



NaOH-Activated Fly Ash for Copper(II) Removal from Laboratory Wastewater

Muhammad F. A. Khairullah¹, Ira Ryski Wahyuni^{2*}, Vina Amalia¹, Imam Rozali Fathar³

¹ Department of Chemistry, Faculty of Science and Technology, UIN Sunan Gunung Djati Bandung, Jl. A.H. Nasution No.105, Bandung, 40614, Indonesia

² Department of Environmental Engineering, Faculty of Science and Technology, UIN Sunan Gunung Djati Bandung, Jl. A.H. Nasution No.105, Bandung, 40614, Indonesia

³ Lumas Multi Sarana, Jl. Neptunus Barat 1 Blok A15 No. 2 Bandung, Indonesia

Correspondence Email (Author): ira_ryski@uinsgd.ac.id

Received: 17-07-2026

Accepted : 18-08-2026

Published: 31-10-2026

Keywords:

coal fly ash, alkali activation, copper (II) removal, adsorption efficiency, laboratory wastewater

ABSTRACT

The discharge of untreated laboratory wastewater containing highly toxic copper(II) poses a significant environmental risk, highlighting the need for an effective and low-cost treatment material. At the same time, the accumulation of coal fly ash from Indonesia's electricity sector requires sustainable waste valorization strategies. Addressing these dual environmental challenges, this study proposes a 'waste-to-treat-waste' approach by evaluating NaOH-activated fly ash (FA-NaOH) to reduce copper(II) ion levels in laboratory wastewater. FTIR characterization of FA-NaOH identified functional groups including –OH, Si–O, and Al–O, which are responsible for metal ion binding. Adsorption experiments using a copper(II) model solution determined the optimum operating conditions. The optimum adsorbent dosage was 2 g per 100 mL with a contact time of 60 minutes, achieving 99.07% copper(II) removal. Application of the optimized conditions to actual laboratory wastewater achieved 77.10% removal. The lower efficiency indicates the influence of competing heavy metals and other constituents in the wastewater matrix. Although FA-NaOH effectively lowers copper(II) levels, the treated wastewater did not fully comply with regulatory requirements. Therefore, additional pretreatment is recommended to enhance adsorption performance. These findings demonstrate the potential of FA-NaOH as an effective alternative adsorbent for heavy metal removal from laboratory wastewater.

1. INTRODUCTION

In Indonesia, coal-fired power plants are operated using various fuel sources, including 7% crude oil, 9% natural gas, and 50% coal. In the year 2020, the consumption of coal for electricity production reached 127.10 million tons (National Energy Council, 2021). The coal combustion process generates waste in the form of fly ash and bottom ash. This solid waste must be properly managed to avoid significant environmental pollution (Minh et al., 2023).

Until 2021, the utilization of fly ash waste in Indonesia was only around 11%, which is significantly lower than in many other large countries. Government Regulation No. 22 of 2021 has reclassified fly ash as a non-hazardous waste, thereby opening up opportunities for extensive fly ash utilization, particularly in wastewater treatment (Adewuyi, 2021; Antoni et al., 2022).

Fly ash has been widely used in the cement and concrete industry (Prasittisopin, 2026). It can also serve as an adsorbent due to its complex pore structure and high surface area, along

with mineral components such as alumina and silica, which can adsorb impurities in water (Jadaa, 2024). The advantage of using fly ash as a raw material for adsorbents lies in its cost-effectiveness (Lesmana et al., 2026).

Wastewater produced by laboratories contains hazardous pollutants, so treatment is needed before it can be safely discharged into the aquatic environment. In general, the quantity of laboratory wastewater is smaller than that of domestic or industrial wastewater, but this wastewater contains various types of toxic chemicals that are often concentrated and diverse (Dhenkula et al., 2024).

The Chemistry Laboratory is one of the educational facilities in the Chemistry Department at UIN Sunan Gunung Djati Bandung that produces wastewater. The wastewater characteristics of this laboratory include both metal and non-metal substances, identified as cations and anions (Novita et al. 2022). Previous studies have shown that copper(II) ions are present in the highest concentration in chemical laboratory wastewater (Dharmawan & Herdyastuti, 2019).

