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Original Research Article

Valorization of Alum Sludge-Mangosteen Peel Waste into Composite Adsorbent for Dye Removal

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Abstract

Alum sludge from water treatment plants (WTP) and mangosteen peel waste pose waste management challenges in urban areas of Indonesia due to limited disposal space and/or high energy consumption associated with waste incineration. In this study, a composite adsorbent was developed by mixing dried alum sludge (AS) and mangosteen peel (MP) in a 1:1 ratio and stabilizing them using sodium alginate and calcium chloride. The AS/MP composite contained carbon and oxygen with a surface area of 8.684 m^2/g, pore volume of 0.033 cm^3/g, and average pore size of 15.11 nm. Batch adsorption experiments evaluated the effects of adsorbent dosage (0.25–3 g/L), initial dye concentration (5–100 mg/L), and pH (2–10). The AS/MP composite achieved 94% methylene blue removal at a dosage of 1 g/L and initial concentration of 25 mg/L after 2 h at pH 10. The adsorption process followed the Langmuir isotherm and pseudo-second-order kinetic model, suggesting monolayer adsorption and chemisorption, respectively. These findings highlight the potential of the AS/MP composite as an effective adsorbent while promoting circular economy through the valorization of water treatment sludge and agricultural waste. Its application could contribute to sustainable waste management and wastewater treatment, particularly in regions facing challenges in sludge disposal and agricultural waste utilization.

Keywords: Circular economy; composite materials; food waste; isotherm adsorption; methylene blue; sludge reuse

1. Introduction

Water treatment sludge accumulation has become a significant issue because of its high volume and management costs. On average, approximately 100,000 tons of alum sludge are produced daily by conventional water treatment plants (WTPs) worldwide (Bensitel et al., 2023). Sludge generated in conventional WTPs typically contains aluminum in the form of stable aluminum hydroxide ($Al(OH)_3$), resulting from the application of coagulants such as poly aluminum chloride (PAC) and aluminum sulfate (alum, $Al_2(SO_4)_3$) (Ooi et al., 2018). Aluminum hydroxide has the potential to contaminate water bodies if released into the environment, endangering both human and animal health (Teixeira et al., 2011).

Therefore, a sustainable method of alum sludge utilization is needed to minimize operational costs at conventional drinking WTPs and lessen sludge pollution to the environment.

Meanwhile, mangosteen production in Indonesia was 81,431 tons in 2016. Approximately 6 kg of mangosteen peel is generated for every 10 kg of mangosteen fruit consumed (Isnasari et al., 2020). Due to its thick skin and high water content, mangosteen peel takes a long time to decompose. Another issue is the careless disposal of mangosteen peel waste, which frequently results in air pollution (Nasrullah et al., 2019). The high production of organic mangosteen peel waste and treatment plant sludge shows that they are easily available in nature and can be recycled to higher-value resources while simultaneously reducing environmental impacts.

Methylene blue (MB) is a synthetic, carcinogenic, and biodegradation-resistant cationic dye that is widely used in many fields and persists in water (Khan et al., 2022). Thus, the efficient removal of MB from wastewater is essential. The structural complexity and toxicity of MB can make conventional biological processes unsuitable, with insufficient retention time, and under high dye concentration, photochemical oxidation is limited (Khan et al., 2022). Although promising results have been obtained with advanced oxidation processes (AOP), such as Fenton and persulfate reactions, their use in developing countries is limited by the high cost of operation and high chemical oxygen demand (COD), which can overestimate the COD values of hydrogen peroxide and persulfate. However, among the different treatment methods explored, adsorption is one of the most attractive processes for removing dye pollutants (Oladoye et al., 2022; Vedula and Yadav, 2022).

Activated carbon (AC) is a highly effective adsorbent with a high surface area, well-developed porosity, and strong affinity for a variety of pollutants. However, its production is energy-intensive and requires non-renewable precursors, which makes its large-scale application challenging (Gupta and Garg, 2015). Biosorbents originate from natural materials, which are abundant, cheap, and produce fewer by-products than AC, making them a good alternative to AC (Muhammad and Adityosulindro, 2022; Nisrina et al., 2024; Zahro and Adityosulindro, 2023). The appeal of biosorbents is further increased within the framework of the circular economy, where waste is re-introduced into productive cycles instead of being discarded. However, industrial by-products, as well as agricultural residues, can be used as adsorbents and transformed from waste streams into useful materials, as in the case of alum sludge (Muisa et al., 2020; Tony, 2020; Adityosulindro and Lasaufa, 2026). This re-use minimizes disposal issues and contributes to the sustainability of water treatment.

Alum sludge and mangosteen peel have been extensively investigated as single waste adsorbents; however, their performance is limited in achieving significant adsorption capacity, along with high waste content or chemical activation. The activated mangosteen peel is highly demanded in terms of MB capacity of 1193 mg/g (Nasrullah et al., 2019), whereas the raw peel has the capacity of MB removal of ~99.7% at a high dosage (Phawachalotorn and Suwanpayak, 2021). The amount of adsorption sludge needed to achieve high removal efficiency is higher than >3 g L – 1 for both the unmodified and modified forms, with the adsorption capacity of alum sludge being lower than that of biomass-derived carbons (Adityosulindro et al., 2024a, 2024b, 2025). This result points to an important challenge: single-waste adsorbents cannot simultaneously have high adsorption capacity, cost-effectiveness, and scalability. However, overcoming this challenge requires the creation of composite or hybrid adsorbents composed of multiple components derived from the waste, which could improve the porosity, surface chemistry, and adsorption capacity while contributing to sustainable remediation solutions in the context of the circular economy (Hassan and Carr, 2021; Yaashikaa et al., 2021; Nurianto et al., 2024).

