JPPIPA 11(10) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Biocompatible Zn(II) Adsorption Using Tofu-Waste Polyurethane: Effects on Moisture, Ash Content, and pH of Oysters

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Received: June 29, 2025
Revised: August 22, 2025
Accepted: October 25, 2025
Published: October 31, 2025

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DOI: 10.29303/jppipa.v11i10.11911

Abstract: This study aimed to evaluate the performance of a tofu-dregs-based polyurethane adsorbent in removing Zn(II) ions and to examine its effects on the moisture content, ash content, and pH variation in oysters (Crassostrea spp.), as well as to assess compliance with Indonesian National Standards. The method used in this study involved exposing fresh oysters to $ZnSO_4$ solutions at concentrations of 2, 4, and 6 ppm for 60 minutes in the presence of the composite adsorbent. Moisture content was determined gravimetrically at 105 °C, ash content by dry ash at 550 °C, and pH was monitored throughout the contact period. The results showed that the moisture content of fresh oysters remained stable at 89–91% before and after adsorption, while dried oyster samples had reduced moisture levels of 11.0–11.8%, meeting the ≤ 12% limit for dried products. The ash content of the adsorbent increased from 3.00% to 7.80–9.60%, indicating effective retention of Zn(II) ions, whereas the ash content of oysters remained relatively constant at 1.90–1.96%, suggesting minimal accumulation of metal ions in the tissues. A gradual increase in solution pH during the adsorption process confirmed chemical interactions between Zn^{2+} ions and functional groups on the adsorbent surface. These findings demonstrate that the tofu-dregs-based polyurethane adsorbent is effective for Zn(II) removal while maintaining oyster quality within national safety standards, highlighting its potential as an environmentally friendly material for heavy-metal remediation.

Keywords: Ash content; Moisture content; Oyster; pH; Tofu-dregs polyurethane adsorbent; Zn^{2+}

Introduction

Heavy contamination in aquatic ecosystems poses a serious environmental threat due to its metal toxic effects on marine organisms and its potential to enter the food chain, ultimately affecting human health (Abdel-Aziz et al., 2017; Sunartaty et al., 2024a). Among various heavy metals, zinc (Zn^{2+}) is commonly found in coastal waters (Nguyen et al., 2020), originating from industrial effluents, agricultural runoff, and antifouling paints. Oysters (Crassostrea spp.), known for their high filtration capacity (B. Wang et al., 2018) and ability to bioaccumulate metals in their tissues, are widely used as bioindicator organisms for monitoring aquatic pollution (Muliani et al., 2021). However, prolonged exposure to high concentrations of heavy metals can lead to physiological (Azimi et al., 2017) and structural damage in oysters (McCarty et al., 2022). Therefore, the development of environmentally friendly and cost-effective adsorption methods is crucial for reducing metal contamination in aquatic environments, especially those that do not harm aquatic biota (Largitte et al.,

How to Cite:
sunartaty, rita, & Irmayadani. (2025). Biocompatible Zn(II) Adsorption Using Tofu-Waste Polyurethane: Effects on Moisture, Ash Content, and pH of Oysters. *Jurnal Penelitian Pendidikan IPA*, *11*(10), 677–685. https://doi.org/10.29303/jppipa.v11i10.11911

2016). One promising approach is the use of bio-based adsorbents derived from agro-industrial waste (Sunartaty et al., 2022).

Various studies related to tofu residue have been conducted (Sunartaty et al., 2024b)(Sunartaty et al., 2024a) tofu pulp, a by-product rich in lignocellulose and protein content, can be used as a functional filler in polyurethane foam to form a porous composite adsorbent. This material provides suitable active sites for metal ion adsorption while contributing to sustainable waste utilization. However, previous studies have not examined Zn levels in oysters, focusing instead on testing the adsorption of Pb and Cu using polyurethane-based adsorbents. To evaluate the performance and potential impact of tofu pulp-based polyurethane as an adsorbent, this study measured three main parameters in oysters exposed to Zn^{2+} solutions before and after the adsorption process: moisture content, ash content, and pH variation in the solution.

