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Optimization of Desalination Media Based on Blood Clam Shell Waste (Anadara granosa) and Zeolite for Salinity Reduction of Water in the Coastal Area of Sungsang

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Abstract

The availability of clean water in the coastal area of Sungsang faces significant challenges due to seawater intrusion and limited water treatment infrastructure. This study aims to evaluate the effectiveness of a combination of blood cockle (Anadara granosa) shell powder and zeolite as an environmentally friendly desalination solution. The research was conducted through laboratory experiments with treatments including variations in immersion time (10, 20, 30, 40, 50, 60 minutes), activation temperature (50, 100, 150, 200, 250, 300 °C), activation duration (30, 60, 90, 120, 150, 180 minutes), and zeolite mass (5, 10, 15, 20, 25, 30 grams). The main parameters observed were salinity reduction and desalination efficiency, measured using a salinity meter (AR-8012). The results showed that optimal conditions were achieved at an immersion time of 30 minutes, activation temperature of 200 °C, activation time of 90 minutes, and zeolite mass of 25 grams, resulting in a salinity reduction of 25.4 ppt and a maximum desalination efficiency of 74.8%. This combination of biomaterials demonstrates great potential as an energy-efficient and sustainable alternative for seawater desalination in coastal regions.

***Keywords** : Desalination, blood cockle shell, zeolite, adsorption, Sungsang coastal water.*

INTRODUCTION

Clean water is a fundamental human necessity; however, its availability is increasingly threatened by climate change, population growth, and environmental pollution (Maria, 2021). The World Health Organization (WHO, 2023) reports that more than 2 billion people worldwide lack access to safe drinking water, while approximately 3.5 billion reside in regions with limited water supply, including coastal areas (UNESCO, 2023). Indonesia, as a maritime country, possesses extensive coastal regions characterized by high salinity levels and limited freshwater resources (Ayu et al., 2024). One such area is Sungsang, South Sumatra, which faces significant challenges related to seawater intrusion and inadequate clean water infrastructure (Putri et al., 2019). Salinity levels in the waters of Sungsang range from 0 to 20 ppt, classifying them as brackish water (Angraini et al., 2018), and these levels further increase during the dry season, rendering the water unsuitable for consumption (Yuliardi et al., 2024).

Desalination technologies have emerged as a potential solution for reducing water salinity. Conventional methods such as Reverse Osmosis (RO) are effective but require high energy consumption and operational costs (Kutananda et al., 2022). Distillation-based methods, including Multi-Stage Flash (MSF) and Multi-Effect Distillation (MED), can produce high-purity water; however, they remain capital- and energy-intensive (Ersa, 2021; Khoshrou et al., 2017; Son et al., 2020). Electrodialysis offers improved energy efficiency for treating brackish water, yet it is less effective for seawater with high salinity levels (Ersa, 2021; Kutananda et al., 2022).

Adsorption-based methods utilizing natural materials have emerged as energy-efficient and environmentally friendly alternatives. Zeolite has been shown to effectively reduce salinity due to its porous structure (Prihatinningtyas, 2024); however, its performance can be further enhanced through combination with other materials (Purwaningtyas et al., 2020). Blood clam shell waste (Anadara granosa), which is abundant in Indonesia, contains calcium carbonate ($CaCO_3$) and exhibits potential as an ion-binding agent (Tiandho et al., 2018; Pungut et al., 2019; Afriani et al., 2019). Proper utilization of this waste not only mitigates environmental pollution (Purnamasari, 2024) but also holds promise for improving desalination efficiency.

To date, most studies have focused on the use of zeolite or blood clam shell waste individually, while investigations into their combined application to enhance desalination efficiency in coastal regions remain limited (Wibowo et al., 2017; Mailafiya et al., 2019). Therefore, this study aims to evaluate the effectiveness of a combined medium composed of blood clam shell powder and zeolite for the desalination of brackish water in the Sungsang coastal area. The desalination efficiency is assessed through measurements of salinity reduction, and the potential of this approach as an economical and sustainable clean water solution is further examined.

MATERIALS AND METHOD

This study was conducted from January to June 2025 at the Physics, Biology, and Environmental Science Laboratories, Faculty of Science and Technology, Universitas PGRI Palembang. The research employed a combination of survey and experimental methods. The survey was carried out through direct observations in the Sungsang coastal area, Banyuasin II District, Banyuasin Regency, South Sumatra, to obtain brackish water samples. Laboratory experiments were then performed to evaluate the effectiveness of a combined medium consisting of blood clam shell powder and zeolite in reducing water salinity.