The establishment of sludge from industrial and agricultural waste products is a unique development in the field of adsorbent product development. Alum sludge is a material with high inorganic hydroxides and chemical binding sites, but it has limited porosity and moderate adsorption capacity when used alone. Agricultural residues offer a high surface area and high carbon content, but they require activation or high doses to remove a significant amount of dye. Therefore, by combining both waste streams, the composite adsorbent will achieve synergistic adsorption performance, structural

stability, and sustainability by taking advantage of the inorganic matrix of alum sludge and the porous carbon structure of mangosteen peel. This study investigated the ability of the composite of alum sludge and mangosteen peel as an adsorbent for MB dye removal. For the analysis of its efficiency, a few experiments were conducted under various conditions, such as the effect of adsorbent dosage, initial dye concentration, and pH of the solution.

2. Methods

2.1 Materials

The Alum sludge (AS) sample used in this study was collected from Citayam WTP in Depok City, West Java, Indonesia. The wet sludge was dehydrated through cloth filtration, dried under sunlight for 5 days, and then in an oven at 105 °C overnight. The dehydrated AS was cooled and pulverized, and the powder was stored in a dry container for further use. Mangosteen peel (MP) was collected from the municipal solid waste disposal site in Depok City. Prior to use, the peel was air-dried for several days, then oven-dried at 105 °C for 24 h. The dried peel was crushed and sieved using a 100-mesh sieve to obtain particles with a diameter of 75-150 mm (Phawachalotorn and Suwanpayak, 2021). The overall experimental workflow of this study is shown in Figure 1.

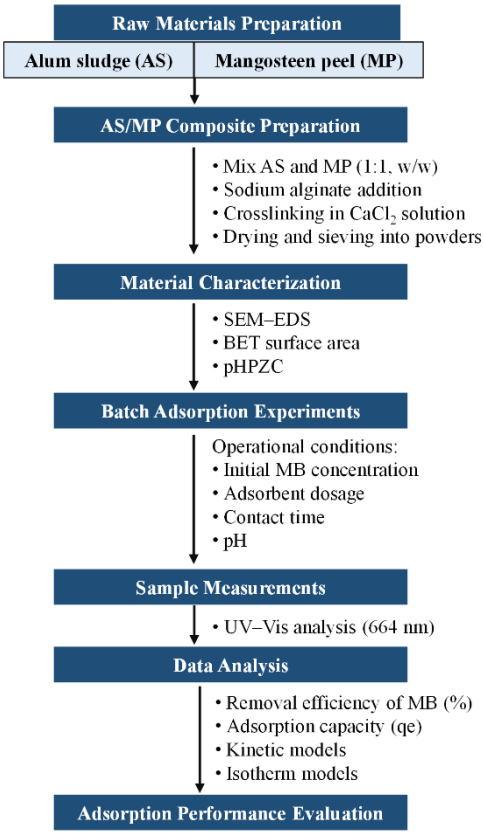


Figure 1. Schematic diagram of the experimental procedure

2.2 Preparation for Composite

In this study, the composite was prepared by mixing dried AS and MP in a weight ratio of 1:1, following the preparation procedure reported by (Nuanhchamnong et al., 2022). In this study, the composite was prepared by mixing dried AS and MP in a weight ratio of 1:1. First, 10 g of AS was dissolved in deionized water and magnetically stirred for 30 minutes at a speed of 300 rpm. Next, 10 g of MP was added to the mixture, which was stirred for an additional hour. The final mixture was then dried at 105 °C overnight to obtain the dried adsorbent powders.

After 24 hours, 20 g of the adsorbent was added to 500 mL of 2% (w/v) sodium alginate solution, which was stirred for 2 hours. The mixture was stirred for another 2 hours before being added dropwise to 500 mL of 0.5 M calcium chloride solution. The final mixture was left overnight, rinsed with deionized water, dried, and sieved to obtain the composite powders.

2.3 Experimental Protocol

An adsorption experiment was conducted to evaluate the feasibility of the proposed AS/MP composite adsorbent for MB removal under controlled laboratory-scale batch conditions. Accordingly, the adsorption performance was investigated by examining the effects of the adsorbent dosage, initial dye concentration, and pH solution. A batch adsorption experiment was conducted to remove MB using the AS/MP composite. This experiment was conducted in a 500 mL glass beaker equipped with a hotplate magnetic stirrer. Unless specified otherwise, 1 g/L of the composite was dispersed in 250 mL of a 50 mg/L MB solution and stirred at 300 rpm. At designated time intervals, small samples were taken, and the separation of the adsorbent from the MB solution was carried out by centrifugation. The absorbance of the remaining MB in the solutions was measured using a UV-visible spectrophotometer (Hach DR6000) at a wavelength of 664 nm. All experimental runs were duplicated to check for the reproducibility of the collected data.

The batch adsorption experimental conditions were adopted from previously established methodologies (Adityosulindro et al., 2025, 2024a; Alam and Anwar, 2020; Phawachalotorn and Suwanpayak, 2021) to ensure methodological consistency and facilitate comparison with published studies. All experimental runs were conducted in duplicate to ensure the reproducibility of the collected data. The experimental results are presented as mean ± standard deviation, and the error bars shown in the corresponding figures represent the standard deviation of duplicate measurements. The goodness-of-fit of the kinetic and isotherm models was assessed using the coefficient of determination (R^2).