Copper(II) ions are toxic to humans when their concentration exceeds the permissible limit (Abubakar, 2024). These ions can accumulate in the human body and inhibit the activity of metabolic enzymes. This condition may cause chronic health problems such as vomiting, a burning sensation in the oesophagus and stomach, diarrhoea, followed by hypotension, liver necrosis, coma and even death (Royer & Sharman, 2023). The maximum allowable copper concentration in wastewater is 10 mg/L (Kementerian Lingkungan Hidup dan Kehutanan, 2021).

Darmayanti et al. (2017) successfully used fly ash as an adsorbent to reduce the concentration of copper(II) ions in solution. From a 100 mg·L⁻¹ copper(II) ion solution, they achieved an efficiency of 93.9%. The fly ash adsorbent showed optimal removal with a contact time of 30 minutes and an adsorbent dosage of 1 g per 100 mL of the solution (Darmayanti et al., 2017).

The adsorption capacity of coal fly ash can be enhanced through an activation process. Activators that can effectively remove heavy metals include H₂SO₄, ZnCl₂, H₃PO₄, as well as alkali metal hydroxides such as NaOH and KOH. (Darmayanti et al., 2018) continued their research by comparing alkali substances as activators for fly ash adsorption to reduce the concentration of copper(II) metal ions from a 50 mg/L copper solution. This study concluded that NaOH achieved higher removal efficiency than KOH and the non-activated fly ash, with an efficiency of 90.63% (Darmayanti et al., 2018).

Suci et al. (2012) reported that NaOH-activated fly ash removed 94.6% of lead(II) ions from a 600 g·L⁻¹ lead solution, with an optimum contact time of 75 minutes and an adsorbent dose of 2 g per 100 mL. The study showed that chemical activation significantly improved the adsorption capacity of fly ash.

Based on this background, this study aimed to determine the optimum adsorption conditions and evaluate the efficiency of NaOH-activated fly ash (FA-NaOH) in reducing copper(II) ions concentrations in laboratory wastewater, and assess its potential to achieve the regulatory discharge standard for copper (II) concentration.

2. METHOD

2.1 Materials

Coal fly ash waste was collected from PLTU Suralaya Banten, and chemical laboratory wastewater samples were collected from UIN Sunan Gunung Djati Bandung. The chemicals used included Cu(NO₃)₂ (analytical grade, Merck®), a 1,000 mg·L⁻¹ Cu standard solution (analytical grade, Merck®), NaOH (analytical grade, Merck®), HNO₃ 65% (analytical grade, Merck®), and demineralized aqua.

2.2 Instruments

Fourier Transform Infra-Red (FTIR) (IR Prestige 12) for functional group characterization. Atomic Absorption Spectrophotometer (AAS) (Agilent Technologies 200 series AA, 240FS-AA) for measuring copper(II) metal ion levels.

2.3 Methods

1. Initial Testing of Laboratory Liquid Waste

Random sampling was applied to collect laboratory wastewater from the Chemistry Laboratory of UIN Sunan Gunung Djati Bandung. The samples were preserved and stored. Initial testing was carried out to determine the concentration of copper(II) ions.

2. FA-NaOH Activation and Characterization

Dried and homogeneous fly ash was mixed with a 3 M NaOH solution for 5 hours under heating and stirring. The resulting residue was separated and dried. The FA-NaOH adsorbent was sieved before use and characterized using FTIR.

3. Optimization of Copper(II) Ion Adsorption with FA-NaOH Adsorbent

The adsorbent dose was determined using mass variations of 2, 3, 4, and 5 g with 100 mL of a 500 mg·L⁻¹ copper(II) model solution. Adsorption was carried out by stirring for 5 minutes at 150 rpm and then allowing the mixture to stand for 60 minutes. The filtrate was analysed for copper(II) ion concentration using AAS (Atomic Absorption Spectrophotometry). The mass variation that showed the highest adsorption capacity was selected as the optimum adsorbent dose. The optimum contact time was determined using time variations of 45, 60, 75 and 90 minutes. Adsorption was carried out at the optimum dose. The filtrate was then analyzed for copper(II) ion concentration using AAS. The contact time with the highest adsorption capacity was selected as the optimum contact time.

