

Analysis of Brackish Water Salinity Reduction in Sungsang Coastal Area Using Adsorption With Zeolite, Powder and Activated Carbon

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Received: 23 06 2026. Accepted: 31 07 2026. Published: 07 2026

Abstract

The availability of clean water in the coastal area of Sungsang is challenged by seawater intrusion and limited water treatment infrastructure. This study analyzed the effectiveness of an adsorption method using zeolite, Cuttlebone powder, and activated carbon to reduce salinity as a simple, low-cost, and environmentally friendly treatment alternative. The research employed an experimental laboratory method. Variables included contact time (20, 40, 60, 80, 100, and 120 minutes), zeolite-to- powder ratios (1:1, 1:2, 1:3, 1:4, and 1:5), and activated carbon masses (2, 4, 6, 8, 10, and 12 grams). All adsorbents were activated at 250°C for 1 hour. Salinity reduction and efficiency were measured using a Salinity Meter (AR-8012). The optimum contact time for zeolite and powder was 80 minutes, achieving efficiencies of 58.80% and 54.81%, respectively. The optimum adsorbent ratio was 1:2, with an efficiency of 61.46%. The addition of 10 grams of activated carbon produced the highest efficiency of 73.05% and reduced salinity by 21.9 ppt. These findings demonstrate that the adsorbent combination effectively reduces salinity and offers a practical, economical, and environmentally friendly option for brackish water treatment.

Keywords: Adsorption, salinity, zeolite, Cuttlebone bone powder, activated carbon.

INTRODUCTION

Clean water is a basic human necessity that plays an important role in supporting public health and welfare (Huang et al., 2024). However, the availability of clean water in coastal areas remains a major issue due to increasing salinity caused by seawater intrusion, climate change, and limited freshwater resources. Globally, most of the Earth's water consists of seawater, while the amount of freshwater that can be directly utilized is very limited (Sipora et al., 2023). This condition is exacerbated by climate change, which causes droughts and sea level rise, thereby increasing salinity in water sources in coastal regions (Qoriatul & Purnomo, 2024). Indonesia, as a maritime country with extensive coastal areas, also has a high level of vulnerability to seawater intrusion and increased groundwater salinity, especially during the dry season (Purnama, 2019).

This problem is clearly observed in the coastal area of Sungsang, South Sumatra. The region is located in an estuarine area influenced by tidal seawater, causing groundwater to become brackish to saline (Nugroho et al., 2023). The salinity level in Sungsang waters has been reported to range from 0–20 ppt and increases during the dry season when river discharge decreases (Angraini et al., 2018). As a result, local communities experience difficulties in obtaining clean water and still depend on rainwater and water supplies from outside the region (Ridho et al., 2019; Yuliardi et al., 2024). This condition highlights the need for water treatment technology capable of reducing salinity using simple and easily applicable methods for coastal communities (Sahu, 2021).

One of the efforts that can be implemented to overcome this problem is through water treatment technology

capable of reducing the salinity level of brackish water (Honarparvar et al., 2021). However, conventional methods such as Reverse Osmosis (RO) and thermal distillation require high investment and energy costs, making them less effective for areas with limited infrastructure (Pontié et al., 2017). Therefore, the adsorption method has developed as an alternative water treatment technology that is more energy-efficient and environmentally friendly (Kasifya et al., 2023). This method works through the adsorption of salt ions by adsorbent materials, enabling the reduction of salinity in both brackish water and seawater (Tahreen et al., 2024).

Various natural materials have been widely used as adsorbents, such as zeolite, powder, and activated carbon. Zeolite has a porous structure and ion-exchange capability that effectively adsorbs dissolved salt ions (Prihatinningtyas & Novianti, 2024b). powder containing calcium carbonate (CaCO_3) contributes to precipitation and ionic interaction processes (Henggu et al., 2019), while activated carbon possesses a large surface area that supports the adsorption process (Heidarinejad et al., 2020). Previous studies have shown that each of these adsorbents is effective in reducing salinity; however, they remove dissolved salt ions through different adsorption mechanisms. Zeolite primarily removes ions through ion exchange, powder promotes ionic interactions and precipitation, whereas activated carbon enhances physical adsorption due to its high surface area. These differences suggest that combining the three adsorbents may provide complementary adsorption mechanisms, thereby improving salinity reduction performance compared with the use of a single adsorbents (Dhumal & Sadgir, 2023).

