CHEMICAL ENGINEERING TRANSACTIONS
VOL. 122, 2025
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Jeng Shiun Lim, Bohong Wang, Guo Ren Mong, Petar S. Varbanov

ISBN 979-12-81206-23-6; **ISSN** 2283-9216
DOI: 10.3303/CET25122078

Efficiency of Waste Mussel Shells (*Perna viridis*) as Adsorbents for Ammonia (NH_3) and Phosphate (PO_4^{3-}) in Lake Water Treatment

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Aquatic plants and algae can grow quickly in lake water that contains excessive levels of minerals like phosphate (PO_4^{3-}) and ammonia (NH_3). This overgrowth frequently jams waterways and causes algal blooms, which lower oxygen levels and kill fish. This study investigates a possible method for purifying nutrient-rich lake water, especially in lakes where ammonia levels fluctuate. The study intends to offer a cost-effective and ecologically advantageous method of treating water by assessing the usage of leftover mussel shells (*Perna viridis*) as a natural adsorbent. Reducing phosphate and ammonia levels in water not only helps restore ecological balance but may also boost fish populations, supporting local fisheries and the economy. This study aims to assess the efficiency of discarded mussel shells in removing phosphate (PO_4^{3-}) and ammonia (NH_3) from lake water. The goal is to determine which nutrient the adsorbent targets more efficiently. Experimental tests were conducted at the Machine Shop of Mapúa Malayan Colleges Laguna, while pre- and post-water treatments were performed at Cosmolab Laboratories, Inc. Lake water samples (500 mL each) were placed in three capped glass jars, each treated with a different amount of mussel shell powder: 4g, 9g, and 14g. After the adsorption process, phosphate removal efficiency was measured using the spectrophotometric method. Both 4g and 9g samples had a 71% reduction, but 14g samples had a noticeably greater reduction of 97.14%. For the 4g and 9g treatments, the phosphate concentrations decreased to 0.1 mg/L, while for the 14g treatment, they decreased to 0.01 mg/L. In contrast, ammonia levels, as determined by the phenate technique, were consistent at 0.5 mg/L in all three samples. These results imply that waste mussel shells have the potential to be used on a larger scale in water treatment systems since they are very good at eliminating phosphate from lake water.

1. Introduction

In the Philippines, mussel shells (*Perna viridis*), sometimes referred to as tahong locally, are a popular and reasonably priced shellfish that is prized for its adaptability and simplicity of preparation. With the highest spawning taking place in April–May and September–October, these bivalves are harvested all year round and flourish in brackish to saline waters. It is predicted that 12,000 megatons are produced annually. *Perna viridis* shells have a lot of potential for environmental uses, especially in wastewater treatment, in addition to their use in the food industry.

Mussel shells, which are made up of about 95% calcium carbonate, can be used as inexpensive and efficient adsorbents to remove contaminants including heavy metals and organic materials (Tizoa-Blanco et al., 2018). Therefore, reusing abandoned mussel shells provides a locally accessible and sustainable way to address the problem of water pollution which is still a major issue in the Philippines and around the world, endangering aquatic ecosystems and public health.

Hazardous algal blooms and eutrophication, which deteriorate water quality and disturb marine life, are caused by pollutants like ammonia and phosphates that come from sewage, industrial discharge, agricultural runoff, fertilizers, and pesticides. Additionally, hazardous heavy metals like lead and mercury found in industrial effluents bioaccumulate in the food chain and endanger the long-term health of both people and wildlife.

Paper Received: 15 June 2025; Revised: 14 July 2025; Accepted: 20 September 2025
Please cite this article as: Tandoc M.J.M., Capinig K.F.P., Paras M.C., Escuadro T.G.T., Escobal C.A.M., 2025, Efficiency of Waste Mussel Shells (Perna viridis) as Adsorbents for Ammonia (NH_3) and Phosphate (PO_4^{3-}) in Lake Water Treatment, Chemical Engineering Transactions, 122, 463-468 DOI:10.3303/CET25122078

Furthermore, sediments from farming and building projects clog gills and disturb ecosystems, lowering water purity and endangering aquatic life. An estimated 55 people perish every day in the Philippines from waterborne illnesses and inadequate sanitation infrastructure, while about nine million people still depend on contaminated water sources (Jones, 2015).