2.4 Analytical Methods

The physicochemical characteristics of the AS/MP composite were thoroughly investigated. Its surface morphology and elemental composition were analyzed using Scanning Electron Microscopy coupled with Energy Dispersive X-Ray spectroscopy (SEM-EDX, JEOL JSM-6510LA). The pore structure was examined through nitrogen adsorption–desorption isotherms at 77 K, with surface area determined by the Brunauer–Emmett–Teller (BET) method (Quantachrome Nova 1200e). In addition, the point of zero charge (pHpzc) of the carbonaceous phase was established using the mass titration technique.

3. Result and Discussion

3.1 Characterisation of Composite

The SEM image results indicate that the AS/MP composite material is non-homogeneous, featuring an uneven structure with a smooth, non-porous surface (Figure 2). Additionally, the AS/MP composite contains numerous spherical aggregates with various-sized cavities and protrusions dispersed throughout. This surface morphology has been reported in previous studies (Benalia et al., 2024). Such small and spherical aggregates form a wider and broader surface, resulting in a large number of active sites for MB adsorption (Poormand et al., 2017).

The EDX spectrum of the AS/MP composite (Figure 2) confirms the presence of oxygen (45.95%), carbon (33.13%), chlorine (7.24%), calcium (5.95%), and minor elements (7.73%). The peaks of oxygen and carbon are the main ones, which are functional groups on the surface, such as hydroxyl (–OH), carbonyl (C=O), and carboxyl (–COOH), which are important for hydrogen bonding and dipole–dipole interactions with MB (Li et al., 2022). The high oxygen intensity also represents the existence of oxide minerals from AS, which gives polarity and affinity of the composite to cationic dyes. At the same time, the carbon comes from the organic residue and microbial activity during the storage of sludge, which

further elevates the π–π stacking interaction force between the aromatic carbon domain and the MB molecules.

The presence of chlorine and calcium also reinforces the concept of a heterogeneous surface chemistry of the composite. The origin of chlorine can be due to residual coagulant species, and the origin of calcium can be due to mineral inclusions that can enhance ion exchange and electrostatic attraction with MB cations. For sludge-based or biomass adsorbents, oxygenated and carbonaceous sites are known to work synergistically and improve the efficiency of the dye removal process (Ling et al., 2017; Li et al., 2022). Therefore, the EDX data confirmed that the adsorption ability of the AS/MP composite is due to electrostatic forces, hydrogen bonding, and π–π interactions between the dye molecules and the functional groups present on the surface.

BET analysis indicated that the surface area of the composite was 8.684 m^2/g, the pore volume was 0.033 cm^3/g, and the average pore diameter was 15.11 nm. The surface area obtained here is comparable to that of previous studies on adsorbents made from alum sludge (Adityosulindro et al., 2024a, 2024b). The point of zero charge (pH_{pzc}) was 5.85, indicating that at neutral pH, the adsorbent surface has a negative charge, improving the attraction and binding ability of the positively charged species.

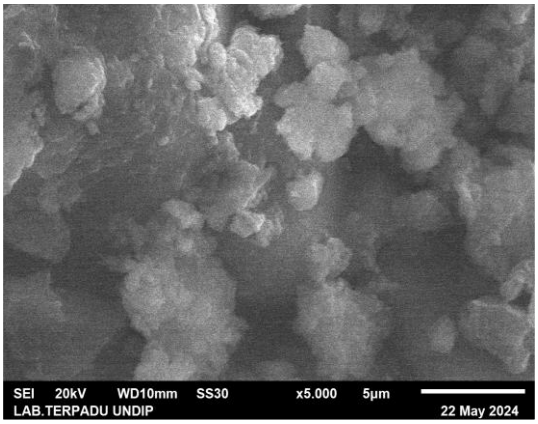


Figure 2. SEM images of AS/MP composite

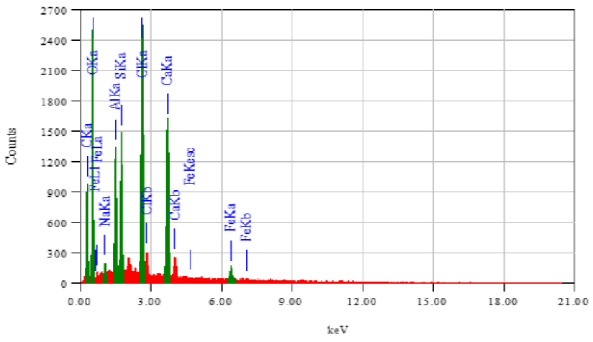


Figure 3. EDX mapping of AS/MP composite

Table 1. Detection of AS/MP composition by EDX

Element	C	O	Na	Al	Si	Cl	Ca	Fe
(%)	44.21	46.02	0.27	1.7	1.74	3.27	2.38	0.41

3.2 Adsorption of MB Dye

3.2.1 Effect of Composite Dosage

An increase in the composite dosage resulted in a significant enhancement of MB removal efficiency, as shown in Figure 4. This improvement is due to the increased number of active sites to which dye molecules can bind. At pH 7, the –OH functional groups on the composite surface are deprotonated (pH_{pzc} = 5.85), leading to electrostatic attraction between the MB cationic molecules and the negatively charged composite surface. The adsorption site density is effective in affecting the steady increment of removal efficiency as the dosage increases.