In addition to adsorbent type, the efficiency of the adsorption process is strongly influenced by operational parameters, including contact time,

adsorbent composition, and adsorbent mass (Murphy et al., 2023). Contact time determines the duration of interaction between dissolved salt ions and the adsorbent, whereas adsorbent composition and mass affect the availability of active sites for ion adsorption (Manurung et al., 2025). Although previous studies have demonstrated the potential of zeolite, cuttlebone powder, and activated carbon as adsorbents for salinity reduction, most investigations have focused on the use of single adsorbents or limited combinations without systematically optimizing the operational parameters. Furthermore, studies evaluating the combined effects of contact time, zeolite-to-cuttlebone powder composition, and activated carbon mass for reducing the salinity of brackish water, particularly from the Sungsang coastal area, remain limited (Khazri et al., 2026). Therefore, this study investigates the integration of zeolite, cuttlebone powder, and activated carbon through the systematic optimization of contact time, adsorbent composition, and activated carbon mass to enhance salinity reduction in brackish water from the Sungsang coastal area. The findings are expected to provide an effective, low-cost, and environmentally friendly alternative for brackish water treatment while improving the understanding of the synergistic effects of combined natural adsorbents for salinity reduction.

MATERIALS AND METHOD

Brackish water samples were collected from the coastal area of Sungsang, Banyuasin Regency, South Sumatra, Indonesia. The adsorbent materials consisted of 100 mesh natural zeolite (Acquasolutions, South Sumatra, Indonesia), 100 mesh powder (Toko Mustika Djamu), and 100 mesh activated carbon (Sinar Filter, Indonesia). Distilled water, a salinity calibration solution, and standard NaCl solutions (652 ppm, 7 ppm,

and 50 ppt; Cavalese) were used for salinity meter calibration. The instruments used included an AR-8012 salinity meter, beakers, measuring cylinders, a YHG digital balance, a stainless-steel spatula, a glass stirring rod, porcelain crucibles, and a HOT YCO-N01 oven.

The experiment was conducted in four sequential stages to evaluate the effectiveness of adsorbents in reducing the salinity of brackish water. First, natural zeolite, powder, and activated carbon were thermally activated at 250°C for 1 h before use. The optimum contact time was determined separately for natural zeolite and powder by varying the adsorption time from 20 to 120 min using 50 mL of brackish water and 15 g of each adsorbent. During the adsorption process, the mixture was manually stirred using a glass stirring rod to ensure adequate contact between the adsorbent and the brackish water sample. After the optimum contact time for both adsorbents had been established, the zeolite-to- powder composition was varied at ratios of 1:1, 1:2, 1:3, 1:4, and 1:5 while maintaining a constant total adsorbent mass of 15 g. Subsequently, activated carbon was added at masses of 2, 4, 6, 8, 10, and 12 g under the optimum contact time and adsorbent composition to evaluate its effect on salinity reduction. Salinity was measured before and after each treatment using a calibrated AR-8012 salinity meter.

The main parameters evaluated were the initial and final salinity values,

whereas the experimental variables included contact time, adsorbent composition, and activated carbon mass. The adsorption performance was assessed based on salinity reduction (ppt) and salinity reduction efficiency (%). Experimental data were obtained through laboratory measurements, presented in tables and graphs, and analyzed using Equations (1) and (2) to calculate salinity reduction and its efficiency, thereby identifying the optimum operational conditions for salinity reduction through adsorption.

RESULTS AND DISCUSSION

1. Effect of Zeolite Soaking Contact Time on Salinity Reduction and Salinity Reduction Efficiency

Contact time is a critical operational parameter in adsorption because it determines the duration of interaction between adsorbent surfaces and dissolved ions, thereby affecting adsorption capacity and salinity reduction efficiency. This study evaluated the effect of zeolite soaking time on salinity reduction by varying the contact time from 20 to 120 minutes. All tested samples had the same initial salinity of 30.1 ppt, allowing the effect of contact time to be evaluated as the main factor affecting adsorption performance.

