Characterization of marine coral fragment-derived calcium oxide and its performance in chloramphenicol removal from water

Sofyatuddin Karina[1,2], *Vicky* Prajaputra[1,2*], *Nadia* Isnaini[3,4], *Putri Sri* Rahayu[1], and *Mastavioni* Sihombing[1]

[1]Department of Marine Sciences, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[2]Research Center for Marine Sciences and Fisheries, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[3]ARC-PUI Nilam Aceh, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[4]Department of Pharmacy, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia

Abstract. Chloramphenicol, a widely used antibiotic, is a persistent pollutant in aquatic environments, posing a threat to both human health and aquatic ecosystems. This study investigates the use of calcium oxide (CaO) derived from marine coral fragments as a natural adsorbent for the removal of chloramphenicol from water. Marine coral was calcined to obtain CaO, which was then characterized using techniques such as X-ray fluorescence (XRF) and Fourier-transform infrared spectroscopy (FTIR). Chloramphenicol was detected at a maximum absorption wavelength of 278 nm using UV-Vis spectroscopy. The adsorption efficiency of CaO was tested by varying the adsorbent weights (0.05 g, 0.075 g, and 0.1 g) and chloramphenicol concentrations (5, 10, 15, 20, and 25 mg/L). Results indicated that an adsorbent weight of 0.05 g was most effective, achieving an adsorption efficiency of 7.05%. The highest adsorption capacity, 0.28 mg/g, was observed at a chloramphenicol concentration of 20 ppm. However, the overall adsorption efficiency of CaO was relatively low, indicating the need for further development, such as the creation of biocomposites, to improve its adsorption capabilities. This study demonstrates that while marine coral-derived CaO shows potential as an eco-friendly adsorbent, additional research and optimization are necessary to enhance its effectiveness for water treatment applications.

1 Introduction

The presence of pharmaceutical pollutants in aquatic environments has raised serious environmental and health concerns, particularly antibiotics like chloramphenicol, widely used in human, veterinary, and aquaculture settings [1]. Chloramphenicol is a broad-spectrum antibiotic effective against a range of bacterial infections, making it a valuable tool in aquaculture for preventing and controlling diseases that can rapidly spread through fish

* Corresponding author: vicky_prajaputra@usk.ac.id

and shrimp farms [2]. In intensive aquaculture practices, antibiotics are often used to maintain the health of large populations of fish, prevent bacterial outbreaks, and reduce losses, which can be particularly severe in closed or semi-closed aquatic systems [3]. However, the frequent use of chloramphenicol has led to its accumulation in water sources, where it poses risks due to its persistence and low biodegradability, leading to environmental and human health concerns [4].

Adsorption is a cost-effective and easily applicable technique for effectively reducing the concentration of organic compounds, in wastewater [5]. This process involves the uptake of organic compounds, which accumulate on the surface of adsorbent particles, driven by interactions with the active sites on that surface [6]. The success of adsorption is largely determined by the surface area, the number of active sites, and the accessibility of the adsorbent to the compounds being adsorbed [7]. Various types of adsorbents have been tested for the removal of organic pollutants, including activated carbon [8, 9], beach sand [10, 11], silica (SiO_2) [12, 13], magnetite [14, 15], volcanic ash soil [16, 17], pumice [18, 19], zeolites [20, 21], chitosan [22, 23], bentonite [24, 25], kaolin [26, 27], and composite [28-30]. Currently, the development of locally sourced, affordable adsorbents for wastewater treatment is attracting the attention of many researchers, aiming to enhance the efficiency and sustainability of the wastewater treatment process.