4. Application of FA-NaOH Adsorbent in Laboratory Liquid Waste

FA-NaOH adsorbent with optimum dose and time was used for the adsorption of copper(II) metal ions on sampled liquid waste. The adsorption efficiency was measured from the initial concentration and the concentration after adsorption.

3. RESULTS AND DISCUSSION

3.1 Fly Ash Preparation

The fly ash collected from PLTU Suralaya, Banten, is known to be class F fly ash with a combined SiO₂, Al₂O₃, Fe₂O₃ content greater than 70% (specifically 82.85%), and calcium content less than 10% (specifically 7.91%). This fly ash is pozzolanic, meaning it has the ability to interact with heavy metal ions through its pozzolanic microporous structure (Anrozi & Trihadiningrum, 2017). Class F fly ash contains minerals such as quartz, mullite, hematite, and lime, making it suitable for use as an adsorbent (Aigbe et al., 2021). The presence of silicate glass allows fly ash adsorbents to have many active sites on the solid surface that can interact with adsorbates such as metal ions (Singh et al., 2023). Fly ash preparation was carried out to remove water and homogenize particle size, thereby optimizing the reaction between fly ash and activator (Puspitarini et al., 2018).

3.5 Optimization of Copper(II) Metal Ion Adsorption with FA-NaOH Adsorbent

Figure 4a shows that as the adsorbent mass increases, the adsorption capacity decreases, with a reduction from 24.83 $\text{mg}\cdot\text{g}^{-1}$ to 9.99 $\text{mg}\cdot\text{g}^{-1}$. This occurs because adsorption capacity is expressed as the mass of heavy metals absorbed per unit mass of adsorbent ($\text{mg}\cdot\text{g}^{-1}$), so increasing the adsorbent mass can result in a lower calculated adsorption capacity (Mokhatab et al., 2019; Rendana et al., 2025). In contrast, adsorption efficiency increases with increasing adsorbent mass, because the mass of the adsorbent is directly proportional to the number of adsorbent particles available in the solution, allowing more heavy metal ions to be adsorbed (Guo et al., 2025; Lo et al., 2012;). However, the difference in adsorption efficiency among the mass variations is relatively small, ranging from 99.33% to 99.98%. Therefore, the optimum adsorbent mass was determined to be 2 g, which showed the highest adsorption capacity of 24.83 mg/g and an efficiency of 99.33%.

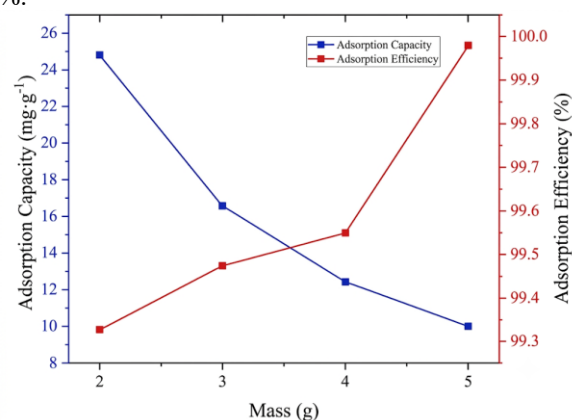
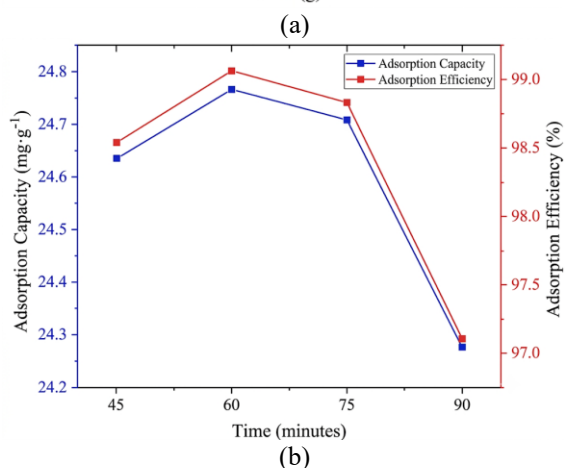