In contrast, the adsorption capacity (mg g – 1) showed the opposite trend, with the highest capacity of 120 mg/g at the lowest dose (0.25 g/L 1). At higher dosages, more sites are added, but most are not occupied with an adsorbate at the same concentration, which decreases the capacity per unit mass (Rápó and Tonk, 2021). Furthermore, a reduced concentration gradient between the MB molecules in solution and the surface of the adsorbent is expected to reduce the driving force for mass transfer (Han et al., 2011). Thus, the adsorption capacity gradually decreased with increasing dosage, from 120 mg/g (0.25 g/L 1) to 17 mg/g (3 g L – 1). This dual behavior suggests the influence of electrostatic attraction, site saturation, and concentration gradient effects on the adsorption performance.

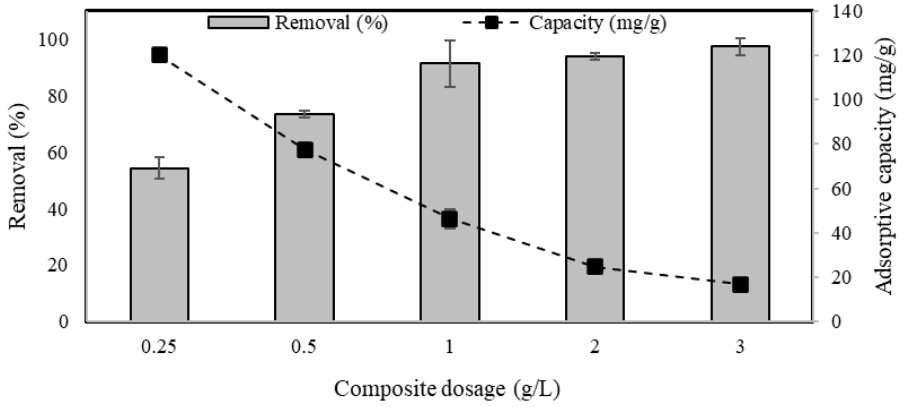


Figure 4. Effect of composite dosage
($[MB]_o$ = 50 mg/L, pH 7)

3.2.2 Effect of MB Initial Concentration

The initial concentration had a negative effect on the removal efficiency of the MB dye, as shown in Figure 5. When the dye was used at a lower concentration (5 mg/L), the remaining dye molecules did not occupy all the adsorption sites, leading to a low removal efficiency of 57%. Site utilization improved to 94% at a concentration of 25 mg/L. However, the results revealed that above this point, there was a decrease in efficiency with further increments of MB at constant composite concentration owing to the increased speed of site saturation (Etim et al., 2016).

In contrast, the adsorption capacity (mg g – 1) increased at elevated concentrations. This phenomenon can be attributed to the increase in the driving force for mass transfer owing to the increased concentration gradient, leading to more uptake per unit mass of the adsorbent (Soltani et al., 2021). The same trend was observed in the dye adsorption capacities obtained from waste materials used in agriculture and industry, where the higher the initial dye concentration, the higher the dye adsorption capacity, but the lower the efficiency, owing to the saturation of the adsorption sites as well as to the competitive interactions between dyes and adsorbent (Etim et al., 2016; Soltani et al., 2021). The results suggest that the initial concentration plays a dual role, as it controls the site occupancy and removal efficiency, and simultaneously enhances the adsorption capacity via gradient-driven effects.

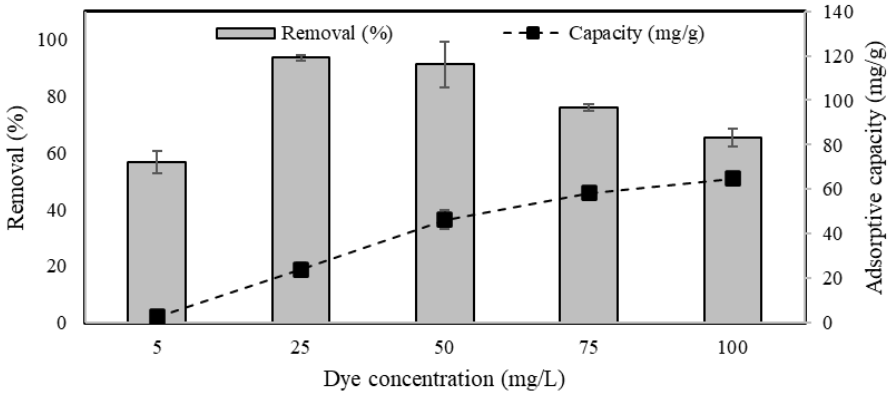


Figure 5. Effect of initial MB concentration
(Adsorbent dosage = 1 g/L, pH = 8-9)

3.2.3 Effect of pH Solution

The removal efficiency decreased with the initial pH in the range of 2–4 but increased at higher initial pH 10, as shown in Figure 6. This is similar to the pH_{pzc} value, as AS/MP has a pH_{pzc} of 5.85. In addition, MB pollutants are known to have a pKa of 3.8. MB is present in different chemical states depending on the pH of the solution. It exists as a positively charged cationic pollutant at pH > 3.8, and as a neutral molecular form at pH < 3.8 (Salazar-Rabago et al., 2017). The initial pH was 10 and the pH_{pzc} was lower than the initial pH, which indicates that the surface of the adsorbent was negatively charged. This electrostatically attracted the positively charged MB to the AS/MP surface to enhance its adsorption efficiency.

At an initial pH of 2 (pH < pH_{pzc}), the AS/MP surface should be positively charged due to the excess presence of H^+ ions, which in turn leads to electrostatic repulsion with the cationic MB molecules (Yunusa et al., 2021). However, the interactions other than electrostatic force that may occur at initial pH of 2, Hydrogen bonding between –OH functional groups and N atom in MB, n–π conjugation between Al–OH and aromatic rings in MB, and hydrophobic interaction can affect the adsorption of MB, which lead to higher adsorption efficiency (Fan et al., 2017; Xia et al., 2024).