Moisture content indicates tissue hydration and potential structural damage(Alfiyani et al., 2019); ash content reflects the mineral composition of oyster tissues and pH changes provide insights into the metal–adsorbent interaction and the chemical behavior of the solution (Moreno-Piraján et al., 2012). These parameters provide comprehensive information regarding both the efficacy of the adsorption process and the biocompatibility of the adsorbent with oyster tissues (Kumar et al., 2019). The findings are expected to contribute to the development of safe and effective adsorption technologies for aquatic heavy metal remediation (Pangestu et al., 2020).

Method

Materials and Equipment

This study used fresh oysters (Crassostrea spp.), zinc sulfate ($ZnSO_4$) solutions at concentrations of 2 ppm, 4 ppm, and 6 ppm, and polyurethane foam made from tofu pulp as the adsorbent. The equipment used included a drying oven set at 105°C, a muffle furnace (±550°C), an analytical balance, a digital pH meter, magnetic stirrer with speed control, beakers, and porcelain crucibles.

Research Procedure

The research procedure began with the adsorption process using polyurethane adsorbents, followed by pH, moisture content, and ash content measurements. The research flow chart can be seen in Figure 1.

Adsorption Treatment

The adsorption process was conducted to observe changes in moisture content, ash content, and pH of the solution due to the interaction between oysters, Zn^{2+} solution, and the tofu-pulp-based polyurethane adsorbent. Oyster samples (approximately 10 grams) were immersed in 100 mL of $ZnSO_4$ solution (2 ppm, 4 ppm, and 6 ppm) containing polyurethane foam as the adsorbent. The adsorption was carried out at room temperature (±27°C) for 60 minutes, with continuous stirring using a magnetic stirrer at 100 rpm to ensure homogeneous mixing and effective contact. Sampling in this study was conducted to assess the effects of Zn^{2+} adsorption using tofu pulp-based polyurethane on oysters and the adsorbent material. Moisture content and ash content of oyster samples were measured at two specific time points: before the adsorption process (0 minutes) to represent initial conditions, and after 60 minutes of adsorption to evaluate any changes. Ash content of the polyurethane adsorbent was analyzed both prior to its use and after the adsorption process, specifically at the end of 60 minutes for each Zn^{2+} concentration treatment (2 ppm, 4 ppm, and 6 ppm). Meanwhile, the pH of the $ZnSO_4$ solution was monitored at regular intervals throughout the 60-minute adsorption period—at 0, 10, 20, 30, 40, 50, and 60 minutes—for each concentration, in order to observe the dynamics of the adsorption process over time.

Determination of Moisture Content in Oysters

Moisture content was determined using the gravimetric method. The sample was first weighed to obtain the wet mass (crucible + wet sample), then dried in an oven at 105°C until a constant weight was achieved. Measurements were conducted on oyster samples at 0 minutes and 60 minutes of the adsorption process. The moisture content was calculated using the following formula:

$$\text{Moisture Content } \% = \frac{(W1-W2)}{(W1-W0)} x100\% \tag{1}$$

Where:
W_0 = Weight of empty crucible (g)
W_1 = Weight of crucible + wet sample (g)
W_2 = Weight of crucible + dry sample (g)

Determination of Ash Content

Ash content was analyzed using the dry ashing method. Samples were incinerated in a muffle furnace at approximately 550°C until all organic matter was removed, leaving only inorganic residue (ash). For oysters: at 0 minutes (before adsorption) and 60 minutes (after adsorption). For polyurethane: before use and after adsorption with each Zn concentration (2 ppm, 4 ppm, and 6 ppm).

The ash content was calculated with the formula:

$$\text{Ash Content } (\%) = \frac{(W2-W0)}{(W1-W0)} x100\% \quad (2)$$

Where:
W_0 = Weight of empty crucible (g)
W_1= Weight of crucible + dry sample (g) (before ashing)
W_2 = Weight of crucible + ash after incineration (g).