Figure 4. Adsorption mechanism of copper(II) metal ions by FA-NaOH adsorbent

Furthermore, the optimum mass is used in contact time optimization. Figure 4b shows an increase in adsorption capacity to 24.77 $\text{mg}\cdot\text{g}$ at 60 minutes. The adsorption capacity subsequently decreased to 24.28 $\text{mg}\cdot\text{g}$ at 90 minutes. During the adsorption time, more and more adsorbates are absorbed until the adsorbent surface is fulfilled by the adsorbate and is no longer able to adsorb or achieve equilibrium between adsorption and desorption rates (Qiu et al., 2018). After passing the optimum time, desorption occurs so that the value of the adsorption capacity decreases because there is no more

vacuum or reaction in the active group, and the metal ions are released again (Irawan et al., 2015) .

3.6 Application of FA-NaOH Adsorbents in Laboratory Liquid Waste

The adsorption capacity obtained by FA-NaOH when applied to wastewater is 23.49 $\text{mg}\cdot\text{g}$. This value shows relatively good performance compared to previous studies. However, comparisons with previous studies should be interpreted cautiously because the adsorption parameters and experimental conditions may differ. A comparison of adsorption capacity values reported in the previous studies using fly ash or fly ash-based adsorbents for copper(II) ions removal can be seen in Table 1.

The removal efficiency achieved was 77.10%, indicating that the FA-NaOH adsorbent was not sufficiently effective for reducing copper(II) ion concentrations in laboratory wastewater. This may occur because laboratory wastewater contains various metal ions other than copper, resulting in competitive adsorption among different metals (Dhenkula et al., 2024). As reported by (Ghofur, 2022), Laboratory wastewater from the chemistry laboratory of UIN Sunan Gunung Djati Bandung contains other metals besides copper, including Cr, Zn, Cd, Pb, Fe and Ni.

Table 1. Comparison of Cu(II) adsorption performance with previous fly-ash-based studies

Adsorbent	Solution	ΔC	Q	%E	Source
FA	Model Cu	74.38	1.98	82.36	(Syaputra et al., 2025)
FA-KOH	Model Cu	25.34	16.89	42.00	(Darmayanti et al., 2018)
FA-NaOH	Model Cu	45.32	30.21	81.01	(Darmayanti et al., 2018)
Fly ash	Model Cu	85.70	11.43	85.70	(Darmayanti et al., 2017)
FA-NaOH	Model Pb	283.66	14.18	94.55	(Suci, 2012)
FA-NaOH (lead ion)	Model Cu	495.32	24.77	99.06	This Research
FA-NaOH	Waste	469.82	23.49	77.10	This Research

Information:

ΔC : Decreased Concentration ($\text{mg}\cdot\text{L}^{-1}$)

Q : Adsorption Capacity ($\text{mg}\cdot\text{g}^{-1}$)

%E : Adsorption Efficiency (%)

The level of copper(II) ions in laboratory wastewater after treatment was 139.53 $\text{mg}\cdot\text{L}^{-1}$, which did not meet the regulatory limit for copper(II) in wastewater based on Government Regulation No. 22 of 2021, which requires concentrations below 10 mg/L . However, this condition may be improved by adjusting pH and temperature, and by using a combined treatment method such as coagulation, electrolysis and filtration for laboratory wastewater treatment (Agustina et al., 2024; Nurhayati et al., 2020).

3.7 Study Limitations

The adsorption parameters were optimized using a single-metal model solution. Consequently, when applied to actual laboratory wastewater, the removal efficiency decreased from 99.07% to 77.10% due to the complex matrix and competition from coexisting metal ions. Moreover, FA-NaOH alone was insufficient to achieve the regulatory discharge limit of 10

mg·L⁻¹. Future studies could optimize adsorption parameters using real laboratory wastewater, evaluate adsorption performance under competitive multi-metal conditions, and investigate suitable pre-treatment processes to improve treatment performance and achieve regulatory compliance.