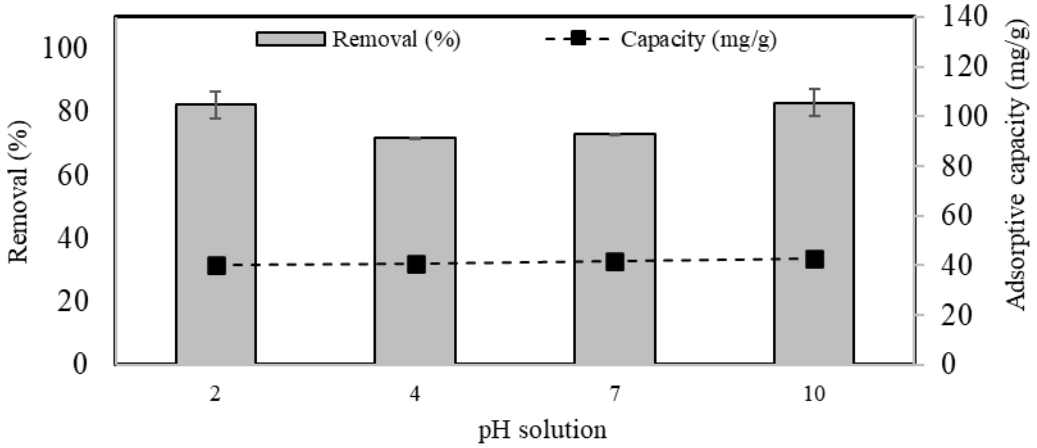
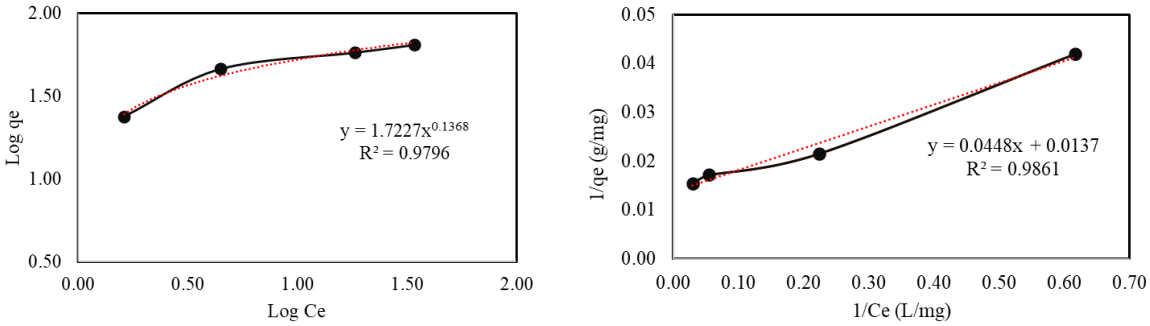


Figure 6. Effect of initial pH solution
($[MB]_o$ = 50 mg/L, adsorbent dosage = 1 g/L)

3.3 Adsorption Isotherm

In this study, two models of adsorption isotherms, Langmuir and Freundlich, were used to characterize the adsorption process. The adsorption isotherms provide information on the interaction between the molecules of pollutants (dye) and the surface of the adsorbent. The Langmuir and Freundlich isotherms were used to approximate the adsorption of MB onto the AS/MP composite, as shown in Figure 7, and the most appropriate model was the Langmuir model, which indicates that MB was adsorbed to form a monolayer over the available adsorption sites. The highest adsorption capacity obtained was 72.99 mg/g (KL = 0.306 L/mg and RL = 0.032–0.412; R^2 = 0.9861), which is similar to that obtained by the previous research that used only alum sludge as an adsorbent (Adityosulindro et al., 2024a) or mixing saffron petals powder with AC (Davarnejad et al., 2018) (Table 2).



(a) (b)

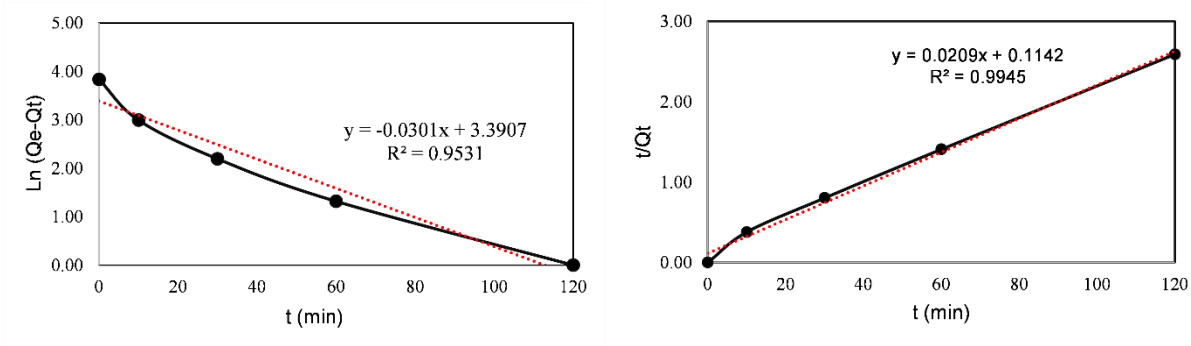
Figure 7. Isotherm adsorption of (a) Freundlich and (b) Langmuir models

