered one of the most efficient for the removal of heavy metal contaminants.

Given the aforementioned issues, researchers are focusing on how fly ash and bottom ash affect pH, Fe, Mn, and TSS changes in acid mine drainage treatment. Additionally, because these adsorbent raw materials are inexpensive and reusable, they are a good choice for study.

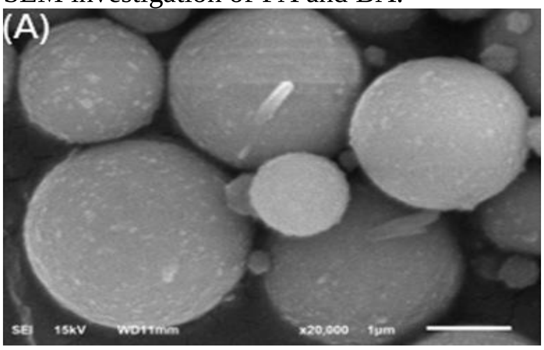
METHODOLOGY

Research Procedures



RESULT AND DISCUSSION

Figure 1 shows the results of the SEM investigation of FA and BA.



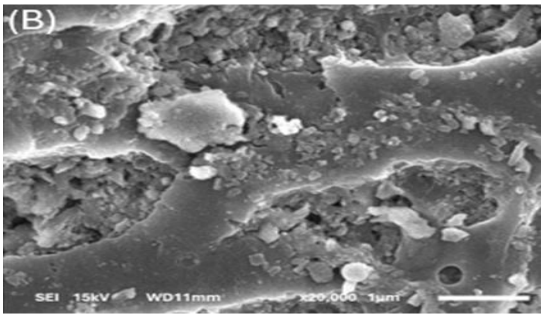


Figure 1. Surface morphology of fly ash (A) and botoom ash (B)

Table 1 presents the results of acid mine drainage treatment using varying masses of FA and BA as adsorbents.

Table 1. Experiment Result

Parameters	AMD	Acid Mine Drainage After Adsorption								
		Fly Ash (grams)			Bottom Ash (grams)			Fly Ash Mix Bottom Ash 50%:50% (grams)		
		10	20	30	10	20	30	10	20	30
pH	2.8	6.5	6.7	6.9	6.8	6.9	7.5	6.3	6.4	6.7
Fe	12.2	3.3	2.6	2.5	2.4	2.2	1.6	3.2	2.5	2.3
Mn	7.9	7.6	7.4	7.1	2.4	2.1	0.9	7.5	7.2	6.3
TSS	40	35	30	25	32	15	5	28	30	22

Surface Characterization (SEM)

The SEM results in Figure 1 (FA) and Figure 2 (BA) indicate that BA has a greater number of surface voids compared to FA. The formation of pores and voids on the adsorbent surface is influenced by the thermal activation process. These characteristics suggest that both FA and BA have strong potential for use as effective adsorbents.

Effect of Adsorbent on PH, Fe, Mn, TSS

FA and BA were tested for their effectiveness in reducing pH and TSS levels to determine the optimal adsorbent mass for each parameter. The adsorption process occurs as acid mine drainage molecules are attracted to the surface of FA and BA due to intermolecular forces. Van der Waals interactions, arising from slight charge differences, cause contaminants to adhere to the adsorbent surfaces. Additionally, the negatively charged carboxyl groups in acid mine drainage are electrostatically attracted to the positively charged surfaces of FA and BA, forming a thin layer of particles on the adsorbent surface.

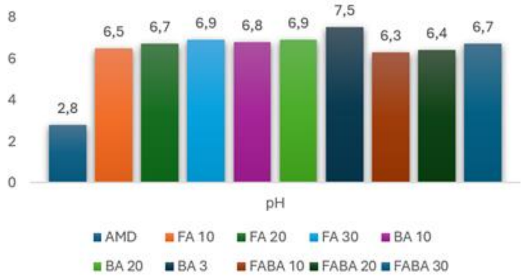


Figure 2. Effect of adsorbent on pH

The initial pH of acid mine drainage was 2.8 (Figure 2). Treatment with 30 g of FA increased the pH to 6.9, while 30 g of BA raised it to 7.5. A combined treatment using 30 g of FA and BA resulted in a pH of 6.7. These results align with previous studies by Grogerius and Rusli (2021) and Hisni et al. (2023), which showed that 1 g of FABA could raise the pH of 200 mL of acid mine drainage from 3.7 to 7.3.