Laguna de Bay, the biggest freshwater lake in the Philippines and an essential resource for Metro Manila, is a well-known example. It provides around one-third of the fish in the area and is essential to industry, agriculture, and the production of hydroelectric power. However, overfishing, industrial waste, and untreated sewage are all contributing to Laguna de Bay's growing pollution. On a scale where "A" denotes exceptional quality and "F" denotes the worst, signifying significant environmental degradation, recent evaluations of the lake's water quality have placed it between grades "C" and "F" for fishery use.

Previous research has investigated the use of various calcium-rich biowaste materials such as oyster shells, eggshells, and mollusk shells for wastewater treatment due to their adsorptive properties and high calcium carbonate content (Tizoa-Blanco et al., 2018; Huang et al., 2016). Studies have shown their efficacy in removing pollutants such as heavy metals and organic compounds from contaminated water. However, despite the abundance of *Perna viridis* in the Philippines, there is limited research focused on its use as an adsorbent, particularly in the context of local water bodies like Laguna de Bay. Furthermore, existing studies often rely on controlled laboratory conditions using synthetic solutions, which may not accurately reflect the complexity of real-world polluted water systems. There remains a lack of data on the performance of *Perna viridis* shells in treating actual lake water containing mixed contaminants from domestic, agricultural, and industrial sources.

This study seeks to address the identified research gap by evaluating the adsorption potential of *Perna viridis* (green mussel) shells for pollutant removal using water samples collected directly from Laguna de Bay. By utilizing a locally abundant and typically discarded biowaste material, the research aims to contribute to the development of sustainable, low-cost, and contextually appropriate water treatment strategies suited to the Philippine setting. Specifically, the study targets pressing environmental issues affecting the lake, including the occurrence of fish kills sudden mass die-offs of fish that severely impact the livelihood of local fishers. One of the primary causes of fish kills is algal blooms, which are triggered by excessive nutrient loading, particularly elevated concentrations of ammonia (NH_3) and phosphate (PO_4^{3-}) in the water (Angeles, 2019).

1.1 Objectives

This study generally aims to determine how well waste mussel shells (*Perna viridis*) work as an adsorbent to remove phosphate (PO_4^{3-}) and ammonia (NH_3) from contaminated lake water, specific objectives are:

1. To assess the potential of waste mussel shells as a natural, low-cost adsorbent material.
2. To evaluate the effect of mussel shell powder on the concentrations of ammonia and phosphate in contaminated water.
3. To compare the adsorption efficiency of mussel shells for ammonia versus phosphate.
4. To determine the relationship between the amount of mussel shell adsorbent used and the reduction in ammonia and phosphate levels.

2. Methodology

Waste mussel shells were collected from a local restaurant, thoroughly cleaned, oven-dried, crushed, and sieved to a particle size of 0.3 mm, then calcined at 750°C for 3 h to prepare the adsorbent material. The resulting shell powder was stored for use in the adsorption experiments. The process of mussel shell adsorbent and the experimental workflow is presented in Figure 1, which shows the major steps from collection to adsorption testing.

Figure 1: (a) Oven machine used for drying mussel shells prior to processing, (b) mussel shells after oven-drying and (c) powdered mussel shells after crushing, sieving (0.3 mm) calcination at 750°C

One liter of lake water from Sta. Rosa, Laguna de Bay, was initially analyzed as control to determine baseline concentrations of ammonia (NH_3) and phosphate (PO_4^{3-}). As shown in Figure 2, subsequent water samples were treated separately with 4 g, 9 g, and 14 g of mussel shell powder in individual jars, which were intermittently shaken for 3 h to facilitate adsorption. Both pre-treatment and post-treatment samples were analyzed by Cosmolab Laboratories to assess changes in contaminant levels. Due to limitations in sample volume and resource constraints, replicates were not performed; instead, the study focused on obtaining preliminary data to evaluate the potential of waste mussel shells as an adsorbent.