The equipment used in this study included a salinity meter (AR-8012), beakers, graduated cylinders, an oven, a digital balance, a spatula, a stirring rod, crucibles, crucible tongs, a desiccator, and a 100-mesh sieve. The materials consisted of brackish water samples collected from the Sungsang coastal area, 100-mesh blood clam shell powder, 100-mesh natural zeolite, distilled water, and NaCl calibration solutions.

The research procedure comprised the following steps: (1) preparation of materials, including the thermal activation of blood clam shell powder; (2) application of treatment variations, which included soaking time (10–60 minutes), activation temperature (50–300 °C), activation duration (30–180 minutes), and zeolite mass (5–30 g); (3) desalination process by mixing 50 mL of brackish water samples with the adsorbents according to the treatment conditions; and (4) measurement of salinity before and after treatment using a calibrated salinity meter.

The primary parameter observed was the initial and final salinity, while the independent variables included soaking time, activation temperature, activation duration, and zeolite mass. The dependent variables were salinity reduction (ppt) and desalination efficiency (%). Data were collected through laboratory measurements, presented in tables and graphs, and analyzed using formulas for salinity reduction and desalination efficiency to determine the optimal treatment combination.

RESULT AND DISCUSSION

1. **Effect of Soaking Time of Blood Clam Shell Powder on Salinity Reduction and Desalination Efficiency**

Figure 1 illustrates that increasing the soaking time of blood clam shell powder influenced salinity reduction (Rs) and enhanced desalination efficiency (η). These parameters were analyzed to determine the optimal soaking duration between the adsorbent and the solution, which plays a crucial role in the ion absorption process by the adsorbent material.

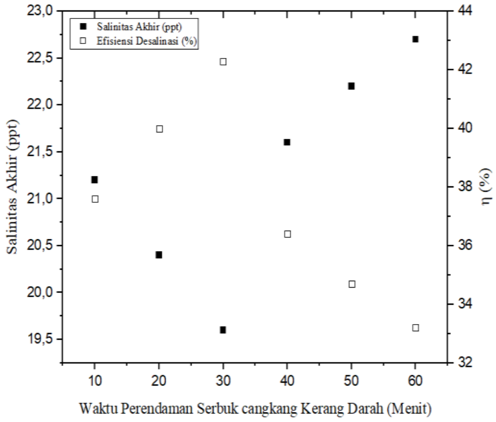

Figure 1. Effect of soaking time on final salinity and desalination efficiency

All tested samples had the same initial salinity of 34.0 ppt, making soaking duration the primary variable for evaluating the effectiveness of the adsorption process. The results indicated that both salinity reduction and desalination efficiency gradually increased with longer soaking times, from 10 to 30 minutes. At a soaking duration of 30 minutes, the optimum result was achieved, with a final salinity of 19.6 ppt, corresponding to a salinity reduction of 14.4 ppt. Under these conditions, desalination efficiency reached a maximum value of 42.3%.

These findings indicate that the adsorption of salt ions by blood clam shell powder reaches maximum effectiveness at a contact time of 30 minutes. The high efficiency at this stage is attributed to the substantial concentration gradient of salt ions between the solution and the adsorbent surface, which facilitates optimal diffusion of ions into the pores of the adsorbent material. This diffusion process accelerates the uptake of salt ions by the medium, thereby enhancing the overall system efficiency (Zhang et al., 2023).

However, after the soaking time reached 30 minutes, both salinity reduction and desalination efficiency showed a marked decline. At 40 minutes, the final salinity was recorded at 21.6 ppt, corresponding to a salinity reduction of only 12.4 ppt, with desalination efficiency decreasing to 36.4%. This decline continued at soaking durations of 50 and 60 minutes, where both salinity reduction and desalination efficiency further decreased. These results indicate that the effectiveness of the adsorption process diminishes as soaking time extends beyond the optimal point. The observed reduction suggests that the adsorbent medium had reached saturation, a condition in which all active sites and pores of the adsorbent are fully occupied by salt ions. Under such conditions, no additional space is available to bind new ions, preventing the adsorption process from proceeding optimally (Svobodova et al., 2018). As a result, the adsorbent's capacity to uptake salt ions experienced a drastic reduction (Stiyati Prihatini & Syauqiah, 2017). In addition to saturation, the reduction in adsorption efficiency may also be attributed to desorption, which involves the release of previously bound salt ions from the adsorbent surface back into the solution (Liu et al., 2017). This phenomenon is supported by the findings of Ariyani et al. (2018), who reported that excessively long soaking times can lead to saturation of the adsorbent medium, thereby reducing ion adsorption efficiency. Wibowo et al. (2017) also reported that, after reaching the optimum point, the adsorption capacity tends to decline due to the limited availability of active sites on the adsorbent surface.