Figure 3. Effect of adsorbent on Fe.

Figure 3 shows that the initial Fe concentration in acid mine drainage was 12.2 mg/L. Treatment using 30 g of fly ash (FA) reduced the Fe level to 2.5 mg/L, while bottom ash (BA) at the same mass decreased it further to 1.6 mg/L. A combination of 30 g FA and BA resulted in an Fe concentration of 2.3 mg/L. This result aligns with the study by Dona (2021), which reported a 97.20% reduction in Fe concentration during leachate treatment using coal fly ash at the Blang Bintang landfill, indicating strong removal efficiency.

Figure 4. Effect of adsorbent on Mn.

The FA adsorbent at 30 g reduced Mn concentration from 7.9 mg/L to 7.1 mg/L. The BA adsorbent at the same mass showed greater effectiveness, reducing Mn levels to 0.9 mg/L. The combination of FA and BA at 30 g decreased Mn concentration to 6.3 mg/L. These results are supported by findings from Muhammad (2022), who reported that boiler ash at a dose of 1.5 g/L reduced Mn levels in acid mine drainage from 0.560 mg/L to 0.04 mg/L after 10 days of treatment.

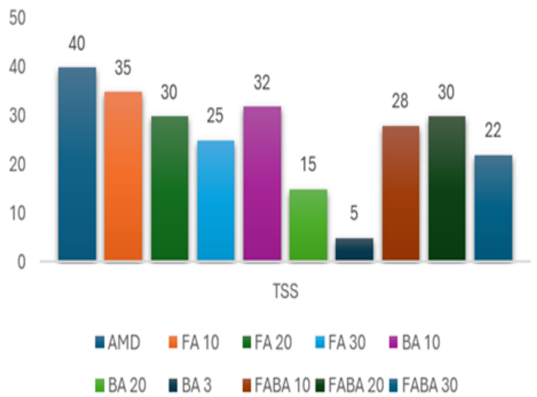


Figure 5. Effect of adsorbent on TSS.

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Test results showed that the most effective adsorbent was bottom ash (BA) at 30 g, which reduced TSS from 40 mg/L to 5 mg/L. This finding is consistent with research by Arnesya and Siti (2023), which demonstrated that fly ash and bottom ash could reduce TSS levels, with FA achieving a 69.1% reduction in batik wastewater and BA achieving a 20.4% decrease (Arnesya & Siti, 2023).

Normality Test

The Kolmogorov–Smirnov test compares the cumulative distribution of empirical data to a theoretical normal distribution. A non-significant p-value ($p > 0.05$) indicates no significant difference between the distributions (Wahyu, 2012).

The purpose of this test is to determine whether the residuals follow a normal distribution. Normally distributed residuals indicate that the regression model performs adequately.

One approach to assess this is by examining the data distribution along the diagonal line in the Normal P–P Plot of regression standardized residuals, which serves as a basis for evaluating model assumptions.

Regression models that spread out along the line and trace the diagonal line are considered regular and appropriate for predicting the independent variable (I. Ghozali, 2013).

Alternatively, the One Sample Kolmogorov Smirnov test method can be used to check for normalcy. The following are the test criteria (S. Santoso, 2013):

- The data is considered regularly distributed if the significance value (Asym Sig 2 tailed) is greater than 0.05.
- The data is not normally distributed if the Asym Sig 2 tailed significance value is less than 0.05.

Prior to doing statistical tests, the normality test must be performed. The objective is to ascertain the normality of the residual data that was utilized in the investigation.

Regression models are good and appropriate for statistical testing if the data is regularly distributed.