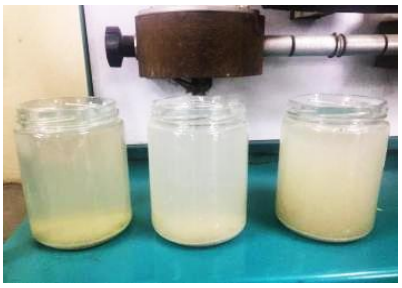
(a)  (b) 

Figure 2: (a) Lake water samples (500 mL) treated with 4 g, 9 g, and 14 g of mussel shell adsorbent from left to right (L–R), (b) experimental setup showing treated samples shaken for 3 h to facilitate adsorption

3. Results and Discussion

Laguna Lake water is classified as Class C under the freshwater quality guidelines established by the Department of Environment and Natural Resources (DENR). For reference, the allowable concentration limits for ammonia (NH_3) and phosphate (PO_4^{3-}) under Class D standards which are less stringent are 0.75 mg/L and 5 mg/L, respectively. In this study, the initial concentrations of ammonia and phosphate in the lake water were measured at <0.1 mg/L and 0.35 mg/L, as shown in Table 1. Both values are well within the acceptable limits for Class D waters and fall below the thresholds for Class C classification, indicating relatively low nutrient pollution at the time of sampling.

Table 1: Initial analysis of Ammonia (NH_3) and Phosphate (PO_4^{3-}) in lake water sample

Parameter	Unit	Method	Effluent STD.	Results
Ammonia	mg/L	Phenate Method	0.5 mg/L	<0.1 mg/L
Phosphate	mg/L	Spectrophotometric	1 mg/L	0.35 mg/L

As shown in Table 2, the phosphate (PO_4^{3-}) concentrations in the samples treated with 4 g and 9 g of mussel shell adsorbent were both recorded at <0.1 mg/L. In contrast, the sample treated with 14 g of adsorbent exhibited a notably lower phosphate level of <0.01 mg/L, representing the highest removal efficiency among the three treatments. This outcome is likely due to the increased surface area provided by the larger quantity of shell powder, which enhances adsorption capacity.

Table 2: Phosphate (PO_4^{3-}) levels in lake water samples after treatment

Adsorbent (g)	Effluent Standard (mg/L)	Levels of Phosphate (mg/L)
4	1 mg/L	<0.1 mg/L
9	1 mg/L	<0.1 mg/L
14	1 mg/L	<0.01 mg/L

Table 3 indicates that ammonia (NH_3) concentrations remained consistent across all three treated samples, each showing a post-treatment level of <0.5 mg/L. This suggests that the variation in the amount of mussel shell powder had no significant impact on ammonia removal, implying limited or negligible adsorption capacity of the material for ammonia under the given experimental conditions.

Table 3: Ammonia (NH_3) levels in lake water samples after treatment

Adsorbent (g)	Effluent Standard (mg/L)	Levels of Ammonia (mg/L)
4	0.5 mg/L	<0.5 mg/L
9	0.5 mg/L	<0.5 mg/L
14	0.5 mg/L	<0.5 mg/L

3.1 Efficiency of the adsorbent to Ammonia (NH_3) and Phosphate (PO_4^{3-})

In Figure 3, light microscopy revealed that the waste mussel shell powder consists of irregular, angular particles with rough, porous surfaces typical of calcined calcium carbonate biowaste. This morphology provides abundant active sites for adsorption, enhancing the material's capacity to bind phosphate ions through surface interactions. The varied particle sizes and porous texture increase surface area, which is beneficial for adsorption efficiency. However, the irregular shape and heterogeneity may limit adsorption of smaller, more soluble pollutants like ammonia, which often require different binding mechanisms beyond surface adsorption.

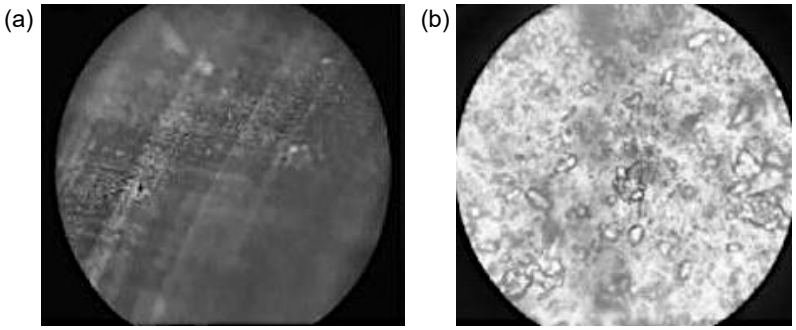


Figure 3: Light microscope morphology of waste mussel shell powder (a) before and (b) after adsorption