Table 2. Comparison of AS/MP adsorption capacity with other adsorbent on MB removal

Adsorbents	q_m (mg/g)	References
AS/MP	72.99	This study
Alum sludge	37.45	(Adityosulindro et al., 2024a)
Alum sludge	21.63	(Yeshitila et al., 2025)
Alum sludge conditioned with lime+ferric chloride mixture	67.94	(Tayeb et al., 2022)
Thermally treated alum sludge	25.44	(Yusuff et al., 2017)
Sludge from drinking WTP	35.7	(Soliman et al., 2023)

3.4 Adsorption Kinetic

Figure 8 shows the comparison of the pseudo-first order and pseudo-second order kinetic models which have been evaluated. The pseudo-first-order model gave an R^2 value of 0.9531, a rate constant (k_1) of 0.0692 g/mg·min, and an adsorption capacity at equilibrium (q_e) of 2459 mg/g. The pseudo-second-order model, however, gave an R^2 = 0.9945, a rate constant k_2 = 0.004 g/mg·min, and a calculated q_e of 47.74 mg/g. The good correlation between the data and the pseudo-second-order model indicates that the adsorption process is chemisorption due to electron sharing or exchange between MB molecules and the active sites of the AS/MP composite.



(a) (b)

Figure 8. Kinetic adsorption of MB: (a) pseudo-first order and (b) pseudo-second order

4. Applications, Limitations and Perspectives

In this study, a composite adsorbent made from alum sludge and mangosteen peel was developed as a practical and low-cost adsorbent for small-scale wastewater treatment systems. The efficacy of its MB removal shows promise in the textile and dye manufacturing industry, especially in areas where AC is not economically viable. The cost of AC is approximately USD 3–5 per kg, whereas sludge-based AC is typically produced at less than a third of the cost of AC based on local processing costs (Zhao et al., 2021). The practice of valorizing local waste streams is in line with circular economy principles and allows for the mitigation of environmental impacts related to sludge disposal and fruit fermentation.

Although the AS/MP composite is immensely promising, it also has some drawbacks. The measured surface area of AC is modest compared to that of commercial AC, which may restrict the adsorption capacity for complex pollutants. Furthermore, this study only examined one model dye, and the results do not apply to actual industrial effluents. The AS/MP composite demonstrated excellent adsorption abilities in laboratory settings, but its effectiveness in real-world scenarios depends on the complexity of the wastewater and its operational scalability. However, industrial effluents may contain mixed dyes, salts, organic materials, and others that can lower the adsorption capacity by 30–50% from the adsorption capacity of single-dye systems (Zhao et al., 2021; Adityosulindro, 2026). Additionally, the regeneration capability plays an important role in long-term applications. The regeneration procedure of alum-based adsorbents has been proven to be feasible for 3–5 cycles, with moderate loss of efficiency, by mild chemical washing, thermal treatment (Benalia et al., 2024), or Fenton oxidation (Adityosulindro and Lasaufa, 2026).

Future studies should focus on advanced modification methods to increase porosity and surface chemistry, as well as expanding the range of pollutants to include a variety of contaminants and real wastewater streams. The suitability of the AS/MP composite for continuous-flow systems needs to be explored, and assays for real wastewater samples, re-use potential, regeneration approaches, cost, and life-cycle analysis need to be performed to ensure feasibility and sustainability. The feasibility and sustainability of reusing it and exploring regeneration, cost, and life-cycle analysis will be key to investigating the re-use potential. In developing countries, such as Indonesia, socio-economic aspects should be considered, in addition to technical improvements. In summary, this research plays a role in broader initiatives aimed at creating sustainable wastewater management systems, providing a blueprint for transforming waste into valuable resources, and mitigating environmental issues.

5. Conclusions

In this study, the alum sludge–mangosteen peel (AS/MP) composite was effective in removing MB dye, with an impressive removal efficiency of 94% after 120 minutes and a dye concentration of 25 mg/L at pH 10. The maximum adsorption capacity was 120 mg/g at a concentration of 0.25 g/L 1. The equilibrium data fit well with the Langmuir isotherm model, the values of q_e = 72.99 mg/g, K_L = 0.306

L/mg, and R^2 = 0.9861 clearly indicate monolayer adsorption. The pseudo-second-order model (k_2 = 0.004 g/mg·min – 1; q_e = 47.74 mg/g; R^2 = 0.9945) was well supported by kinetic analysis, which indicates that chemisorption is the predominant mechanism. The analysis of SEM-EDX revealed that the material is mainly composed of oxygen (46.02%) and carbon (44.21%), which contributes to the presence of hydrogen bonding and polar interactions. Furthermore, BET analysis showed a surface area of 8.684 m^2/g 1 and a pore diameter of 15.11 nm, highlighting the composite's potential for effective adsorption. The results confirm the AS/MP composite as a reliable and effective dual-waste adsorbent, demonstrating its performance comparable to that of single-waste biosorbents and promoting the concept of a circular economy. Future studies promise to investigate regeneration, real effluent applications, and surface modification to further increase scalability and sustainability.

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Ethics Statement

This research did not involve human participants, animal subjects, or the use of sensitive data; therefore, ethical approval was not required.

CRediT Author Statement

Sandyanto Adityosulindro: Idea development, Resources, Manuscript Review and Revision, Supervision, Acquisition. **Najla Auliyanissa Kamali**: Research Design, Formal Analysis, Investigation. **Yenni Trianda**: Data Curation, Manuscript Draft Preparation. **Nopa D. Maulidiany**: Result Verification, Manuscript Draft Preparation. **Lucky Caesar Direstiyani**: Visualization, Manuscript Review and Revision. **Denny Halim**: Manuscript Review and Revision. **Sucipta Laksono**: Manuscript Review and Revision

References

Adityosulindro, S. 2026. Modified Sidoarjo volcanic mud as adsorbent for the decolourisation of textile wastewater. Environmental Research, Engineering and Management 82, 119–128.