Coral fragments rich in calcium carbonate ($CaCO_3$) have begun to be recognized as a natural adsorbent for adsorbing organic pollutants in wastewater [31]. Their abundant availability and porous surface structure offer significant potential for waste treatment applications. Through the calcination process, $CaCO_3$ from coral fragments can be transformed into calcium oxide (CaO), which possesses basic properties, a larger surface area, and more active sites for the adsorption process [32]. Previous studies have demonstrated the efficacy of CaO as an adsorbent for organic pollutants. For example, Kelle et al. [33] investigated the adsorption of methylene blue onto CaO and found that it exhibited high adsorption capacity, primarily due to its high surface area and basicity, which enhanced the interaction with the dye molecules. Similarly, a study by Hemmami et al. [34] highlighted the potential of CaO in removing heavy metal (Pb^{2+}, Cr^{2+}, Cd^{2+} and Hg^{2+}) from aqueous solutions, reporting that the adsorption efficiency improved significantly with increasing temperature and adsorption time of the pollutants. However, to date, there has been no research investigating the characteristics and potential of CaO derived from coral fragments as an adsorbent for chloramphenicol, leaving its adsorption capacity largely unknown. Therefore, the ability of CaO from coral fragments to uptake chloramphenicol in water will be investigated in this study.

2 Experimental

2.1 Materials

This research was conducted in marine chemistry and biotechnology fisheries laboratory, Faculty of Marine and Fisheries, Universitas Syiah Kuala. The primary samples, consisting of marine coral fragments, were collected from the Inong Bale Beach area, specifically at the geographic coordinates of 5.5553° N latitude and 95.2972° E longitude. The acquired samples were then rinsed in distilled water, dried at 100°C, and ground into a powder before used as raw materials for preparing the calcium oxide (CaO). All chemical used in this experiment, including chloramphenicol ($C_{11}H_{12}Cl_2N_2O_5$), hydrogen chloride (HCl), and sodium hydroxide (NaOH) were ordered from Merck with high grade quality.

2.2 Calcium oxide preparation from marine coral fragments

The preparation of Calcium Oxide (CaO) from marine coral fragments involved an initial cleaning and drying of the coral samples to eliminate contaminants. The coral fragments were then calcined at 900°C for 3 hours. During this thermal treatment, the calcium carbonate ($CaCO_3$) within the coral underwent decomposition, producing CaO and releasing carbon dioxide (CO_2). Following calcination, the CaO was allowed to cool prior to characterization. The characterization of the resulting CaO employed several analytical techniques, including X-Ray Fluorescence (XRF) for elemental composition analysis and Fourier Transform Infrared Spectroscopy (FTIR) to identify functional groups.

2.3 Chloramphenicol adsorption

2.3.1 Effect of chloramphenicol concentration

An amount of 0.05 g of adsorbent was added to 10 mL of chloramphenicol solution with a concentration range of 5–25 mg/L. The mixture was stirred and then left for 3 hours at room temperature (30 °C). After the adsorption period, the treated solutions were centrifuged for one minute, and the final chloramphenicol concentrations were measured using a UV-Vis spectrophotometer. The adsorption efficiency (%A) and chloramphenicol uptake capacity (q_t, in mg/g) were then calculated according to Equations 1 and 2, respectively.

$$\%A = \frac{(C_0 - C_t) \times 100}{C_0} \quad (1)$$

$$q_t = \frac{(C_0 - C_t) \times V}{m} \quad (2)$$

where C_0 and C_t are the initial chloramphenicol concentration (mg/L) and the chloramphenicol concentration after a 3-hour adsorption time (mg/L), respectively; m is the mass of the adsorbent (g), and V is the total volume of the chloramphenicol solution (L).

2.3.2 Effect of adsorbent dosage

To assess the effect of adsorbent dosage on chloramphenicol removal, varying amounts of adsorbent (0.05 g, 0.075 g, and 0.1 g) were individually added to 10 mL of chloramphenicol solution at a fixed concentration of 20 mg/L. Each mixture was stirred thoroughly and then allowed to stand for 3 hours at room temperature (30 °C). Following this period, the solutions were centrifuged for one minute to separate the adsorbent particles. The chloramphenicol concentration in the resulting supernatant was measured using a UV-Vis spectrophotometer. The adsorption capacity, represented as uptake capacity (q_t, in mg/g), was subsequently calculated based on Equation 2.