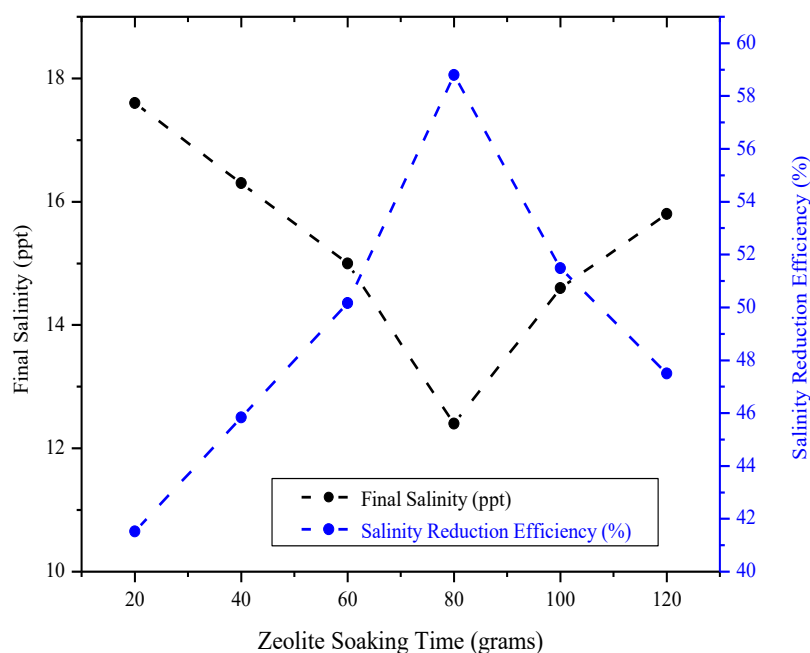


Figure 1. Effect of Zeolite Soaking Contact Time on Salinity Reduction and Salinity Reduction Efficiency

The results showed that increasing the zeolite contact time from 20 to 80 minutes improved the salinity reduction efficiency from 41.52% to 58.80%. This improvement indicates that longer contact time enhanced the diffusion of dissolved salt ions into the porous structure of zeolite and increased their interaction with available active sites. The porous structure and ion-exchange capability of zeolite facilitate the adsorption of dissolved ions, resulting in greater salinity reduction (Islamiyati et al., 2022; Sofith & Effendi, 2020). The optimum performance was obtained at 80 minutes, with a final salinity of 12.4 ppt and a salinity reduction of 17.7 ppt, indicating that this duration provided sufficient interaction time between zeolite and dissolved ions.

Further extension of contact time to 100 and 120 minutes resulted in decreased efficiency, reaching 51.49% and 47.50%, respectively. This reduction was attributed to the saturation of adsorption sites, where most active sites and pores of zeolite became occupied by adsorbed ions, limiting further ion uptake (Zi et al.,

2024). In addition, prolonged contact may promote desorption, causing previously adsorbed ions to be released back into the solution and reducing overall adsorption efficiency (Pratomo et al., 2017; Melki et al., 2024).

The reduction of salinity by zeolite occurred through adsorption and ion-exchange mechanisms. The negatively charged framework of zeolite enables the attraction of positively charged ions such as Na^+ , which can be exchanged with cations such as Ca^{2+} , K^+ , and Mg^{2+} present within the zeolite structure (Mastinu et al., 2019). However, excessive contact time does not necessarily improve adsorption performance because the availability of active sites becomes limited after reaching equilibrium conditions (Svobodová et al., 2024; Syauqiah et al., 2011). Therefore, the contact time of 80 minutes was considered the optimum condition in this study. This result provides an important operational basis for improving zeolite performance and supporting the subsequent development of combined

adsorbent systems for brackish water salinity reduction.

2. Effect of Powder Soaking Contact Time on Salinity Reduction and Salinity Reduction Efficiency

Contact time is a critical operational parameter in the adsorption process

because it controls the interaction duration between powder and dissolved ions, thereby influencing adsorption capacity and salinity reduction efficiency. Therefore, this study was conducted to determine the optimum soaking time of powder by varying the contact time from 20 to 120 minutes.