4. CONCLUSION

FTIR analysis indicated the presence of -OH, Si-O, and Al-O groups in FA-NaOH. Under optimized conditions (2 g per 100 mL solution, 60 minutes contact time), the adsorbent achieved a 99.07% copper(II) removal efficiency in model solutions. However, its performance decreased to 77.1% when treating actual laboratory wastewater, failing to meet the regulatory discharge limit of 10 mg·L⁻¹. This reduction was likely due to competitive adsorption by coexisting heavy metals in the wastewater matrix. Therefore, supplementary pre-treatment processes, such as pH adjustment, coagulation, or filtration, are recommended to enhance the overall treatment efficiency and achieve compliance with water quality standards.

REFERENCES

- Abdullah, A., Hussin, K., Abdullah, M. M. A. B., Yahya, Z., Sochacki, W., Razak, R. A., Bloch, K., & Fansuri, H. (2021). The Effects of Various Concentrations of NaOH on The Inter-Particle Gelation of a Fly Ash Geopolymer Aggregate. *Materials*, 14(5), 1–11. <https://doi.org/10.3390/ma14051111>
- Abubakar, U. S. (2024). Copper And Lead As Environmental Pollutant and Their Elemental Toxicity – A Review. *Science World Journal*, 19(2). <https://doi.org/10.4314/swj.v19i2.8>
- Adewuyi, Y. G. (2021). Recent advances in fly-ash-based geopolymers: Potential on the utilization for sustainable environmental remediation. *ACS Omega*, 6(24), 15532–15542. <https://doi.org/10.1021/acsomega.1c00662>
- Agustina, T. E., Arita, S., Melwita, E., Bahrin, D., Marcellia, R., Irdiansyah, H., & Ramadhini, T. K. (2024). Laboratory Wastewater Treatment by Using Combination Methods of AOPs and Chemical-Physical Pretreatments. *Ecological Engineering & Environmental Technology*, 25(1), 216–226. <https://doi.org/10.12912/27197050/175112>
- Aigbe, U. O., Ukhurebor, K. E., Onyancha, R. B., Osibote, O. A., Darmokoesoemo, H., & Kusuma, H. S. (2021). Fly ash-based adsorbent for adsorption of heavy metals and dyes from aqueous solution: a review. *Journal of Materials Research and Technology*, 14, 2751–2774. <https://doi.org/10.1016/j.jmrt.2021.07.140>
- Anrozi, R., & Trihadiningrum, Y. (2017). Kajian Teknologi dan Mekanisme Stabilisasi/Solidifikasi untuk Pengolahan Limbah B3. *Jurnal Teknik ITS*, 6(2), 445–450.
- Antoni, A., Tanuwijau, F., & Hardjito, D. (2022). Investigasi Potensi Fly Ash dari PLTU Baru atau Belum Dikenal Sebagai Material Pengikat pada Beton. In *Petra Press*.
- Darmayanti, L., Notodarmodjo, S., & Damanhuri, E. (2017). Removal of Copper(II) Ions in Aqueous Solutions by Sorption onto Fly Ash. *Journal of Engineering and Technology Science*, 49(4), 546–569. <https://doi.org/10.5614/j.eng.technol.sci.2017.49.4.9>