3 Results and discussion

3.1 Chemical composition of calcined coral fragments

The chemical composition analysis of coral fragments before and after calcination, as shown in Table 1, revealed a significant transformation, particularly in calcium oxide (CaO) content.

Before calcination, CaO constituted 55.4% of the material, while after calcination, it increased to 94.8%, indicating the decomposition of calcium carbonate ($CaCO_3$) into CaO due to the high-temperature process. This high CaO concentration reflected the primary component of coral as calcium carbonate, effectively converted during calcination. Minor components such as magnesium oxide (MgO) and silicon oxide (SiO) showed slight increases from 2.5% to 2.7% and from 0.8% to 0.9%, respectively, and strontium oxide (SrO) remained constant at 0.4%, suggesting their stability through calcination. Trace elements, including sodium oxide (Na_2O), potassium oxide (K_2O), iron oxide (Fe_2O_3), manganese oxide (MnO), and zinc oxide (ZnO), remained relatively unchanged, indicating the retention of trace metals common in marine materials. Phosphorus pentoxide (P_2O_5) also maintained a constant level of 0.4%, suggesting minimal organic residue transformation. The loss on ignition (LOI) decreased drastically from 40.6% before calcination to 0.9% afterward, indicating the elimination of organic and volatile compounds, which further confirmed the purity of the calcined material as predominantly CaO.

Table 1. Chemical composition of coral fragments before and after calcined process.

Composition	Percentage (%)	
	Coral fragments	Calcined coral fragments
CaO	55.4	94.8
MgO	2.5	2.7
SiO	0.8	0.9
SrO	0.4	0.4
Na_2O	0.3	0.3
K_2O	0.2	0.2
Fe_2O_3	0.3	0.3
MnO	0.05	0.05
ZnO	0.05	0.05
P_2O_5	0.4	0.4
LOI	40.6	0.9

3.2 FTIR analysis

Figure 1 presents the FTIR spectra of commercial CaO powder, marine coral samples before calcination, and after calcination at 900°C for 3 hours. The spectra displayed distinct absorption peaks that indicated specific functional groups. In commercial CaO, the characteristic CaO peak appeared at a wavenumber of 3643 cm^{-1}, while CO_3^{2-} peaks were observed at 713 cm^{-1} and 874 cm^{-1}. In the spectrum of uncalcined coral powder, no CaO absorption peak was observed. However, after calcination at 900°C, a CaO peak emerged at the same wavenumber as that of commercial CaO. Additionally, the intensity of the CO_3^{2-} absorption peak at 874 cm^{-1} decreased. Additionally, the intensity of the CO_3^{2-} absorption peak at 874 cm^{-1} begins to diminish. The decrease in carbonate peak intensity at 1411 cm^{-1} and 874 cm^{-1} after calcination indicates the decomposition of $CaCO_3$ into CaO [28]. This transformation confirmed that the calcination process effectively converted calcium carbonate in the marine coral to calcium oxide, as evidenced by the characteristic peaks.