The relationship between soaking time and both salinity reduction and desalination efficiency indicates an optimum point at a duration of 30 minutes. A soaking time that is too short does not allow sufficient contact for salt ions to interact effectively with the adsorbent surface, resulting in suboptimal adsorption. Conversely, excessively long soaking times can lead to saturation of the adsorbent medium, which reduces its capacity to uptake salt ions (Ariyani et al., 2018 ; Stiyati Prihatini & Syauqiah, 2017). Selecting an appropriate contact time is a key factor in optimizing the desalination process using blood clam shell powder as the adsorbent medium (Daud et al., 2017).

2. Effect of Thermal Activation Temperature of Blood Clam Shell Powder on Salinity Reduction and Desalination Efficiency

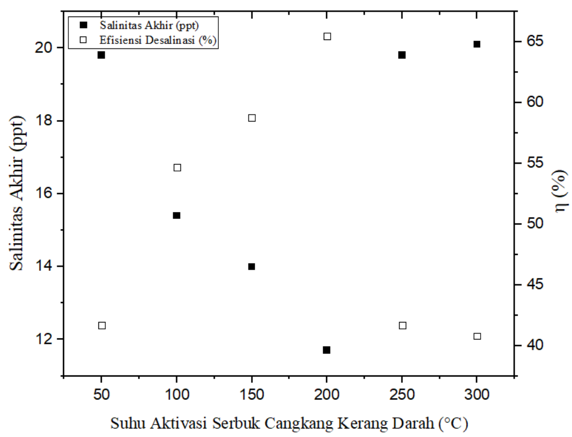

Figure 2. Effect of thermal activation temperature of blood clam shell powder on final salinity and desalination efficiency.

Figure 2 illustrates that variations in the thermal activation temperature of blood clam shell powder affected salinity reduction (Rs) and desalination efficiency (η) at the optimum soaking time of 30 minutes. The results showed that increasing the activation temperature from 50 °C to 200 °C gradually enhanced the performance of the adsorbent. Maximum efficiency was achieved at an activation temperature of 200 °C, with a final salinity of 11.7 ppt, corresponding to a salinity reduction of 22.3 ppt, and a peak desalination efficiency of 65.5%. This improvement indicates that an activation temperature of 200 °C can modify the structure of the blood clam shell powder by forming micropores and expanding the active surface area. These morphological changes increase the diffusion rate and enhance the adsorption capacity for Na^+ and Cl^- ions into the pores of the adsorbent. (Mojoudi et al., 2019). These findings are consistent with the study by Li et al. (2023), whO reported that increasing the activation temperature can significantly enhance the adsorption capacity of biomineral-based materials. Thermal activation at this temperature plays a crucial role in modifying the surface characteristics of the adsorbent, particularly by increasing the surface area and the number of active pores, which directly contributes to the effectiveness of salt ion adsorption from the solution (Laos et al., 2016).

However, at activation temperatures of 250 °C and 300 °C, the adsorption performance declined markedly compared to the previously determined optimum temperature. The final salinity at 250 °C and 300 °C was recorded at 19.8 ppt and 20.1 ppt, respectively, increasing from the 11.7 ppt observed at 200 °C. Corresponding salinity reductions decreased to 14.2 ppt and 13.9 ppt, resulting in desalination efficiencies of 41.7% and 40.8%. This reduction is likely due to damage to the micropore structure caused by excessive activation temperatures. Overheating can lead to pore densification or even collapse, thereby reducing the material's capacity to adsorb salt ions (Gunawan et al., 2024). As a result, the available adsorption sites for ion uptake are drastically reduced. This phenomenon is consistent with the findings of Wibowo et al. (2017), who reported that excessive activation temperatures can lead to pore structure degradation and a reduction in adsorption efficiency. A similar observation was reported by Saputra et al. (2024), stating that high temperatures during thermal activation can result in the loss of pore structure and a decrease in the adsorbent's surface area.