Measurement of pH

The pH of the $ZnSO_4$ solution was measured using a calibrated digital pH meter. Measurements were taken at 0, 10, 20, 30, 40, 50, and 60 minutes of the adsorption process to monitor changes in acidity or alkalinity during contact with the adsorbent. These measurements were conducted for all three Zn concentrations (2 ppm, 4 ppm, and 6 ppm).

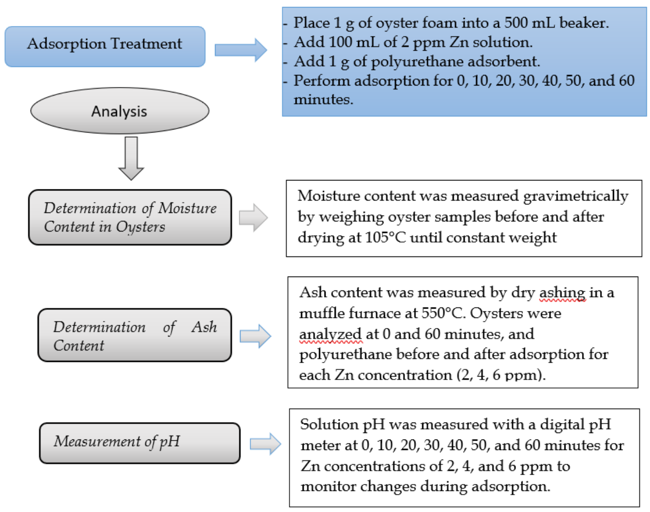

Figure 1. Research flow chart

Result and Discussion

Determination of Moisture Content in Fresh Oysters Before and After Adsorption

Oysters (Crassostrea spp.) are marine organisms known for their ability to bioaccumulate heavy metals within their tissues (Jordan-Cooley et al., 2021). Due to their natural capacity to filter seawater and trap suspended particles (Febrianessa et al., 2021), oysters have become important bioindicator species for monitoring aquatic pollution (Notodarmojo et al., 2021), including contamination by heavy metals such as zinc (Zn) (Muliani et al., 2021).

In this study, oysters were used as a biological medium to interact with Zn solutions, to which a tofu waste-based polyurethane adsorbent was introduced. One of the key parameters used to assess the physical changes in oysters following exposure to heavy metals and adsorbents is moisture content. According to Boadu et al. (2023) moisture content reflects the amount of water retained within oyster tissues and can be influenced by chemical, biological, or physical interactions with the adsorbent material (Khownpurk et al., 2018). Therefore, evaluating the moisture content of oysters before and after the adsorption process is essential to determine whether significant structural alterations occur in the tissue as a result of the treatment (Giang et al., 2025).

The gravimetric method was employed to determine the moisture content of oyster samples. The oysters were first exposed to Zn solutions at concentrations of 2 ppm, 4 ppm, and 6 ppm. The initial weights (cup + wet sample) were recorded, after which the samples were dried in an oven at 105 °C for several hours until a constant weight was reached (cup + dry sample). The weight of the empty cup, along with the initial and final weights, was used to calculate the wet and dry weights of the oyster samples, from which moisture content was determined.

$$\text{Moisture Content } \% = \frac{(W1-W2)}{(W1-W0)} x100\% \quad (3)$$

Table 1. Total Water Content of Fresh Oysters before and After Adsorption

Zn Concentration (ppm)	Sample Condition	Moisture Content (%)
2	Before Adsorption Process	89.0%
4	Before Adsorption Process	91.0%
6	Before Adsorption Process	89.0%
2	After the adsorption process	91.0%
4	After the adsorption process	90.0%
6	After the adsorption process	90.8%

Based on the data presented above, the moisture content of oysters prior to the adsorption process ranged between 89% and 91%. After undergoing the adsorption process for 60 minutes with Zn at the same concentrations, the moisture content remained within a similar range, specifically 90% to 91%. These findings suggest that the adsorption process using tofu pulp-based polyurethane adsorbent did not significantly alter the water content of the oyster tissues. The stability of moisture content is critical, as a substantial decrease could indicate dehydration or structural damage to the oyster's biological tissues. However, in this study, the moisture levels remained relatively high and consistent, indicating that the application of the adsorbent did not compromise the integrity of the oyster soft tissues.