3.2 Percentage Removal (%) of Ammonia (NH_3) and Phosphate (PO_4^{3-})

The adsorption process demonstrated effective reduction of phosphate (PO_4^{3-}) concentrations across all treated lake water samples was shown in Figure 4. From an initial concentration of 0.35 mg/L, phosphate levels decreased to <0.1 mg/L in the samples treated with 4 g and 9 g of mussel shell powder, and further declined to <0.01 mg/L in the sample treated with 14 g. This trend suggests that increasing the quantity of adsorbent enhances phosphate removal efficiency. The minimal difference observed between the 4 g and 9 g treatments may be due to the relatively small variation in adsorbent mass, which was insufficient to produce a measurable change. However, the 14 g treatment yielded a noticeably lower phosphate level, indicating improved performance at higher adsorbent concentrations. In contrast, ammonia (NH_3) levels showed no significant variation across treatments, with all post-treatment samples recording concentrations of <0.5 mg/L. The initial ammonia level was <0.1 mg/L, indicating an increase following the adsorption process. This unexpected rise is likely due to natural fluctuations in nitrogen content in the lake water, potentially caused by surface runoff, sediment resuspension, or groundwater input, rather than the effect of the mussel shell adsorbent itself.

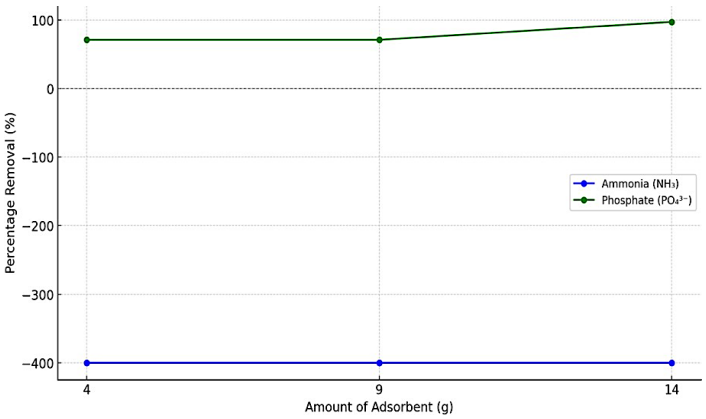


Figure 4: Percentage removal of Ammonia (NH_3) and Phosphate (PO_4^{3-}) using varying amounts of mussel shell adsorbent

Phosphate removal by *mussel* shells is driven by their calcium carbonate ($CaCO_3$) content, which enables both adsorption and precipitation mechanisms. Calcium ions released or exposed on the shell surface form low-solubility calcium phosphate compounds that adhere to or precipitate out of solution. This process is rapid, often reaching equilibrium within min to h, and involves inner-sphere complexation and ion exchange at active surface sites on calcite or aragonite minerals. Ammonia (NH_3/NH_4^+), however, exhibits little removal in this system due

to its neutral or positive form in water and its negligible affinity for calcium carbonate surfaces. Unlike phosphate, ammonia does not form insoluble complexes or precipitates with Ca^{2+} ions, nor does it participate in ion exchange processes with $CaCO_3$. As a result, ammonia remains largely unaffected by mussel shell adsorption under typical experimental conditions.

3.3 Data Analysis

To assess how waste mussel shells (*Perna viridis*) influence phosphate and ammonia levels in lake water, one-tailed paired t-tests were carried out. For phosphate (PO_4^{3-}) the starting hypothesis assumed no meaningful change in concentration after treatment. In practice, phosphate dropped from 0.35 mg/L at baseline to as low as 0.01 mg/L when 14 g of mussel shell powder was applied. The statistical output ($t(2) = 39.08$, $p < 0.01$) points toward a strong reduction in phosphate under these test conditions.

Ammonia (NH_3), on the other hand, showed the opposite trend. From an initial value below 0.1 mg/L (estimated at 0.08 mg/L), concentrations increased to about 0.5 mg/L after treatment. The paired t-test also flagged this change as significant ($t(2) = 24.7$, $p < 0.01$). This resulted in a calculated “removal efficiency” of –400%, which simply reflects the sharp increase from a very low starting point.