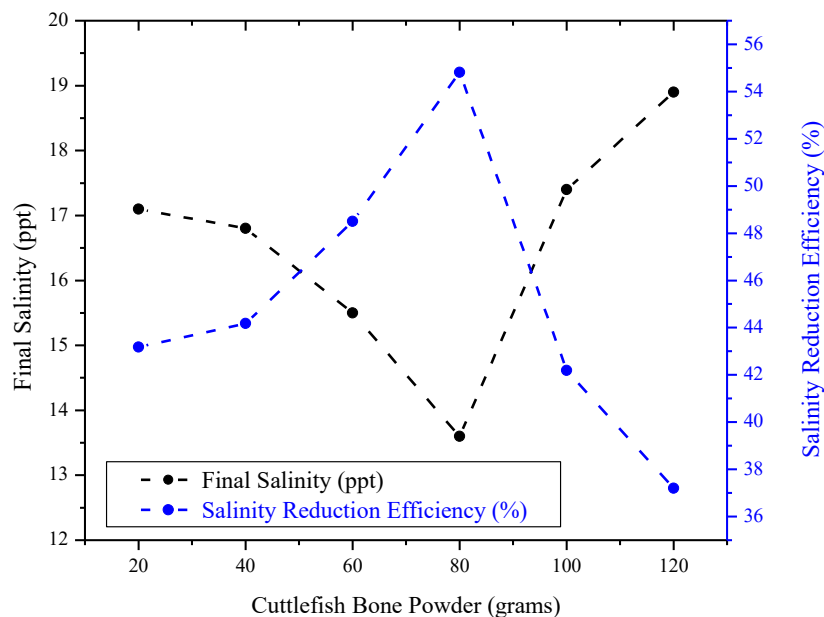


Figure 2. Effect of Cuttlebone Powder Soaking Contact Time on Salinity Reduction and Salinity Reduction Efficiency

Figure 2 shows the effect of powder contact time on salinity reduction and salinity reduction efficiency. Increasing the contact time from 20 to 80 minutes reduced the final salinity from 17.1 ppt to 13.6 ppt and increased the salinity reduction efficiency from 43.18% to 54.81%. The optimum condition was obtained at 80 minutes, indicating that this duration provided sufficient interaction between the adsorbent and dissolved salt ions. The improvement in adsorption performance with increasing contact time was attributed to enhanced ion diffusion into the porous structure of powder, allowing greater interaction between dissolved ions and active adsorption sites (Pramudya et al., 2024; Islamiyati et al., 2022).

After exceeding the optimum contact time, the salinity reduction efficiency decreased to 42.19% at 100 minutes and 37.20% at 120 minutes. This reduction indicates that prolonged contact time did not further enhance adsorption performance due to the limitation of available active sites. The saturation of adsorption sites and pores by previously adsorbed ions may reduce the ability of powder to capture additional ions from the solution (Azzan et al., 2023; Tagar et al., 2023). The adsorption capability of powder is related to its porous structure and calcium carbonate (CaCO_3) content, which contributes to ionic interactions during the removal of dissolved ions in brackish water (Robot et al., 2025; Sholikah et al., 2023).

The relationship between contact time and adsorption performance indicates that 80 minutes represents the optimum condition for powder application. Short contact times may limit the interaction between salt ions and adsorption sites, whereas excessive contact times may lead to saturation conditions and reduced adsorption efficiency (Kusumaningrum et al., 2022). Therefore, the optimum contact time of 80 minutes was selected as the operational condition for further optimization using combined adsorbent systems.

3. Effect of Zeolite and Cuttlebone Powder Composition Combination on Salinity Reduction and Salinity Reduction Efficiency

Variations in zeolite and powder composition influenced the salinity reduction performance and salinity reduction efficiency of brackish water. In this stage, adsorbent composition ratios of 1:1, 1:2, 1:3, 1:4, and 1:5 were evaluated using a constant total adsorbent mass of 15 g and an optimum contact time of 80 minutes. The initial salinity of 30.1 ppt

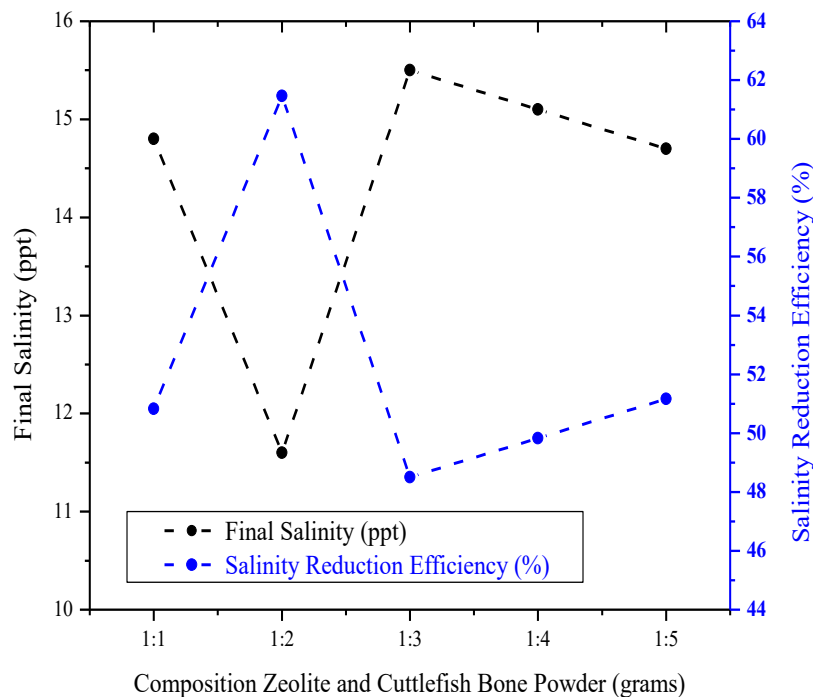


Figure 3. Effect of Zeolite and Powder Composition on Salinity Reduction and Salinity Reduction Efficiency.