To determine whether the observed moisture content complies with quality standards, reference was made to the Indonesian National Standard (SNI) (2013). A relevant standard is SNI 2729:2013 – Fresh Oysters (Crassostrea spp.). While this standard does not explicitly define the maximum moisture content—unlike those for dried products—it evaluates oyster quality based on physical parameters such as odor, color, texture, and the absence of excessive mucus or tissue damage (Akpan et al., 2019). Fresh oysters are naturally characterized by high moisture content, typically ranging from 85% to 92%, depending on environmental factors and individual size. In this study, the measured moisture content of 89%–91% falls within this acceptable range, suggesting that the oysters remained in a physiologically normal state, without signs of dehydration or tissue deterioration that could affect their quality (Z. Wang et al., 2023).

Furthermore, the moisture content values before and after the adsorption process confirm that oysters inherently possess high water content (Fauzi et al., 2022), consistent with their soft tissue structure. The slight variations observed after 60 minutes of contact further reinforce that the interaction with the tofu pulp-based polyurethane adsorbent did not lead to any adverse physical effects or tissue dehydration.

Moisture Content of Dried Oysters after the Adsorption Process

As a follow-up and comparative approach, a drying process was performed on oyster samples previously subjected to the adsorption treatment using Zn solutions at concentrations of 2 ppm, 4 ppm, and 6 ppm. The purpose was to produce oyster flour, which inherently has a significantly lower moisture content after undergoing a controlled dehydration process at approximately 60–70°C, in accordance with standards for dried food products. According to SNI (1999) for dried foods, the maximum allowable moisture content is 12%. Thus, the drying procedure aimed to reduce the water content to comply with this requirement. The moisture content of the oyster flour samples following 60 minutes of contact with the adsorbent is presented in Table 2.

Table 2. Moisture Content of Oyster Flour

Treatment of Sample	Moisture Content (%)
After the adsorption process	11.0%
After the adsorption process	11.5%
After the adsorption process	11.8%

Based on the table, it can be observed that the drying process was generally optimal and effective. Although slight variations were noted among treatments, all moisture content values remained below the maximum threshold for dried products, as specified by SNI which is 12%. The observed differences in moisture content between treatments are likely attributed to natural variability in tissue water content, as well as potential effects from residual adsorbent or differences in internal water bonding influenced by varying Zn concentrations. When compared to the initial moisture content of fresh oysters (89–91%), a reduction of approximately 78–80% was recorded following the drying process.

This substantial decrease confirms the effectiveness of the dehydration process in converting wet oyster tissues into a stable dried form (flour) (Jordan-Cooley et al., 2021). Dried oyster flour is not only more suitable for long-term storage and easier handling and packaging, but also applicable for further analysis (Boadu et al., 2023), such as heavy metal quantification based on dry weight or the development of value-added food products (Adeleke et al., 2024). Although the final moisture content of the oyster flour remained within the acceptable limit, a slight increasing trend was observed with increasing Zn concentrations (from 2 ppm to 6 ppm).

This trend suggest that higher Zn concentrations influence the interaction between Zn ions and tissue proteins or bound water molecules (Renu et al., 2017), potentially affecting the efficiency of moisture removal during the drying process. Nevertheless, this variation remained within acceptable limits and did not significantly affect the overall dehydration efficiency (Mulana et al., 2018).

Ash Content of Polyurethane Adsorbent

The ash content analysis was conducted to evaluate the level of residual inorganic matter in the polyurethane-based adsorbent before and after its application in the adsorption of Zn^{2+} ions (Alfiyani et al., 2019). The analysis followed the dry ashing method, where samples were incinerated at 550 °C in a muffle furnace until complete combustion of organic matter was achieved, leaving behind only mineral residues. These residues represent both inherent minerals from the raw materials and the adsorbed metal ions.