Because this analysis was based on a very small dataset with no replicates, the statistical power is limited. As such, the t-test results should be viewed as suggestive rather than conclusive. External influences such as microbial activity, changes in ambient nitrogen, or the release of nitrogen compounds from the shells themselves may have affected the ammonia readings. Within the scope of this study, waste mussel shells appeared highly effective for phosphate removal but unsuitable for ammonia reduction.

4. Summary

The study evaluated the efficacy of waste mussel shells (*Perna viridis*) as an adsorbent for removing phosphate (PO_4^{3-}) and ammonia (NH_3) from lake water. Initial concentrations were 0.35 mg/L for phosphate and less than 0.1 mg/L for ammonia. Following treatment, phosphate levels decreased markedly, reaching below 0.1 mg/L with 4 g and 9 g of adsorbent, and further declining to 0.01 mg/L with 14 g, demonstrating a dose-dependent increase in removal efficiency. Conversely, ammonia concentrations increased to approximately 0.5 mg/L across all treatments. A maximum phosphate removal efficiency of 97.14% was found using percentage removal calculations, while ammonia showed a negative removal rate of –400%, which was probably caused by time of sample collection or natural variations in nitrogen levels. These findings show that, under the investigated conditions, waste mussel shell powder is an excellent and economical adsorbent for phosphate removal but unsuccessful for ammonia reduction.

5. Conclusions and Recommendations

This study showed that, under the measured conditions, waste mussel shells (*Perna viridis*) are unsuccessful at removing ammonia (NH_3) from contaminated lake water, but they are very effective at removing phosphate (PO_4^{3-}). Using 14 g of powdered mussel shell, the sample's phosphate concentration decreased from its starting value of 0.35 mg/L to less than 0.01 mg/L, with a maximum removal efficiency of 97.14%. This suggests that the removal of phosphate is dose-dependent, with more adsorbent amounts producing better outcomes. On the other hand, ammonia levels in all treated samples increased from a starting value of less than 0.1 mg/L to less than 0.5 mg/L after treatment, resulting in a negative removal rate of –400%. This discrepancy is likely due to the low affinity between calcium carbonate and ammonia/ammonium ions, as well as potential external nitrogen inputs during the experimental process.

The findings confirm the potential of waste mussel shells as a sustainable, locally available, and low-cost adsorbent for phosphate remediation in aquatic systems such as Laguna de Bay. However, the results also highlight the limitations of mussel shells in treating nitrogen-based pollutants, specifically ammonia. The selective removal emphasizes the need for multi-barrier or integrated water treatment approaches when addressing complex pollutant profiles in natural waters.

To improve the accuracy, reproducibility, and overall impact of future studies, the researchers recommend the following:

- Enhanced equipment – Employ a more suitable shaker such as an incubator shaker or orbital shaker to ensure consistent agitation, temperature control, and reproducibility throughout the adsorption process.
- Optimization of adsorption parameters – Systematically study the effects of contact time, shaking speed, and temperature to determine the optimal operational conditions for maximum adsorption efficiency.

- Continuous and controlled procedures – Minimize time gaps between sample collection, preparation, and treatment to reduce variability caused by environmental factors such as nutrient inflow or microbial activity.
- Expanded water quality analysis – Incorporate additional parameters including nitrate (NO_3^-), total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), and pH. These metrics would offer a more comprehensive evaluation of the mussel shell's treatment capacity and its effect on overall water quality.
- Targeted treatment for ammonia – Investigate the use of complementary materials or technologies to address ammonia removal and create a complete treatment process. For example, coupling mussel shell powder with zeolites could enhance ammonium ion adsorption due to their high cation-exchange capacity, while integrating mussel shell application into a biofiltration system could utilize nitrifying and denitrifying microorganisms to biologically convert ammonia into less harmful forms. Other potential approaches include the use of activated carbon, constructed wetlands, or sequential treatment stages where phosphate is removed first by mussel shells, followed by targeted ammonia removal media.

Acknowledgments

The authors would like to acknowledge the staff of the machine shop at Mapua Malayan Colleges Laguna for their technical assistance and guidance during the experimental procedures. The support of the institution in providing access to research facilities is gratefully recognized. The authors also appreciate the assistance of the laboratory personnel in sample preparation and analysis, as well as the library staff for facilitating access to scientific resources.

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