decreased after all treatments, indicating that different adsorbent compositions affected the adsorption performance and interaction between the adsorbents and dissolved salt ions. As presented in Figure 3, the 1:1 composition ratio resulted in a final salinity of 14.8 ppt, with a salinity reduction of 15.3 ppt and a salinity reduction efficiency of 50.83%. This result indicates that the interaction

between the available adsorption sites and dissolved salt ions was not yet optimal at this composition ratio (Zhang et al., 2024). Increasing the proportion of powder at the 1:2 composition ratio improved the adsorption performance, achieving the highest salinity reduction efficiency of 61.46% with a salinity reduction of 18.5 ppt. This increase indicates the occurrence of a synergistic

effect between zeolite as an ion-exchange material and powder containing CaCO_3 , which contributes to ionic interactions during the salt ion removal process (Tagar et al., 2023; Al-Mur & Almeelbi, 2026).

The adsorption performance of zeolite is associated with its crystalline porous structure and ion exchange capacity, which enable dissolved ions such as Na^+ and Mg^{2+} to interact with exchangeable cations, including Ca^{2+} and K^+ , within the zeolite framework. This ion exchange mechanism contributes to reducing dissolved salt concentrations in brackish water (Prihatinnyas & Novianti, 2024). Meanwhile, powder containing calcium carbonate (CaCO_3) contributes through ionic interactions and the availability of additional adsorption sites, which support the removal of dissolved ions from the solution (Niu et al., 2022). The combination of these two adsorbent provides complementary adsorption mechanisms, where zeolite facilitates ion exchange while powder enhances ionic interactions, resulting in improved salinity reduction performance (Khazri et al., 2026). Furthermore, the porous structure of powder supports ion diffusion and increases the interaction between dissolved ions and the adsorbent surface.

However, increasing the zeolite proportion at the 1:3 and 1:4 composition ratios reduced the salinity reduction efficiency to 48.50% and 49.83%, respectively. This decrease suggests that an inappropriate proportion between zeolite and powder may reduce the synergistic interaction between both adsorbents, resulting in lower adsorption effectiveness. Excessive zeolite content may also affect the distribution of

adsorption sites and reduce the contribution of CaCO_3 from powder in supporting the adsorption process (Pérez-Botella et al., 2022). At the 1:5 composition ratio, the salinity reduction efficiency slightly increased to 51.16% with a salinity reduction of 14.7 ppt. However, this value remained lower than the optimum condition, indicating that a higher proportion of zeolite did not further improve the adsorption performance due to an imbalance in the adsorbent composition (Tagar et al., 2023). Similar conditions have been reported where an unsuitable adsorbent ratio may reduce adsorption efficiency due to limited interaction between the combined materials (Zohir et al., 2023).

Overall, the optimum composition was obtained at the zeolite-to- powder ratio of 1:2, which produced the highest salinity reduction efficiency. This result demonstrates that the balance between zeolite as an ion-exchange adsorbent and powder as a CaCO_3 -based adsorbent plays an important role in improving the effectiveness of brackish water salinity reduction.

4. Effect of Activated Carbon Mass Addition on Salinity Reduction and Salinity Reduction Efficiency

After the optimum contact time and adsorbent composition had been established, the adsorption system was further evaluated by varying the activated carbon mass. This stage aimed to determine the optimum activated carbon mass for enhancing salinity reduction under the optimum contact time of 80 min and the zeolite-to- powder composition ratio of 1:2.