Adityosulindro, S., Annisa, S., Halim, D. and Kusrestuwardhani 2025. Modification of alum sludge as adsorbent for removal of Rhodamine-B Dye in water. Indonesian Journal of Urban and Environmental Technology 8, 65–81.

Adityosulindro, S., Firdaus, A. and Hartono, D.M. 2024a. Removal of methylene blue from aqueous solutions by adsorption on alum sludge: effect of operating parameters. Serambi Engineering 9, 10520–10530.

Adityosulindro, S. and Lasaufa, V.R. 2026. Teknologi pengolahan air limbah berkelanjutan dengan adsorben lumpur alum: komparasi adsorben baru, bekas pakai, dan regenerasi fenton. Jurnal Lingkungan dan Sumberdaya Alam (JURNALIS) 9, 85–99.

Adityosulindro, S., Nabila, F., Rus, A.M., Hartono, D.M. and Moersidik, S.S. 2024b. Investigation of methylene blue adsorption on alum sludge using full factorial 2k design. International Journal of Environment and Waste Management 35, 151–164.

Alam, M.Z. and Anwar, A.H.M.F. 2020. Nutrients adsorption onto biochar and alum sludge for treating stormwater. Journal of Water and Environment Technology 18, 132–146.

Benalia, A., Derbal, K., Baatache, O., Khalfaoui, A., Pizzi, A., Lehchili, C., Khalfaoui, A. and Pizzi, A. 2024. Removal of dyes from water using aluminum-based water treatment sludge as a low-cost coagulant: use of response surface methodology. Water (Basel). 16, 1400.

Bensitel, N., Haboubi, K., Azar, F.-Z., El Hammoudani, Y., El Abdouni, A., Haboubi, C., Dimane, F. and El

Kasmi, A. 2023. Potential reuse of sludge from a potable water treatment plant in Al Hoceima city in northern Morocco. Water Cycle 4, 154–162.

Davarnejad, R., Pishdad, R. and Sepahvand, S. 2018. Dye adsorption on the blends of saffron petals powder with activated carbon: response surface methodology. International Journal of Engineering 31.

Etim, U.J., Umoren, S.A. and Eduok, U.M. 2016. Coconut coir dust as a low cost adsorbent for the removal of cationic dye from aqueous solution. Journal of Saudi Chemical Society 20, S67–S76.

Fan, S., Wang, Y., Wang, Z., Tang, Jie, Tang, Jun and Li, X. 2017. Removal of methylene blue from aqueous solution by sewage sludge-derived biochar: Adsorption kinetics, equilibrium, thermodynamics and mechanism. Journal of Environmental Chemical Engineering 5, 601–611.

Gupta, A. and Garg, A. 2015. Utilisation of sewage sludge derived adsorbents for the removal of recalcitrant compounds from wastewater: Mechanistic aspects, isotherms, kinetics and thermodynamics. Bioresource Technology 194, 214–224.

Hassan, M.M. and Carr, C.M. 2021. Biomass-derived porous carbonaceous materials and their composites as adsorbents for cationic and anionic dyes: A review. Chemosphere 265, 129087.

Isnasari, Y., Nasution, S.Y. and Ratnasari, D. 2020. Techno-economic and supply chain analysis of nano tea made from mangosteen peel as functional food. IOP Conference Series: Earth and Environmental Science 528, 012047.

Khan, Idrees, Saeed, K., Zekker, I., Zhang, B., Hendi, A.H., Ahmad, A., Ahmad, S., Zada, N., Ahmad, H., Shah, L.A., Shah, T., Khan and Ibrahim 2022. Review on methylene blue: its properties, uses, toxicity and photodegradation. Water (Basel). 14, 242.

Li, H., Budarin, V.L., Clark, J.H., North, M. and Wu, X. 2022. Rapid and efficient adsorption of methylene blue dye from aqueous solution by hierarchically porous, activated starbons®: Mechanism and porosity dependence. Journal of Hazardous Materials 436, 129174.

Ling, Y.P., Tham, R.-H., Lim, S.-M., Fahim, M., Ooi, C.-H., Krishnan, P., Matsumoto, A. and Yeoh, F.-Y. 2017. Evaluation and reutilization of water sludge from fresh water processing plant as a green clay substituent. Applied Clay Science 143, 300–306.

Muhammad, R. and Adityosulindro, S. 2022. Biosorption of brilliant green dye from synthetic wastewater by modified wild algae biomass. Evergreen 09, 133–140.

Muisa, N., Nhapi, I., Ruziwa, W. and Manyuchi, M.M. 2020. Utilization of alum sludge as adsorbent for phosphorus removal in municipal wastewater: A review. Journal of Water Process Engineering 35, 101187.

Nasrullah, A., Saad, B., Bhat, A.H., Khan, A.S., Danish, M., Isa, M.H. and Naeem, A. 2019. Mangosteen peel waste as a sustainable precursor for high surface area mesoporous activated carbon: Characterization and application for methylene blue removal. Journal of Cleaner Production 211, 1190–1200.

Nisrina, K.F., Adityosulindro, S. and Direstiyani, L.C. 2024. Utilization of Sidoarjo volcanic mud as heterogeneous catalyst in persulfate oxidation process for congo red dye removal: a preliminary study. Jurnal Presipitasi 21.