The Kolmogorov-Smirnov test was used in this study to perform the normality test. Table 2 below displays these results:

Table 2. Normality Test

One-Sample Kolmogorov-Smirnov Test

		Unstandardized Residual
N		12
Normal Parameters^{a,b}	Mean	.0000000
	Std. Deviation	7.00510751
Most Extreme Differences	Absolute	.164
	Positive	.164
	Negative	-.154
Test Statistic		.164
Asymp. Sig. (2-tailed)		.200^{c,d}

a. Test distribution is Normal.
b. Calculated from data.
c. Lilliefors Significance Correction.
d. This is a lower bound of the true significance.

The Asymp. Sig. (2-tailed) value is 0.200, which is based on the Kolmogorov-Smirnov test in Table 2. Because the Asymptotic Sig (2-tailed) value is above 0.05, the residual data in this research regression model is normally distributed

Heteroscedasticity Test

Heteroscedasticity testing is employed to determine whether the residuals of several observations exhibit unequal variance within a regression model. Heteroscedasticity arises when the variance of residuals across observations is not constant, violating one of the classical assumptions of linear regression. A commonly used method to detect heteroscedasticity is the Glejser test, which involves regressing the absolute values of residuals on the independent variables. Residuals are defined as the differences between observed and predicted values of the dependent variable, while their absolute values represent the non-negative magnitude of these deviations. If the significance value

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between the independent variables and the absolute residuals exceeds 0.05, heteroscedasticity is considered absent (Gun, 2020). The heteroscedasticity test results are showed in the Table 3.

Table 3. Heteroscedasticity Test.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	3.749	1.134		3.307	.011
	X1	-.436	.354	-1.761	-1.231	.253
	X2	.134	.158	.399	.847	.422
	X3	.604	.382	2.027	1.579	.153

a. Dependent Variable: Abs_RES

The results of the X1 heteroscedasticity test on Y indicate that X1, X2, and X3 are more than 0.05. X1's significance value on Y is 0.253, X2's on Y is 0.422, X3's on Y is 0.188, and X4's on Y is 0.153. Thus, it may be said that there is no heteroscedasticity in the variable mass of FA and BA (X1, X2, X3).

Hyphotesis (T test)

T-test is a method to determine the effect of independent variables on dependent variables. The significance threshold used is 0.05. If the significance value is smaller than the confidence level, we accept the alternative hypothesis, which states that the independent variable has a partial impact on the dependent variable (Ghozali, 2013). This test determines the extent to which the independent variable, alone or in combination with the dependent variable, affects the dependent variable. This test is individual, using the statistical t-test for each independent variable (Bawono, 2006).

n = 12
k = 3
α = 5% (0,05)
t = (5%: (df= 12-3)
t = (0,05:9)

According to the test criteria:

If t count exceeds t table (2.262), then Ho is rejected, If t count < table (2.262), then ha is acceptable. Based on the results of the SPSS 23 test, the t test results are displayed in the table 4.

Table 4. T Test

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.878	2.673		.703	.502
	X1	2.594	2.490	2.962	2.741	.002
	X2	2.744	2.421	2.435	2.769	.004
	X3	2.055	2.533	2.698	2.688	.003

a. Dependent Variable: Y

Table 4 indicates that the t test indicates that X1 has a significance value (Sig.) of 0.002 with an α value (degree of significance) of 0.05, meaning 0.002 < 0.05 or there is a significant effect, and the t test indicates 2.741> t table (2.262); X2 has a significance value (Sig.) of 0.04 with an α value (degree of significance) of 0.05, meaning 0.04 < 0.05 and the t test indicates 2.769 > t table (2.262); X3 has a significance value (Sig.) of 0.03 with an α value (degree of significance) of 0.05, meaning 0.03 < 0.05 and the t test indicates 2.688 > t table (2.262). Before adsorption (Y), there is a considerable impact on acid mine drainage as indicated by the significance value (X1,X2,X3) and the t value (X1,X2,X3). The path analysis above's findings can be explained as follows:

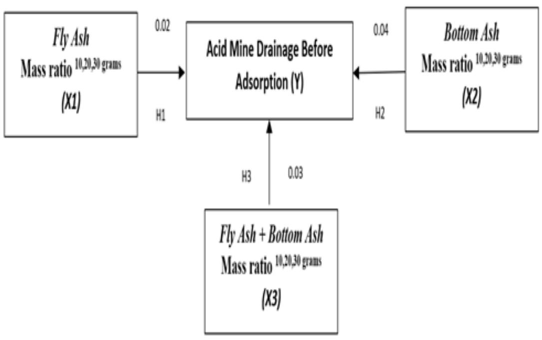

Figure 6. Path Analysis Results

- H1: X1 Positively affects acid mine drainage effluent before adsorption (Y) – Accepted.
- H2: X2 Positively affects acid mine drainage effluent before adsorption (Y) – Accepted.
- H3: X3 Positively affects acid mine drainage effluent before adsorption (Y) – Accepted.

Coefficient of Determination

The coefficient of determination test is used to determine the relative contribution of independent variable (X) and dependent variable (Y), with factors outside the model explaining the remaining amount. An acceptable model is one where the coefficient of determination is one or almost one (Sugiyono, 2013). The following formula was used to get the coefficient of determination:

Table 5. Coefficient of Determination

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.940[a]	.883	.839	6.02876

a. Predictors: (Constant), X3, X2, X1

The output table 5 indicates that the mass of FA and BA X1, X2, and X3 is an independent variable. Its influence on the acid mine drainage prior to adsorption (Y) is 83.9%. This is indicated by the Adjusted R Square value (coefficient of determination) of 0.839.

CONCLUSION

This research shows that the variation of adsorbent mass of FA and BA has an effect on acid mine drainage. The optimal mass of BA is 30 grams, which increases pH from 2.8 to 7.5, reduces Fe from 12.2 mg/L to 1.6 mg/L, Mn from 7.9 mg/L to 0.9 mg/L, and decreases TSS from 40 mg/L to 5 mg/L. SEM analysis shows that BA has more surface voids and higher carbon content than FA, increasing its adsorption capacity. A thin layer of fine particles is formed more effectively on BA, increasing pollutant retention. The Adjusted R^2 value of 83.9% confirms a strong correlation between adsorption efficiency and the mass of FA (X1), BA (X2), and their combination (X3). Further research is recommended to explore the effect of varying adsorption time and combining other low-cost adsorbents to optimize acid mine drainage treatment.

Nomenclature

df	degree of significance
n	amount of data
k	number of variables
α	degree of significance
X1	Fly ash (ratio mass 10,20,30 grams)
X2	Bottom ash (ratio mass 10,20,30 grams)
X3	Fly ash + bottom ash (ratio mass 10,20,30 grams
Y	Acid mine drainage before adsorption
FA	Fly ash
BA	Bottom ash
FABA	Fly ash mix bottom ash

REFERENCES

Amsya, R. M., Zakri, R. S., & Fiqri, M. R. (2021). Analisis pengaruh penggunaan fly Ash dan kapur tohor pada penetralan PH air asam tambang di PT. mandiangin bara prima. Jurnal Sains Dan Teknologi: Jurnal Keilmuan Dan Aplikasi Teknologi Industri, 21(1), 109. DOI: 10.36275/stsp.v21i1.368.

Bawono. A, "Multivariate Analysis with SPSS," Salatiga: STAIN Salatiga Press, (2006).

Damayanti, R. (2018). Abu batubara dan pemanfaatannya: Tinjauan teknis karakteristik secara kimia dan toksikologinya. Jurnal Teknologi Mineral dan Batubara, 14(3), 213-231.

Ghozali. I, "Application of Multivariate Analysis with IBM SPSS 21 Program,”. *Semarang: Diponegoro*

University Publishing Agency, (2013).