Table 3. Ash Content of Polyurethane Adsorbent (PUA) Before and After Zn Adsorption

Sample	Condition of Polyurethane	Weight of Ash (g)	Ash Content (%)
Polyurethane without adsorbent	Before Adsorption Process	0.150	3.00%
PUA + Zn 2 ppm	After the adsorption process	0.390	7.80%
PUA + Zn 4 ppm	After the adsorption process	0.440	8.80%
PUA + Zn 6 ppm	After the adsorption process	0.480	9.60%

Before being used as an adsorbent, the polyurethane–tofu dregs composite exhibited an ash content of 3.00%, representing the natural inorganic constituents derived from the tofu waste material. After the adsorption of Zn(II) ions, the ash content increased in proportion to the initial Zn concentration, reaching 7.80%, 8.80%, and 9.60% for 2, 4, and 6 ppm treatments, respectively. This increase reflects the accumulation of non-volatile inorganic residues—primarily Zn ions—that remain embedded within the adsorbent matrix after combustion. Importantly, all recorded ash content values remained well below 10%, indicating both efficient adsorption and minimal inorganic overload within the polymer structure.

The rise in ash content with increasing Zn concentration suggests successful metal retention within the polyurethane matrix. This retention likely occurs through interactions between Zn(II) ions and active functional groups present in the adsorbent, such as hydroxyl (–OH), carboxyl (–COOH), and amine ($–NH_2$) groups, originating from both the polyurethane backbone and the tofu dregs filler (Sunartaty et al., 2024a). These chemical interactions are stable and persist through the ashing process, further confirming the strength of the metal binding within the composite.

Notably, the ash content of the composite not only satisfies the Indonesian National Standard (SNI 06-3730-1995), which stipulates a maximum ash content of 15% for adsorbent materials, but also aligns with the general quality benchmark for activated carbon-based adsorbents, which typically require ash contents to remain below 10% to ensure high adsorption efficiency and surface reactivity. Maintaining ash content under this threshold—as achieved in this study—demonstrates that the polyurethane–tofu dregs composite has a balanced composition, with sufficient organic functional groups for adsorption while avoiding excessive inorganic load that could inhibit performance.

Therefore, the observed ash content profile supports the structural integrity and chemical stability of the adsorbent throughout the adsorption process. These findings reinforce the composite's potential for repeated or large-scale use in wastewater treatment applications, where material durability and adsorption efficiency are critical. The low ash content also minimizes the risk of surface fouling and ensures that the composite retains its effectiveness over time. Taken together, the ash content analysis provides strong validation for the composite's suitability as an environmentally friendly, low-cost, and chemically stable adsorbent for heavy metal remediation.

Table 4. Ash Content of Oyster Samples Before and After Heavy Metal Adsorption

Oyster/Zn Concentration (ppm)	Sample Condition	Ash Weight (g)	Ash Content (%)
2	Before Adsorption Process	0.095	1.90
4	Before Adsorption Process psi	0.098	1.96
6	Before Adsorption Process	0.096	1.92
2	After the adsorption process	0.095	1.90
4	After the adsorption process	0.096	1.92
6	After the adsorption process	0.097	1.94

Ash Content of Oysters Before and After Zn Adsorption

The determination of ash content in soft oyster tissue was conducted to evaluate the changes in total inorganic mineral content resulting from the adsorption of Zn(II) metal ions. Ash content was measured using the dry ashing method, which involves incinerating the biological samples in a muffle furnace at approximately 550 °C until all organic matter is completely combusted. The remaining inorganic residue represents the total mineral content, including both essential elements (such as calcium, magnesium, phosphorus, and zinc) and potential contaminants. This parameter is important for assessing whether the adsorption process affects the natural mineral composition of the biological sample.