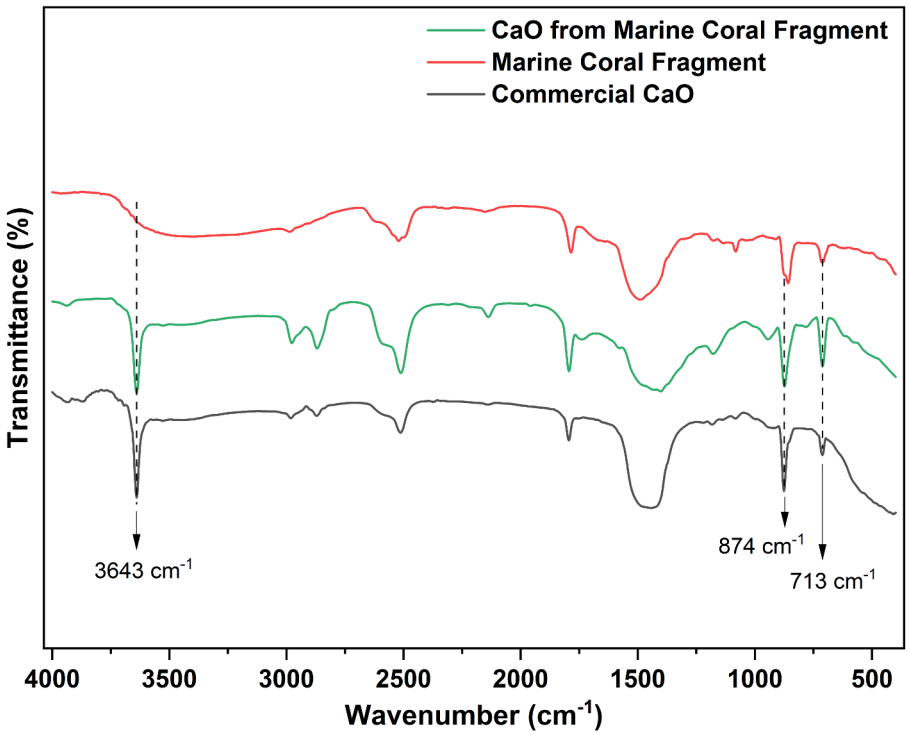

Fig. 1. FT-IR spectra of CaO from marine coral fragments.

3.3 The maximum wavelength of chloramphenicol

The maximum wavelength of a chloramphenicol-in-methanol solution was measured with a UV-Vis spectrophotometer, and the findings are depicted in Figure 2. The maximum wavelength was determined by measuring the absorbance of the chloramphenicol solution across a wavelength range of 250 nm to 500 nm. The measurements showed a peak absorbance of 0.054 at 276 nm, indicating that light at this wavelength interacted most strongly with chloramphenicol molecules, resulting in a maximum absorbance peak. This peak was a crucial indicator for identifying or measuring chloramphenicol concentration in solution, as each compound has a unique absorbance profile within a specific wavelength range. Therefore, 276 nm was selected as the optimal wavelength for chloramphenicol analysis using the UV-Vis spectrophotometer.

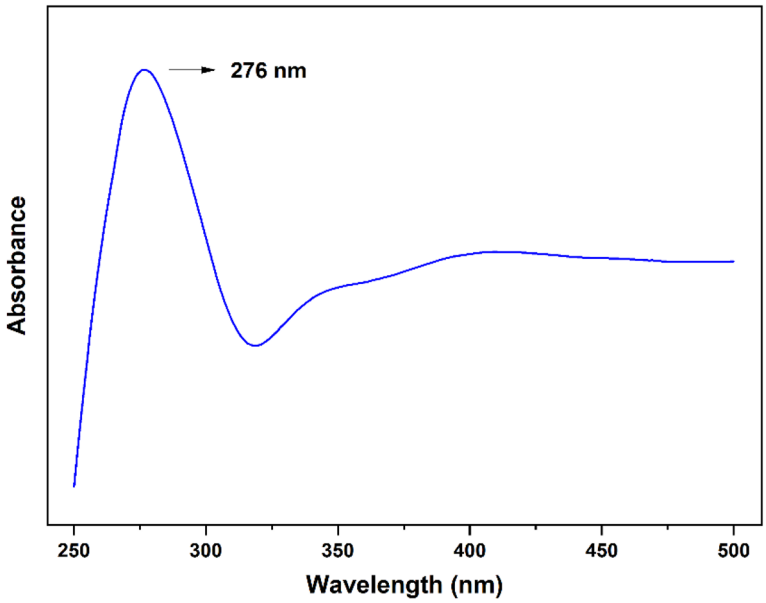

Fig. 2. The maximum wavelength of chloramphenicol in methanol.