Gun. M, "The Importance of the Classical Assumption Test in Multiple Linear Regression Analysis (A Case Study of the Preparation of the Allometric Equation of Young Walnuts)," *Jurnal Ilmu Matematika dan Terapan, 14(3) 333-342 (2020).* DOI: https://doi.org/10.30598/barekengvol14iss3pp333-342.

GEMILAR, M. I. (2022). Pemanfaatan Limbah Abu Boiler Kelapa Sawit Terhadap Perubahan Nilai pH dan Kadar Logam (Fe, Mn) Pada Air Asam Tambang (Doctoral dissertation, UNIVERSITAS JAMBI).

I. Ghozali, " Application of Multivariate Analysis with the IBM SPSS 23 Program," *Eighth print, Semarang: Diponegoro University Publishing House, (2013).*

Kinasti. M. A, Lestari. E, Mayasari. D, " POTENSI PEMANFAATAN LIMBAH PEMBAKARAN BATUBARA (BOTTOM ASH) PADA PLTU SEBAGAI MEDIA TANAM DALAM UPAYA MENGURANGI PENCEMARAN LINGKUNGAN," *Jurnal Kilat, 7(1), 36–46 (2018).* DOI: 10.33322/kilat.v7i1.97.

Martini, S., Yuliwati, E., & Kharismadewi, D. (2020). Pembuatan Teknologi Pengolahan Limbah Cair Industri. *Jurnal Distilasi*, *5*(2), 26-33. DOI: https://doi.org/10.32487/jtt.v3i2.89.

M. Arifin, M.S. Yusuf, F.N. Chalik, C.A. Nurhawaisyah, S.R. Jafar, N. Asmiani, N. Heriansyah, A.F. Ansariah, Budiman A.A, " Analysis of Coal Fly Ash Neutralization Characteristics of Acidic Water with Acid Buffer Characteristic Curve Method," *Jurnal Geomine, 9(3), 218–228 (2021).* DOI: 10.33536/jg.v9i3.980.

Meriestica, F. L., Badhurahman, A., & Gautama, R. S. (2021, May). Study of rare earth elements potential in acid mine drainage from coal mine: a case study. In IOP Conference Series: Earth and Environmental Science (Vol. 753, No. 1, p. 012024). IOP Publishing. DOI: 10.1088/1755-1315/753/1/012024

Nugraha. C, Rolliyah, "Utilization of Fly Ash and Bottom Ash for Rock and Acid Water Management in Coal Mines," *(2021).*

Oktaviansyah, I., Yuliwati, E., & Ariyanto, E. (2024). Optimization of Domestic Wastewater Treatment Using a Mixture of Coconut Shell Activated Carbon Adsorbent and Fly Ash. *Sainmatika: Jurnal Ilmiah Matematika dan Ilmu Pengetahuan Alam*, *21*(2), 122-133. DOI: https://doi.org/10.31851/sainmatika.v21i2.16246

Oktaviansyah, I., Hindriarsana, A. Y., & Wahyudi, A. (2024). Pengaruh Karbon Aktif Tempurung Kelapa dan Karbon Aktif Industrial Terhadap Parameter Ammonia Pada Danau Sipin. *Jurnal Redoks*, *9*(2), 137-146. DOI: https://doi.org/10.31851/redoks.v9i2.14541

Oktaviansyah, I., & Masriatini, R. (2024). Citric Acid Treatment Untuk Rekondisi Dan Penggunaan Kembali Mikrofilter Pada Instalasi Pengolahan Air Bersih. *Jurnal Redoks*, *9*(1), 11-16. DOI: https://doi.org/10.31851/redoks.v9i1.13552

Pratama, H., Nursanto, E., & Ernawati, R. (2022). Efektivitas Kenaikan pH dan Penurunan Konsentrasi Logam Berat pada Air Asam Tambang Mengunakan Fly Ash Sisa Pembakaran Batubara PLTU. Jurnal Ilmiah Lingkungan Kebumian, 4(1), 27-33. doi: https://doi.org/10.31315/jilk.v4i1.6701

Perala, I., Yani, M., & Mansur, I. (2022). Bioremediasi Air Asam Tambang Batubara dengan Pengayaan Bakteri Pereduksi Sulfat Dan Penambahan Substrat Organik. Jurnal Teknologi Mineral dan Batubara, 18(02), 81-95.