The relationship between activation temperature and both salinity reduction and desalination efficiency indicates an optimum at 200 °C. At this temperature, the adsorbent's pore structure develops optimally, enhancing the performance of the adsorption process. Activation temperatures below 200 °C are insufficient to fully open the pore structure, resulting in limited adsorption capacity. Conversely, temperatures above 200 °C tend to cause physical damage to the adsorbent material, such as pore densification or collapse, leading to a reduction in active surface area and a decrease in the effectiveness of salt ion uptake.

3. Effect of Activation Duration of Blood Clam Shell Powder on Salinity Reduction and Desalination Efficiency

Figure 3 shows that variations in the thermal activation duration of blood clam shell powder influenced the effectiveness of the desalination process, as indicated by salinity reduction (Rs) and desalination efficiency (η). Increasing the activation time from 30 to 90 minutes demonstrated that the adsorption process became progressively more effective with longer activation durations.

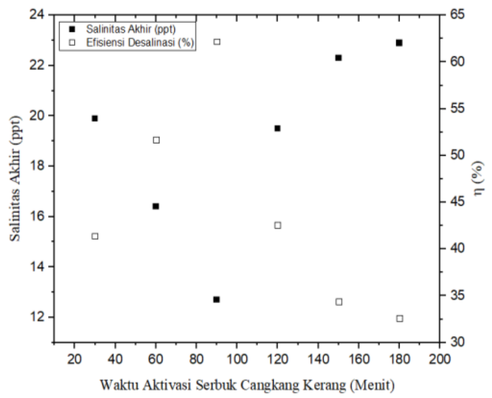

Figure 3. Effect of activation duration of blood clam shell powder on final salinity and desalination efficiency.

The highest salinity reduction was achieved at an activation time of 90 minutes, with a reduction of 21.3 ppt, resulting in a final salinity of 12.7 ppt and a maximum desalination efficiency of 62.2%. These results indicate that heating for 90 minutes allows for the optimal formation of micropore structures on the adsorbent surface, thereby increasing the active surface area and enhancing the adsorption capacity for salt ions more efficiently. This finding is supported by the theory presented by Wang et al. (2023), who stated that thermal activation with an adequate duration can significantly improve the physical structure of the material. This activation results in the formation of fine pores and microscopic channels within the adsorbent structure, which contribute to an increased active surface area and accelerate the adsorption of solutes. (Putri et al., 2023). Furthermore, a sufficiently long activation duration allows partial decomposition of calcium carbonate ($CaCO_3$), which subsequently enhances the surface reactivity of the material. This improvement strengthens the adsorbent's ability to attract and bind dissolved ions more efficiently. (Martinez et al., 2024).

Under seemingly similar activation conditions, the results actually showed notable differences. Based on the data in Table 4.2 (row 4) and Table 4.3 (row 2), although both treatments involved activation at 200 °C for 60 minutes, the desalination efficiencies differed. In Table 4.2, this treatment resulted in an efficiency of 65.5% with a salinity reduction of 22.3 ppt. In contrast, in Table 4.3, the desalination efficiency was only 51.7% with a salinity reduction of 17.6 ppt. This discrepancy is likely due to differences in the activation methods applied. In Table 4.2, the activation was carried out stepwise, starting from 50 °C up to 200 °C, whereas in Table 4.3, the sample was heated directly to 200 °C. Stepwise heating provides a more stable condition for pore formation while reducing the risk of structural damage to the adsorbent material (Samghouli et al., 2025). In contrast, direct heating may induce thermal shock, which can damage the micropore structure, thereby reducing adsorption effectiveness and lowering desalination efficiency (Bannov et al., 2021).

Increasing the activation duration beyond 90 minutes, particularly at 120, 150, and 180 minutes, resulted in a marked decline in both salinity reduction and desalination efficiency. At an activation time of 180 minutes, the desalination efficiency decreased to 32.6%, with a final salinity of 22.9 ppt, corresponding to a salinity reduction of only 11.1 ppt. This reduction indicates that excessive heating can damage the micropore structure on the adsorbent surface, leading to a decreased capacity for salt ion adsorption. This phenomenon is consistent with the findings of Wang et al. (2023), who reported that excessive heating can damage fine pores, thereby reducing the active surface area and adsorption efficiency. Overheating may cause pore shrinkage or even collapse, decreasing the material's capacity to adsorb solutes. Consequently, the active surface area and the number of available adsorption sites are reduced, leading to a decline in the adsorbent's ability to uptake salt ions. This reduction is consistent with the findings of Wibowo et al. (2017), who reported that excessively long activation times can cause particle agglomeration and damage the pore structure of the adsorbent.