- Darmayanti, L., Notodarmodjo, S., & Damanhuri, E. (2018). Removal of Copper (II) Ions in Aqueous Solutions by Sorption onto Alkali Activated Fly Ash. *MATEC Web of Conferences*, 147(16). <https://doi.org/10.1051/matecconf/201814704007>
- Darmayanti, L., Kadja, G. T. M., Notodarmodjo, S., Damanhuri, E., & Mukti, R. R. (2019). Structural alteration within fly ash-based geopolymers governing the adsorption of Cu²⁺ from aqueous environment: Effect of alkali activation. *Journal of Hazardous Materials*, 377, 305–314. <https://doi.org/10.1016/j.jhazmat.2019.05.086>
- Dharmawan, A. P., & Herdyastuti, N. (2019). Penentuan Kapasitas Adsorpsi Karbon Aktif sebagai Adsorben Logam Tembaga dalam Limbah Laboratorium. *UNESA Journal of Chemistry*, 8(3), 111–115.
- Dhenkula, S. P., Shende, A. D., Deshpande, L., & Pophali, G. R. (2024). An overview of heavy metals treatment & management for laboratory waste liquid (LWL). *Journal of Environmental Chemical Engineering*, 12(4), 113165. <https://doi.org/10.1016/j.jece.2024.113165>
- Ghofur, E. N. (2022). Pengolahan Limbah Laboratorium Kimia UIN Sunan Gunung Djati Bandung Menggunakan Metode Netralisasi, Elektrokoagulasi, dan Ozonisasi. *Bachelor Thesis*. UIN Sunan Gunung Djati Bandung.
- Guo, X., Zhang, X., Gao, X., Dong, Y., Zhao, Z., & Fu, H. (2025). Development of high-silica fly ash-based adsorbents for efficient dye removal from wastewater: A comparative study of MSAM and SDS/FA. *RSC Advances*, 15(42), 35158–35174. <https://doi.org/10.1039/d5ra05953d>
- Huang, X., Zhao, H., Zhang, G., Li, J., Yang, Y., & Ji, P. (2020). Potential of Removing Cd(II) and Pb(II) from Contaminated Water Using a Newly Modified Fly Ash. *Chemosphere*, 242(3). <https://doi.org/10.1016/j.chemosphere.2019.125148>
- Irawan, C., Dahlan, B., & Retno, N. (2015). Pengaruh Massa Adsorben, Lama Kontak Dan Aktivasi Adsorben Menggunakan HCl Terhadap Efektivitas Penurunan Logam Berat (Fe) dengan Menggunakan Abu Layang Sebagai Adsorben. *Jurnal Teknologi Terpadu*, 3(2), 110–117.
- Jadaa, W. (2024). Wastewater Treatment Utilizing Industrial Waste Fly Ash as a Low-Cost Adsorbent for Heavy Metal Removal: Literature Review. *Clean Technol.* 6(1), 221–279; <https://doi.org/10.3390/cleantechnol6010013>.
- Kamarzaman, F. F., Al Bakri Abdullah, M. M., Rozainy, M. R., Ahmad, R., Ibrahim, W. M. W., Omar, M. F., Ghazali, C. M. R., & Ibrahim, W. M. A. W. (2024). A comparative review on low-cost adsorbent based alkali-activated materials by adsorption study. *Archives of Metallurgy and Materials*, 69(4), 1385–1394. <https://doi.org/10.24425/amm.2024.151404>
- Lesmana, M. J., Nozaki, T., Fan, X., Darmawan, A., & Juangsa, F. B. (2026). Utilization of fly ash for CO₂ capture through mineral carbonation: An experimental study with Indonesian coal fly ash. *Chinese Journal of Chemical Engineering*, 91, 255–265.