Ramadhani, A., & Khuzaimah, S. (2023). Pemanfaatan Limbah Faba (Fly Ash Bottom Ash) Pltu Karangkandri Sebagai Adsorben Pengolahan Limbah Batik Di Desa Kutawaru Cilacap: Utilization of FABA Waste (Fly ash Bottom ash) of PLTU Karangkandri as an Adsorbent for Batik Waste Process in Kutawaru Village, Cilacap. *Jurnal Rekayasa Bahan Alam dan Energi Berkelanjutan*, *7*(2), 25-32. doi: https://doi.org/10.21776/ub.rbaet.2023.007.02.04.

Redy, F. (2022). Pengolahan Air Terproduksi Dari Lapangan Minyak Menggunakan Limbah Padat (FLY ASH) Dengan Metode Jar Test (Doctoral dissertation, Universitas Islam Riau). DOI: https://repository.uir.ac.id/17722/

Saputro, Y. A., Nailis, E., Ramadhan, M. F., Widagdo, J., & Arifin, S. (2023). Pengolahan Limbah Fly Ash Dan Bottom Ash (Faba) Menjadi Produk Komersil Di Desa Sekuro. Swadimas: Jurnal Pengabdian kepada Masyarakat, 1(01), 35-42. *Jurnal Swadimas, 01(01), 35–42 (2023)*. doi: https://doi.org/10.56486/swadimas.vol1no01.280.

Said, M. S., Nurhawaisyah, S. R., Juradi, M. I., Asmiani, N., & Kusuma, G. J. (2020). Analisis Kandungan Fly Ash Sebagai Alternatif Bahan Penetral Dalam Penanggulangan Air Asam Tambang. *Jurnal Geomine*, *7*(3), 170.

Siregar, A., Syam, A., & Mustafa, M. (2019). Rancangan Media Adsorbsi Zeolit Alam Sebagai Adsorben Emisi Gas Mesin Otomotif. Journal Of Mechanical Engineering Manufactures Materials and Energy, 3(1), 64-75. DOI: https://doi.org/10.31289/jmemme.v3i1.2499.

Syaefudin, M. A., Triantoro, A., & Riswan, R. (2020). Analisis pemanfaatan fly ash dan bottom ash sebagai material alternatif naf yang digunakan dalam upaya pencegahan pembentukan air asam tambang pada PT Jorong Barutama Greston. Jurnal Geosapta, 6(1), 39-42. DOI: http://dx.doi.org/10.20527/jg.v6i1.7873

Susilo, N. A., & Sulistyawati, N. (2019). Penggunaan asam sulfat sebagai aktivator fly ash dalam aplikasi proses koagulasi pada pengolahan limbah cair industri pulp dan kertas. *Jurnal Vokasi Teknologi Industri (JVTI)*, *1*(1). doi: https://doi.org/10.36870/jvti.v1i1.3

S. Santoso, "Mastering SPSS 21 in the Information Age. Jakarta," *PT.ELEK Media Komputindo, (2013).*

Sugiyono, "Quantitative, Qualitative and R&D Research Methods," *Bandung: ALFABETA, (2013)*.

Wahyu. W, " Q&A about Normality Test," *(2012).*

Yudiantoro. D. F, Rahmad. B, Jatmiko. T, Rizkiyanto. Y, Haty. I. P, "Geothermal Environmental Science, Mineral Mining Geology, Oil and Gas, Coal," *(2018)*.

Yao. Z. T, Ji. X. S, Sarker. P. K, Tang. J. H, Ge. L. Q, Xia, M. S, Xi. Y. Q. A, *"Comprehensive Review on The Applications of Coal Fly Ash," Earth. Rev. 141, pp 105–121 (2015).*