Based on the experimental results, the ash content of oyster samples before the adsorption process ranged from 1.90% to 1.96%, reflecting the baseline mineral content of fresh oyster tissue. After the adsorption of Zn(II) using polyurethane adsorbent modified with tofu dregs at concentrations of 2, 4, and 6 ppm, the ash content remained relatively stable, ranging from 1.90% to 1.94%. These slight variations indicate no significant changes in mineral composition due to the adsorption process. The stability of ash content suggests that the adsorbent selectively binds Zn(II) ions from the solution without disrupting or depleting the essential mineral content within the oyster tissue. It is noteworthy that the ash content of fresh oyster tissue is significantly lower than the ash content observed in the polyurethane–tofu dregs adsorbent. Previous analysis showed that the ash content of the adsorbent could increase up to nearly 15% after the adsorption process, which remains within the acceptable range according to SNI 06-3730-1995 (maximum ash content for adsorbents ≤15%). The higher ash content in the adsorbent reflects the accumulation of non-volatile inorganic residues, particularly from the retained Zn ions. In contrast, the oyster samples exhibited consistently lower ash values (under 2%), highlighting that the oysters did not absorb excess metal from the adsorbent. This contrast further confirms that the Zn(II) ions are primarily adsorbed and retained by the composite adsorbent material rather than transferred into the biological matrix of the oysters.

These findings reinforce the conclusion that the polyurethane–tofu dregs adsorbent is selective, efficient, and biologically safe. Literature reports that the typical ash content in the soft tissues of marine organisms ranges from 0.5% to 2%, depending on species and environmental conditions. The values obtained in this study fall within or slightly below this range, suggesting that the oysters remained fresh and free from excess inorganic contamination. Moreover, the consistency of ash content before and after treatment indicates that the adsorption process was conducted under controlled conditions and did not compromise the structural or nutritional integrity of the oyster tissue.

Zn(II) adsorption using polyurethane adsorbent derived from tofu dregs (Taer et al., 2021) does not adversely affect the mineral profile of oyster tissue. The low and stable ash content supports the safety and compatibility of the adsorbent in biological systems (Indrasti et al., 2016). These results also demonstrate the environmental suitability of the composite adsorbent, indicating its potential for eco-friendly heavy metal remediation without posing risks to aquatic organisms (Nguyen et al., 2020). The selective nature of the adsorption process, coupled with minimal biological impact(Muslim, 2017), makes the polyurethane–tofu dregs composite a promising material for practical applications in wastewater treatment (Enniya et al., 2018).

pH Level (Hydrogen Potential)

pH (potential of hydrogen) is a measure of the concentration of hydrogen ions (H^+) in a solution and indicates the degree of acidity or basicity (Imoukhuede et al., 2016; Muhtaroh et al., 2024). The adsorption of Zn^{2+} ions from $ZnSO_4$ solution using tofu pulp-based polyurethane foam not only results in a reduction in metal ion concentration in the solution but also affects the solution's pH (Sulistyawati et al., 2024). The pH scale ranges from 0 to 14, where values below 7 indicate acidic conditions, a value of 7 is neutral, and values above 7 are basic (Gulo et al., 2021). pH plays a critical role in many chemical processes (Setiawan, 2022), including heavy metal adsorption, as it influences the speciation of metal ions in solution and the activity of functional groups on the adsorbent surface. In the context of Zn^{2+} ion adsorption, pH changes during the process can indicate interactions between metal ions and the adsorbent surface, and may also reflect the chemical stability of the system (Zulichatun et al., 2018). The pH values recorded during the adsorption process are presented in Table 5.

Based on experimental measurements, a gradual increase in pH was observed at all $ZnSO_4$ concentrations (2 ppm, 4 ppm, and 6 ppm) as the contact time between the solution and the adsorbent increased. At the initial contact (0 minutes), the $ZnSO_4$ solutions exhibited acidic pH values: 5.40 for 2 ppm, 5.20 for 4 ppm, and 5.00 for 6 ppm. After 60 minutes of adsorption, these values increased to 5.95, 5.68, and 5.40, respectively, corresponding to their initial Zn concentrations.