Nuanhchamnong, C., Kositkanawuth, K. and Wantaneeyakul, N. 2022. Granular waterworks sludge-biochar composites: Characterization and dye removal application. Results in Engineering 14, 100451.

Nurianto, T.M., Laksono, S., Kusrestuwardhani and Adityosulindro, S. 2024. Utilization of fly ash composite from municipal solid waste incineration (MSWI) as an adsorbent to remove methylene blue from wastewater. IOP Conference Series: Earth and Environmental Science 1414, 012007.

Oladoye, P.O., Ajiboye, T.O., Omotola, E.O. and Oyewola, O.J. 2022. Methylene blue dye: Toxicity and potential elimination technology from wastewater. Results in Engineering 16, 100678.

Ooi, T.Y., Yong, E.L., Din, M.F.M., Rezania, S., Aminudin, E., Chelliapan, S., Abdul Rahman, A. and Park, J. 2018. Optimization of aluminium recovery from water treatment sludge using Response Surface Methodology. Journal of Environmental Management 228, 13–19.

Phawachalotorn, C. and Suwanpayak, N. 2021. The efficiency of mangosteen peel for dye removal, in: Journal of Physics: Conference Series. IOP Publishing Ltd, Siam.

Poormand, H., Leili, M. and Khazaei, M. 2017. Adsorption of methylene blue from aqueous solutions using water treatment sludge modified with sodium alginate as a low cost adsorbent. Water Science and Technology 75, 281–295.

Rápó, E. and Tonk, S. 2021. Factors affecting synthetic dye adsorption; desorption studies: a review of results from the last five years (2017–2021). Molecules 26, 5419.

Rashid Ahmed, H. and Kayani, K.F. 2024. A comparative review of Fenton-like processes and advanced oxidation processes for Methylene Blue degradation. Inorganic Chemistry Communications 170, 113467.

Salazar-Rabago, J.J., Leyva-Ramos, R., Rivera-Utrilla, J., Ocampo-Perez, R. and Cerino-Cordova, F.J. 2017. Biosorption mechanism of Methylene Blue from aqueous solution onto White Pine (Pinus durangensis) sawdust: Effect of operating conditions. Sustainable Environment Research 27, 32–40.

Soliman, M.F., Rashed, M.N. and Ahmd, A.A. 2023. Chemical activation of sludge from drinking water treatment plant for adsorption of methylene blue dye. Water Air Soil Pollut. 234, 228.

Soltani, A., Faramarzi, M. and Mousavi Parsa, S.A. 2021. A review on adsorbent parameters for removal of dye products from industrial wastewater. Water Quality Research Journal 56, 181–193.

Tayeb, A., Abdelmoez, W., Farouq, R. and Gedawy, H. 2022. Recycling of conditioned alum sludge use as an adsorbent for decolorization of effluents from the Textile Industry. International Journal of Social Ecology and Sustainable Development 13, 1–11.

Teixeira, S.R., Santos, G.T.A., Souza, A.E., Alessio, P., Souza, S.A. and Souza, N.R. 2011. The effect of incorporation of a Brazilian water treatment plant sludge on the properties of ceramic materials. Applied Clay Science 53, 561–565.

Tony, M.A. 2020. Zeolite-based adsorbent from alum sludge residue for textile wastewater treatment. International Journal of Environmental Science and Technology 17, 2485–2498.

Vedula, S.S. and Yadav, G.D. 2022. Wastewater treatment containing methylene blue dye as pollutant using adsorption by chitosan lignin membrane: Development of membrane, characterization and kinetics of adsorption. Journal of the Indian Chemical Society 99, 100263.

Xia, Y., Zhang, S., Tang, X., Yan, B. and Zheng, H. 2024. Selective adsorption of methylene blue dye by a flocculation sludge-derived adsorbent prepared by carboxymethyl chitosan-based flocculants. International Journal of Biological Macromolecules 278, 134997.

Yaashikaa, P.R., Kumar, P.S., Saravanan, A. and Vo, D.-V.N. 2021. Advances in biosorbents for removal of environmental pollutants: A review on pretreatment, removal mechanism and future outlook. Journal of Hazardous Materials 420, 126596.

Yeshitila, S., Asere, T.G., Yitbarek, M. and Melak, F. 2025. Alumina sludge from water treatment plants for removing methylene blue dye from water: a circular economy approach. International Journal of Environmental Research 19, 127.

Yunusa, U., Usman, B. and Ibrahim, M.B. 2021. Cationic dyes removal from wastewater by adsorptive method: A systematic in-depth review. Algerian Journal of Chemical Engineering 02, 6–40.

Yusuff, S.M., Khim, O.K., Yunus, W.M.Z.W., Fitrianto, A., Ahmad, M.B., Ibrahim, N.A., Osman, M.J. and Chuang, T.C. 2017. Adsorption kinetics and isotherm of methylene blue by thermally treated alum-based water treatment plant sludge. International Journal of Advanced and Applied Sciences 4, 89–93.

Zahro, S.F. and Adityosulindro, S. 2023. Literature Review: Penggunaan bahan berbasis limbah sebagai adsorben untuk degradasi zat warna pada air limbah. Jurnal Kesehatan Lingkungan Indonesia 22, 359–368.

Zhao, W., Xie, H., Li, J., Zhang, L. and Zhao, Y. 2021. Application of alum sludge in wastewater treatment processes: “science” of reuse and reclamation pathways. Processes 9, 612.