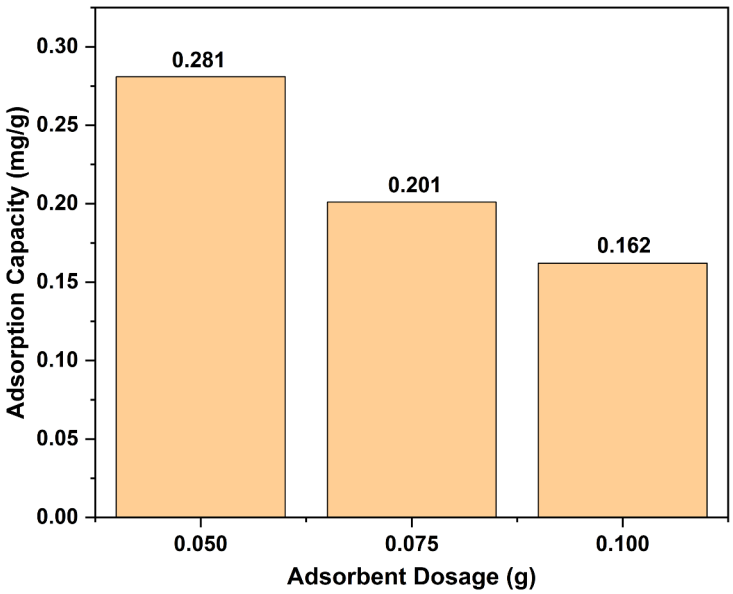

Fig. 3. The adsorption capacity of CaO for chloramphenicol uptake at varying dosages.

3.4 The influence of adsorbent dosage on chloramphenicol adsorption

Figure 3 shows the adsorption capacity of CaO for chloramphenicol at different adsorbent dosages: 0.050 g, 0.075 g, and 0.100 g. The highest adsorption capacity was observed at a dosage of 0.050 g, with a value of 0.281 mg/g. As the adsorbent dosage increased, the adsorption capacity decreased, with values of 0.201 mg/g at 0.075 g and 0.162 mg/g at 0.100 g. This trend suggests that higher dosages of CaO may result in a reduction of adsorption capacity per gram of adsorbent. The decrease in adsorption capacity with increased dosage

could be due to the overlapping of active sites on the CaO surface or aggregation of particles, which reduces the surface area available for chloramphenicol uptake. Consequently, using a lower dosage of CaO appears to optimize the adsorption capacity for chloramphenicol in this study.

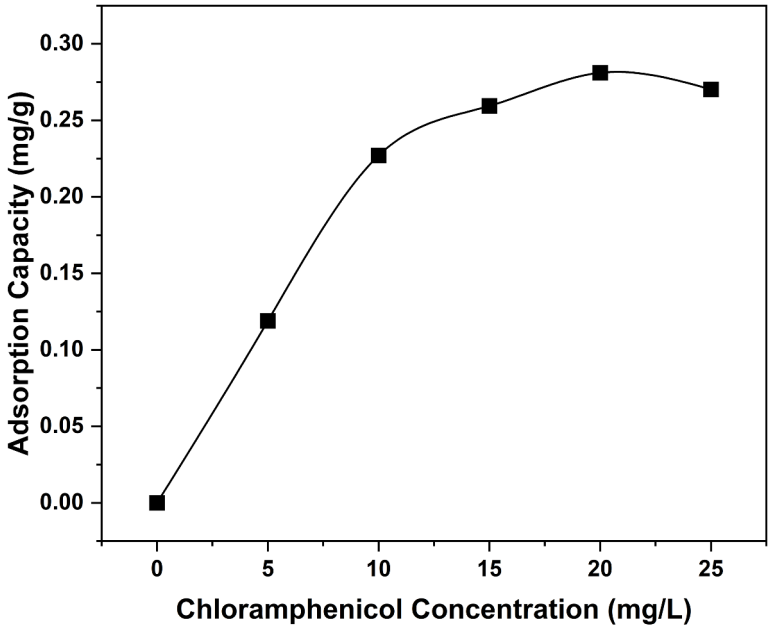

Fig. 4. The adsorption capacity of CaO at varying chloramphenicol concentrations.