- <https://doi.org/10.1016/j.cjche.2025.10.025>
- Lo, S. F., Wang, S. Y., Tsai, M. J., & Lin, L. Der. (2012). Adsorption Capacity and Removal Efficiency of Heavy Metal Ions by Moso and Ma Bamboo Activated Carbons. *Chemical Engineering Research and Design*, 90(9), 1397–1406.
- Minh, V. T. N., Pham, V.-H., Tung, V. H., Tung, C. T., & Phuong, N. T. H. (2023). Firing-associated recycling of coal-fired power plant fly ash. *Journal of Analytical Methods in Chemistry*, 2023, 8597376. <https://doi.org/10.1155/2023/8597376>
- Mokhatab, S., Poe, W. A., & Mak, J. Y. (2019). Natural Gas Dehydration and Mercaptans Removal. In *Handbook of Natural Gas Transmission and Processing* (pp. 307–348). Gulf Professional Publishing. <https://doi.org/10.1016/B978-0-12-815817-3.00009-5>
- Mujkanović, A., & Jovanović, M. (2021). Synthesis of Precipitated Silica from Sodium Silicate Solution by Carbonation Method. *Periodicals of Engineering and Natural Science*, 9(2), 808–819.
- Novita, E., Andriyani, I., & Pradana, H. A. (2022). Characterisation of laboratory wastewater for Planning Wastewater Treatment Plants In a University Campus In Indonesia. *Ecology Environment and Conservation*, 28(August), S45–S50. <https://doi.org/10.53550/EEC.2022.v28i04s.007>
- Nurhayati, I., Vigiani, S., & Majid, D. (2020). Penurunan Kadar Besi (Fe), Kromium (Cr), COD dan BOD Limbah Cair Laboratorium dengan Pengenceran, Kougulasi dan Adsorbsi. *Ecotrophic*, 14(1), 74–87.
- Pemerintah Republik Indonesia. (2021). *Peraturan Pemerintah (PP) Nomor 22 Tahun 2021 tentang Penyelenggaraan Perlindungan dan Pengelolaan Lingkungan Hidup*.
- Peraturan Pemerintah (PP) Nomor 22 Tentang Penyelenggaraan Perlindungan Dan Pengelolaan Lingkungan Hidup (2021).
- Prasittisopin, L. (2026). Power plant waste (fly ash, bottom ash, biomass ash) management for promoting circular economy in sustainable construction: Emerging economy context. *Smart and Sustainable Built Environment*, 15(3), 1341–1365. <https://doi.org/10.1108/SASBE-09-2024-0395>
- Puspitarini, R., Kurniawan, A., & Winarno, H. (2018). Pengaruh Ukuran Partikel, Zat Aktivator, Waktu Aktivasi dan Waktu Serap Adsorben Fly Ash untuk Mendegradasi Logam Timbal (Pb) pada Air Lindi. *URECOL*, 7, 78–86.
- Qiu, R., Chen, F., & Huang, H. (2018). Removal of Cd²⁺ from Aqueous solution using Hydrothermally Modified Circulating Fluidized Bed Fly Ash Resulting from Coal Gangue Power Plant. *Journal of Cleaner Production*, 172, 1918–1927.
- Rendana, M., Saputra, M. R. G., Bangun, F. B., Fattullah, M. I., Maulana, J. A., Nasir, S., & Agustina, T. E. (2025). Comparison coal fly ash-based adsorbent and advanced oxidation process for textile wastewater treatment. *Journal of Engineering and Applied Science*, 72, 174. <https://doi.org/10.1186/s44147-025-00757-y>
- Royer, A., & Sharman, T. (2023). Copper toxicity. In *StatPearls*. StatPearls Publishing
- Singh, K., Singh, A. K., Kumar, A., & Agarwal, A. (2023). Fly ash and TiO₂ modified fly ash as adsorbing materials for removal of Cd(II) and Pb(II) from aqueous solutions. *Journal of Hazardous Materials Advances*, 10, 100256. <https://doi.org/10.1016/j.hazadv.2023.100256>
- Suci, F. C. (2012). Pemanfaatan Abu Layang Batubara (Fly Ash) Teraktivasi sebagai Adsorben Ion Logam Pb(II). Bachelor Thesis. Universitas Airlangga.
- Syaputra, I. A., Hanum, F. F., Rahayu, A., & Sukasuci Lestari, R. (2025). Comparative Adsorption of Copper Ion (Cu²⁺) onto Raw and NaOH-Modified Coal Fly Ash at Various Initial Concentrations. *Journal of Chemical Natural Resources*, 7(2), 125–132.
- Wathi, A. F. D., Utami, A. R. P., Pambudi, T., Kumalasari, M. R., Putra, M. S. N. S., Setyaningsih, S., & Suciana, D. (2026). Alkali activation of coal fly ash: Characterization and potential for oil remediation. *Indonesian Journal of Fundamental and Applied Chemistry*, 11(2). <http://ijfac.unsri.ac.id/index.php/ijfac/article/view/515>