Table 5. pH Values of Zn(II) Solution During the Oyster Adsorption Process

Contact Time (minutes)	2 ppm	4 ppm	6 ppm
0	5.40	5.20	5.00
10	5.55	5.32	5.10
20	5.68	5.43	5.18
30	5.77	5.50	5.25
40	5.85	5.58	5.30
50	5.90	5.63	5.35
60	5.95	5.68	5.40

The extent of pH change was also influenced by the initial concentration of Zn^{2+}. At a lower concentration (2 ppm), the pH increased by +0.55 units (from 5.40 to 5.95), suggesting that adsorption occurred more rapidly and efficiently due to the smaller number of Zn^{2+} ions, allowing more complete interaction with the available adsorption sites. Conversely, at higher concentrations (4 and 6 ppm), the pH increases were smaller—+0.48 and +0.40 units, respectively—possibly due to saturation or limited availability of active sites on the adsorbent.

Overall, the trend demonstrates that the adsorption process not only reduces Zn^{2+} content in solution but also alters its chemical properties, particularly pH, due to shifts in ionic equilibrium. The observed increase in pH serves as an indirect indicator of successful metal ion sorption and chemical interactions between the adsorbent and the solution. However, the final pH values did not reach neutrality (pH 7), indicating that the solution remained mildly acidic. This behavior is consistent with the slightly acidic nature of $ZnSO_4$, which undergoes partial hydrolysis due to Zn^{2+} ion hydration.

The pH increase is attributed to the interaction between Zn^{2+} ions and the active functional groups present on the surface of the tofu-based polyurethane foam, such as hydroxyl (-OH), amine ($-NH_2$), and carboxylate (-COOH) groups (Sunartaty et al., 2023). These groups exhibit weakly basic characteristics, enabling them to bind hydrogen ions (H^+) from the solution or neutralize the acidic behavior of Zn^{2+} during the adsorption process (Sunartaty et al., 2024a). When Zn^{2+} ions are adsorbed onto these functional groups, the concentration of free H^+ ions in the solution decreases, leading to an increase in pH. Furthermore, lignocellulosic components and residual proteins in tofu pulp may provide buffering capacity, further supporting the pH increase.

Therefore, pH monitoring during adsorption provides valuable complementary information for understanding the metal–adsorbent interaction mechanism, including potential chemical reactions and system stability (Husna et al., 2021). From a practical standpoint, these pH shifts are essential for optimizing operating conditions in industrial or environmental applications to ensure safety for biological systems (Muslim et al., 2018) and prevent disruption of the chemical balance in receiving environments (Muslim et al., 2017).

Conclusion

The tofu-dregs-based polyurethane adsorbent effectively removed Zn(II) ions without significantly altering oyster tissue composition. Fresh oysters maintained a moisture content of 89–91% before and after 60 minutes of adsorption, while dried oysters showed reduced moisture levels of 11.0–11.8%, meeting the SNI limit of <12%. The adsorbent's ash content rose from 3.00% to 9.60% with increasing Zn concentrations, confirming efficient metal retention and staying below the 15% limit in SNI 06-3730-1995, whereas oyster ash content remained stable at 1.90–1.96%, indicating minimal metal accumulation. Solution pH increased by up to +0.55 units across $ZnSO_4$ concentrations of 2, 4, and 6 ppm, reflecting chemical interactions between Zn^{2+} ions and functional groups (–OH, –COOH, $-NH_2$) on the adsorbent surface. These results demonstrate that the adsorbent meets Indonesian national standards, maintains oyster quality, and offers environmentally friendly potential for heavy metal remediation in aquatic environments.

Acknowledgments
The authors gratefully acknowledge the Ministry of Research and Technology of the Republic of Indonesia (Kemenristek) for providing financial support through the research grant awarded in 2025.

Author Contributions
Conceptualization, R.S.; Methodology, R.S.; Validation, I.; writing—original draft preparation, R.S.; Writing—Review and editing, R.S.

Funding
This research was funded by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia through the 2025 Research Grant Program. The primary funding was provided under Master Contract Number 134/C3/DT.05.00/PL/2025, with subsequent derivative contracts issued on June 12, 2025, under Contract Numbers 40/LL13/AL.04/AKA.PL/2025 and 030/LPPM-USM/2025.

Conflicts of Interest
The authors declare no conflict of interest.

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