3.5 The influence of concentration on chloramphenicol adsorption

The main objective of examining the effect of concentration on the adsorption process is to understand how varying levels of the adsorbate (chloramphenicol) in solution influence its adsorption onto the surface of CaO. Figure 4 illustrates the impact of chloramphenicol concentrations, ranging from 5 to 25 mg/L, on the adsorption capacity of CaO. As the chloramphenicol concentration increased from 5 mg/L to 20 mg/L, the adsorption capacity of CaO rose from 0.119 mg/g to approximately 0.281 mg/g. When the concentration was further raised to 25 mg/L, the adsorption capacity slightly decreased to 0.270 mg/g, indicating that the active sites on CaO had likely reached saturation. Ahmad [35] suggests that, as the adsorbate concentration rises, the adsorbent surface eventually becomes saturated due to the limited availability of active sites. These results show that CaO effectively adsorbed chloramphenicol at a concentration of 20 mg/L, achieving a removal rate of 7.05%. This limited adsorption performance highlights the need for further optimization, such as incorporating CaO into biocomposites, to enhance adsorption efficiency.

4 Conclusion

This study investigated the potential of calcium oxide (CaO) derived from marine coral fragments as a natural adsorbent for removing chloramphenicol from water. The calcination of coral fragments at high temperatures successfully converted calcium carbonate ($CaCO_3$) into CaO, as evidenced by significant changes in chemical composition and FTIR spectra. CaO showed promising adsorption capabilities, with an optimal adsorption capacity of 0.28

mg/g observed at a chloramphenicol concentration of 20 mg/L. However, the overall adsorption efficiency was relatively low, achieving a maximum removal efficiency of only 7.05%. This limited performance suggests the need for further development, such as incorporating CaO into biocomposites, to enhance adsorption efficiency. Nonetheless, the study highlights the potential of marine coral-derived CaO as an eco-friendly and locally sourced adsorbent, laying the groundwork for more sustainable solutions in water treatment applications targeting pharmaceutical contaminants like chloramphenicol.

Acknowledgment

The present study was financially supported by Universitas Syiah Kuala and the Ministry of Education, Culture, Research, and Technology through the Lector Grant Program for the fiscal year 2024 (Grant number: 366/UN11.2.1/PG.01.03/SPK/PTNBH/2024).

References

1. A. Singh, S.G. Pratap, A. Raj, Occurrence and dissemination of antibiotics and antibiotic resistance in aquatic environment and its ecological implications: a review. Environmental Science and Pollution Research. **31**, 47505–47529 (2024)
2. S.S. Leong, S. Lihan, S.C. Toh, Prevalence of chloramphenicol-resistant gene in Escherichia coli from water sources in aquaculture farms and rivers of Kuching, Northwestern Borneo. Fisheries and Aquatic Sciences. **25**, 202–213 (2022)
3. A. Hossain, M. Habibullah-Al-Mamun, I. Nagano, S. Masunaga, D. Kitazawa, H. Matsuda, Antibiotics, antibiotic-resistant bacteria, and resistance genes in aquaculture: risks, current concern, and future thinking. Environmental Science and Pollution Research. **29**, 11054–11075 (2022)
4. J.N. Naat, S. Suyanta, N. Nuryono, Hydrophobic modification of naturally magnetic silica with methyltrimethoxysilane for enhanced adsorption of chloramphenicol and ciprofloxacin. Case Studies in Chemical and Environmental Engineering. **10**, 100878 (2024)
5. R. Rashid, I. Shafiq, P. Akhter, M.J. Iqbal, M. Hussain, A state-of-the-art review on wastewater treatment techniques: the effectiveness of adsorption method. Environmental Science and Pollution Research. **28**, 9050-9066 (2021)
6. Z. Raji, A. Karim, A. Karam, S. Khalloufi, Adsorption of heavy metals: mechanisms, kinetics, and applications of various adsorbents in wastewater remediation—a review. Waste. **1(3)**, 775-805 (2023)
7. S. De Gisi, G. Lofrano, M. Grassi, M. Notarnicola, Characteristics and adsorption capacities of low-cost sorbents for wastewater treatment: A review. Sustainable Materials and Technologies. **9**, 10-40 (2016)
8. D. Dimbo, M. Abewaa, E. Adino, A. Mengistu, T. Takele, A. Oro, M. Rangaraju, Methylene blue adsorption from aqueous solution using activated carbon of spathodea campanulata. Results in Engineering. **21**, 101910 (2024)
9. O.J. Al-Sareji, R.A. Grmasha, M. Meiczinger, R.A. Al-Juboori, V. Somogyi, K.S. Hashim, A Sustainable Banana Peel Activated Carbon for Removing Pharmaceutical Pollutants from Different Waters: Production, Characterization, and Application. Materials. **17(5)**, 1032 (2024)