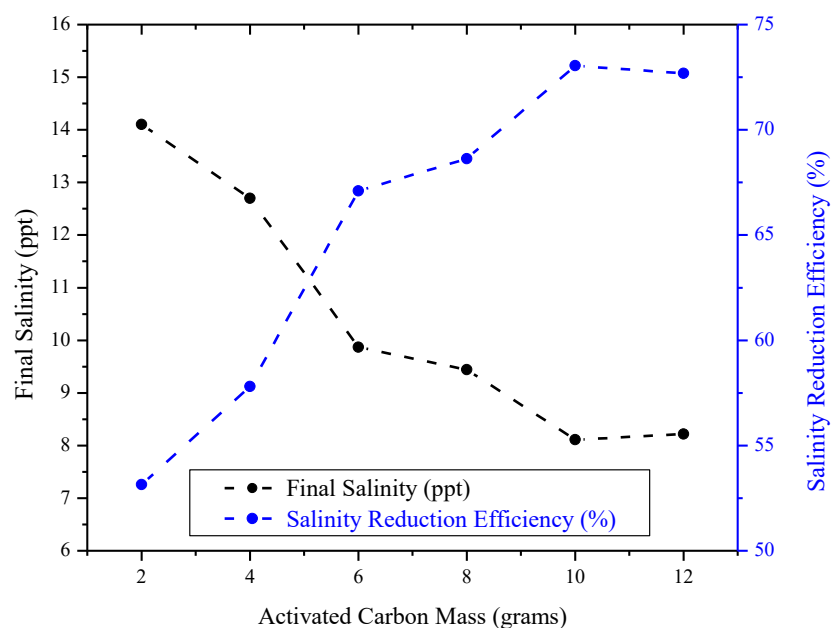


Figure 4. Effect of Activated Carbon Mass Addition on Salinity Reduction and Salinity Reduction Efficiency

As shown in Figure 4, increasing the activated carbon mass generally improved the adsorption performance. The addition of 2 g of activated carbon resulted in a final salinity of approximately 14.1 ppt, corresponding to a salinity reduction of 16.0 ppt and a salinity reduction efficiency of 53.15%. Increasing the activated carbon mass to 4, 6, and 8 g further enhanced salinity reduction to 17.4, 20.2, and 20.6 ppt, with efficiencies of 57.80%, 67.10%, and 68.63%, respectively. The highest adsorption performance was achieved at an activated carbon mass of 10 g, producing a final salinity of 8.2 ppt, a salinity reduction of 21.9 ppt, and the highest salinity reduction efficiency of 73.05%.

The improvement in adsorption performance can be attributed to the high specific surface area and porous structure of activated carbon, which provide abundant active sites for the adsorption of dissolved salt ions (Kasifya et al., 2023). Increasing the adsorbent mass increases the available adsorption surface, thereby promoting more effective diffusion and interaction between dissolved ions and the adsorbent surface (Widayatno, 2017). In

addition, the presence of micropores and mesopores facilitates the transport of ions into the internal pore structure, increasing the adsorption capacity of the material (Fisli et al., 2018). Consequently, a greater number of Na^+ and Cl^- ions can be retained through physical adsorption and electrostatic interactions, leading to higher salinity reduction efficiency.

However, increasing the activated carbon mass to 12 g resulted in a slight decrease in salinity reduction efficiency to 72.69%. This reduction may be attributed to particle agglomeration, which can decrease the effective surface area by partially blocking adsorption pores and limiting access to active sites (Amran & Zaini, 2020). Under these conditions, the diffusion of dissolved ions becomes less efficient, reducing the overall adsorption performance despite the larger adsorbent mass. Overall, the results demonstrate that activated carbon mass is an important operational parameter influencing adsorption performance. An activated carbon mass of 10 g provided the optimum condition, indicating that increasing the adsorbent mass enhances salinity reduction only up to an optimum level,

beyond which adsorption efficiency no longer increases because the available adsorption sites become less effectively utilized.

CONCLUSION

This study demonstrated the effectiveness of integrating natural zeolite, powder, and activated carbon as adsorbents for reducing the salinity of brackish water from the Sungsang coastal area. The optimum adsorption performance was achieved at a contact time of 80 min, a zeolite-to- powder composition ratio of 1:2, and an activated carbon mass of 10 g, resulting in the highest salinity reduction efficiency of 73.05% with a salinity reduction of 21.9

ppt. These findings indicate that optimizing contact time, adsorbent composition, and activated carbon mass improves the adsorption performance of the combined natural adsorbents through complementary adsorption mechanisms. The proposed adsorption system offers a simple, low-cost, and environmentally friendly approach for reducing salinity in brackish water, making it a promising alternative for clean water treatment in coastal areas with limited access to conventional desalination technologies. Future studies should evaluate the regeneration and reusability of the adsorbents, investigate long-term adsorption performance, and assess the applicability of the system under larger-scale or field conditions.

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