The relationship between activation duration and both salinity reduction and desalination efficiency indicates that the optimal activation time is 90 minutes. At this duration, the pore structure and surface area of the adsorbent are in their best condition to support the desalination process. Shorter activation times are insufficient to fully optimize the material's characteristics, whereas excessive durations can damage the adsorbent structure. Therefore, selecting an appropriate activation time is crucial to maintain the efficiency and stability of the material in biomaterial-based desalination processes.

4. Effect of Blood Clam Shell Powder Combined with Zeolite Mass Addition on Salinity Reduction and Desalination Efficiency.

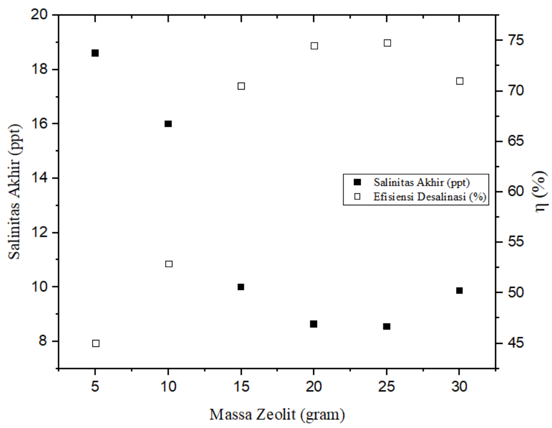

Figure 4. Effect of combining blood clam shell powder with added zeolite mass on final salinity and desalination efficiency.

The results for the combination of blood clam shell powder and added zeolite mass on salinity reduction and desalination efficiency at the optimum conditions of 30 minutes soaking time, 200 °C activation temperature, and 90 minutes activation duration are presented in Figure 4. As shown in Figure 4, salinity reduction increased with the addition of zeolite mass from 5 g to 25 g. At 5 g zeolite, the initial salinity of 34.0 ppt decreased to 18.6 ppt, corresponding to a reduction of 15.4 ppt, with a desalination efficiency of 45.0%. Increasing the zeolite mass to 10 g, 15 g, 20 g, and 25 g resulted in significant increases in salinity reduction to 18.0 ppt, 24.3 ppt, and 25.3 ppt, with efficiencies of 52.9%, 70.5%, and 74.5%, respectively. The highest efficiency was achieved at 25 g zeolite, reaching 74.8% with a salinity reduction of 25.4 ppt. This indicates that at 25 g zeolite, the available active surface for salt ion adsorption is at its most optimal condition. However, when the zeolite mass was increased to 30 g, the desalination efficiency slightly decreased to 71.0%, with a salinity reduction of 24.1 ppt. This reduction is likely due to agglomeration, where zeolite particles adhere to each other and form clusters, thereby limiting the surface area and the number of active pores that would otherwise support the adsorption process (Anbia & Aghaei, 2019). This is consistent with the study Vannier et al. (2024), who reported that, although a larger amount of zeolite is used, its adsorption capacity may decrease because most of the pores become blocked due to particle agglomeration. This condition results in a less optimal desalination process.

CONCLUSION

This study successfully developed a simple desalination system using a combination of blood clam shell powder and zeolite as the adsorbent medium, where each tested parameter contributed to improved efficiency with an optimum at specific conditions. Variation in soaking time revealed that a duration of 30 minutes was optimal, achieving the highest desalination efficiency of 42.3% and a salinity reduction of 14.4 ppt, whereas longer soaking reduced performance due to adsorbent surface saturation and potential ion desorption. Thermal activation temperature variation showed that 200 °C yielded maximum efficiency of 65.5% and a salinity reduction of 22.3 ppt, while higher temperatures damaged the micropore structure and decreased adsorption capacity. The optimal activation duration was achieved at 90 minutes, resulting in an efficiency of 62.2% and salinity reduction of 21.3 ppt, indicating the optimal formation of the adsorbent's micropore structure, whereas longer durations caused active pore damage. The combination of blood clam shell powder and zeolite with an optimum zeolite mass of 25 g provided the best desalination results, with an efficiency of 74.8% and a salinity reduction of up to 25.4 ppt, although further addition led to particle agglomeration that inhibited adsorption. Overall, the optimal combination of these two materials effectively enhanced the performance of the desalination process, offering an efficient and environmentally friendly approach to addressing freshwater scarcity in coastal areas, while also providing a practical solution for waste management and the development of sustainable desalination technologies in the future.

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