10. V. Prajaputra, S. Karina, A. Bismi, P.H. Nuufus, The removal of ciprofloxacin from water by Alue Naga and Leungah beach sand. IOP Conference Series: Earth and Environmental Science. **1356**, 012058 (2024)
11. R. Ansari, A. Mohammad-khah, M. Nazmi, Application of chemically modified beach sand as low cost efficient adsorbent for dye removal. Current Chemistry Letters. **2(4)**, 215-223 (2013)
12. S. Karina, V. Prajaputra, A.W. Perdana, N. Isnaini, A. Bismi, P.H. Nuufus, Removal of tetracycline from aqueous solution by beach sand-based silica. IOP Conference Series: Earth and Environmental Science. **1266**, 012034 (2023)
13. Y. Zhang, Z.A. Qiao, Y. Li, Y. Liu, Q. Huo, Cooperative adsorbent based on mesoporous SiO 2 for organic pollutants in water. Journal of Materials Chemistry. **21(43)**, 17283-17289 (2011)
14. S.K. Panda, I. Aggarwal, H. Kumar, L. Prasad, A. Kumar, A. Sharma, D.V.N. Vo, D.V. Thuan, V. Mishra, Magnetite nanoparticles as sorbents for dye removal: a review. Environmental Chemistry Letters. **19**, 2487-2525 (2021)
15. S. Karina, A.W. Perdana, V. Prajaputra, N. Isnaini, P.H. Nuufus, A. Bismi, Silica-Magnetite Composite as an Eco-Friendly Adsorbent for Aqueous Tetracycline Removal–Kinetic and Isotherm Studies. Ecological Engineering & Environmental Technology. **25**, 82-92 (2024)
16. R. Lavecchia, A. Zuorro, O. Baaloudj, M. Brienza, Trimethoprim removal from aqueous solutions via volcanic ash-soil adsorption: process modeling and optimization. Water. **16(15)**, 2209 (2024)
17. V. Prajaputra, Z. Abidin, Widiatmaka, Methylene Blue Removal Using Developed Material from Volcanic Ash Soils. International Journal of Scientific & Technology Research. **8**, 706-709 (2019)
18. A.R. Kul, V. Benek, A. Selçuk, N. Onursal, Using natural stone pumice in van region on adsorption of some textile dyes. Journal of the Turkish Chemical Society Section A: Chemistry. **4(2)**, 525-536 (2017)
19. V. Prajaputra, Z. Abidin, S. Budiarti, D.T. Suryaningtyas, N. Isnaini, Comparative study of methylene blue adsorption using alkali-activated pumice from Bali and Banten. Journal of Physics: Conference Series. **1882**, 012118 (2021)
20. Y. Dehmani, B.B. Mohammed, R. Oukhrib, A. Dehbi, T. Lamhasni, Y. Brahmi, A. El-Kordy, D.S.P. Franco, J. Georgin, E.C. Lima, A.A Alrashdi, N. Tijani, S. Abouarnadasse, Adsorption of various inorganic and organic pollutants by natural and synthetic zeolites: A critical review. Arabian Journal of Chemistry. **17(1)**, 105474 (2024)
21. V. Prajaputra, Z. Abidin, S. Budiarti, D.T. Suryaningtyas, Synergistic effect of adsorption and Fenton-like oxidation processes for Methylene blue removal using Na-P1 zeolite prepared from pumice. Desalination and Water Treatment. **218**, 401-408 (2021)
22. W.H. Cheung, Y.S. Szeto, G. McKay, Intraparticle diffusion processes during acid dye adsorption onto chitosan. Bioresource technology. **98(15)**, 2897-2904 (2007)
23. I.O. Saheed, W. Da Oh, F.B.M. Suah, Chitosan modifications for adsorption of pollutants–A review. Journal of hazardous materials. **408**, 124889 (2021).
24. A.K. Dhar, H.A. Himu, M. Bhattacharjee, M.G. Mostufa, F. Parvin, Insights on applications of bentonite clays for the removal of dyes and heavy metals from wastewater: a review. Environmental Science and Pollution Research. **30(3)**, 5440-5474 (2023).

25. S. Lubis, Sheilatina, S.S. Nika, V.P. Putra, Adsorption of naphthol blue black dye onto acid activated titania pillared bentonite: Equilibrium study. Oriental Journal of Chemistry. **32**, 1789-97 (2016)
26. W.T. Sibhat, H.S. Ayele, M. Atlabachew, K.S. Mohammed, B.A. Aragaw, B. Abebaw, D.T. Ayele, Effect of Ethiopian kaolin treatment on the performance of adsorptive removal of methylene blue dye. Results in Chemistry. **13**, 102027 (2025)
27. A.R. Tehrani-Bagha, H. Nikkar, N.M. Mahmoodi, M. Markazi, F.M. Menger, The sorption of cationic dyes onto kaolin: Kinetic, isotherm and thermodynamic studies. Desalination. **266**, 274-280 (2011)
28. V. Prajaputra, S. Karina, N. Isnaini, P.S. Rahayu, M. Sihombing, Investigating the potential of coral fragment-based CaO-ZnO biocomposites for the sustainable photodegradation of chloramphenicol. Ecological Engineering & Environmental Technology. **26(2),** 420-427 (2025)
29. K. Li, J. Yan, Y. Zhou, B. Li, X. Li, β-cyclodextrin and magnetic graphene oxide modified porous composite hydrogel as a superabsorbent for adsorption cationic dyes: Adsorption performance, adsorption mechanism and hydrogel column process investigates. Journal of Molecular Liquids. **335**, 116291 (2021)
30. Z. Abidin, A.H. Triawati, S. Sugiarti, A.G. Fahmi, V. Prajaputra, D. Kharisma, Multifunctional Composites of Hydroxy-Fe/Polyacrylates and its Surface Properties. IOP Conference Series: Earth and Environmental Science. **187**, 012073 (2018)
31. P.H. Chen, W.S. Chen, S.A. Chen, W.C. Chen, Synthesis of High-Precision Sub-Micron CaCO3 Anticancer Drug Carriers from Coral Remains. Applied Sciences. **14**, 1336 (2024)
32. S. Widianingsih, I. Yanti, A. Kamari, I. Fatimah, Thermal Conversion of Coral Waste and its Utilization as Low-Cost Catalyst for Biodiesel Production. Science and Technology Indonesia. **9**, 866-875 (2024)
33. H.I. Kelle, E.C. Ogoko, O. Akintola, N.O Eddy, Quantum and experimental studies on the adsorption efficiency of oyster shell–based CaO nanoparticles (CaONPO) towards the removal of methylene blue dye (MBD) from aqueous solution. Biomass Conversion and Biorefinery. **2023**, 1-24 (2023)
34. H. Hemmami, S. Zeghoud, I. Ben Amor, A. Alnazza Alhamad, A. Tliba, A. Alsalme, D. Cornu, M. Bachelany, A. Barhoum, Green synthesis of CaO nanoparticles from chicken eggshells: antibacterial, antifungal, and heavy metal ($Pb2^{+}$, $Cr2^{+}$, $Cd2^{+}$ and $Hg2^{+}$) adsorption properties. Frontiers in Environmental Science. **12**, 1450485 (2024)
35. K. Ahmad, Feasibility of the adsorption as a process for its large scale adoption across industries for the treatment of wastewater: Research gaps and economic assessment. Journal of Cleaner Production. **388**, 136014 (2023).