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Evaluating the Efficacy of Natural Zeolite in Treating Saline Seawater for Multiuse in Southern Jordan

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ABSTRACT

This study investigates the use of various types of natural zeolite stones to treat seawater in the Gulf of Aqaba in Southern Jordan. The research aims to examine the physical and chemical impacts of these stones on the permanent hardness of seawater and their potential for reducing this hardness to the lowest possible level while preserving the water's essential properties. The treated water is intended for diverse practical uses, including agricultural, industrial, and domestic applications. The study's main objective is to minimize the dissolved salts and hardness of highly saline water while maintaining the physical and chemical composition. This research focused on two categories of analysis: (1) the physical effects, which are focused on measuring the percentage of dissolved salts, electrical conductivity, turbidity, color, odor, and pH of water; (2) chemical effects, which cover water components such as carbonates, bicarbonates, sulfates, chlorides, calcium, magnesium, potassium, sodium, nitrates, nitrites, and heavy metals before, during, and after treatment. Field testing instruments were employed alongside laboratory-based sampling and analysis to ensure precise and reliable documentation throughout the study. The extent of lead removal from water using zeolite was implemented in Jordan by a researcher from Zarqa University, who achieved good results with water discharged from a battery manufacturing plant that processes lead. The results were as follows: The zeolite used was one ton; daily factory water usage was 20 m^2; working days were 100; and discharged water volume was 2000 m^3. Finally, permissible pollution limits were safe and compliant with international specifications. The experimental results in this study showed that initial TDS values exceeding 38,000 ppm were reduced by more than 50% in several cases.

INTRODUCTION

The zeolite group includes several hydrous silicate minerals with similar chemical compositions and natural occurrences. These minerals are primarily aluminum, sodium, and calcium silicates and typically contain a high percentage of water. Zeolite minerals have a hardness ranging from 3.5 to 5.5 and a specific gravity between 2.0 and 2.4. Many zeolite minerals melt rapidly, often accompanied by swelling and foaming. They are classified as secondary minerals and are commonly found in volcanic rocks' voids, gaps, and veins. Zeolite minerals are lightweight and fragile, and they occur in various colors, such as orange, yellowish green, light green, and colorless or white, with fine crystal sizes measured in fractions of a millimeter. Water hardness is a scientific term used to describe the condition in which water contains high concentrations of dissolved salts, particularly calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. This condition affects the water's physical and chemical properties, often leading to reduced lathering with soap, a salty or bitter taste, and challenges in domestic and industrial applications. The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) have established guidelines defining acceptable salt concentrations for water used for human, animal, and agricultural use.

The major contributors to water hardness include calcium (Ca), magnesium (Mg), bicarbonates (HCO_3^-), sulfates (SO_4^{2-}), calcium carbonate ($CaCO_3$), and calcium sulfate ($CaSO_4$). High levels of these dissolved salts, particularly bicarbonates, sulfates, chlorides, and carbonates, are often responsible for water hardness. In addition, there are two types of water hardness: temporary hardness, which is primarily caused by bicarbonate salts, and permanent hardness, which results from calcium and magnesium salts in the form of sulfates and chlorides. These salts do not precipitate upon heating and, therefore, require chemical treatment for removal.

The negative impacts of using hard water include the deposition of magnesium and calcium salts, which form scale layers on the interior surfaces of vessels and pipes, reducing their thermal conductivity. This issue leads to the formation of insulating layers, which increase energy consumption, whether electric or fuel-based, both in intensity and duration. Also, the accumulation of deposits increases the likelihood of pipe blockages and internal corrosion due to chemical interactions between the salts and the metallic components of the thermal systems. There are some restrictions related to zeolite-based nanocomposites because the process of breaking bonds destroys and disintegrates the crystalline structure of the zeolite material and causes it to lose one of its most important properties, which are the structural voids that are considered the storehouse of the outputs of the ion exchange process that zeolite possesses.

REVIEW OF LITERATURE

Jordan has severe water scarcity and highly salinized water sources, particularly in areas like the Gulf of Aqaba. Jordan's dedication to large-scale ecological wastewater management is exemplified by Al-Samra Wastewater Treatment Plants (2024), which uses life cycle assessment (LCA) techniques to maximize environmental and performance results. Several studies have also been conducted to study the effect of using zeolite in water treatment. Kumar and Singh (2024) provide a general overview of zeolite uses for eliminating various contaminants from wastewater, such as dyes, phenolic compounds, and heavy metals. They examine how synthesis methods, adsorption processes, and operational factors affect removal effectiveness. Li et al. (2024) explore the field of modified zeolites and critically assess their improved performance in heavy metal removal, corroborating their findings.

Al-Farajat & Al-Khashman (2024) approve using natural zeolites in aquatic environments. Their experimental investigation evaluated the effects of zeolite filtration on biological parameters and water quality in the aquaculture of European seabass. A thorough analysis of natural zeolites as dual-purpose sorbents that can remove carbon dioxide and heavy metals from wastewater is conducted by Mambetova et al. (2024). Their research highlights the zeolites' adsorption-facilitating structural properties and their promise as environmentally friendly materials for combined air and water purification systems. An overview of next-generation desalination methods, such as forward osmosis, membrane distillation, electrodialysis, and solar desalination, is given by Genesis Water Technologies (2024).

Despite their high technological cost, these new approaches could work with systems based on natural materials, such as zeolites, to provide hybrid solutions in areas with limited water resources. Indeed, Jordan's strategic efforts to secure a long-term water supply using Red Sea water are demonstrated by large-scale projects like the Aqaba-Amman Water Desalination and Conveyance Project (European Investment Bank, 2023) and the deep subsea desalination partnership between Waterise and Jordan Phosphate Mines Company (2024).

The literature evaluation confirms natural zeolites' effectiveness, adaptability, and environmental sustainability in water treatment, especially when eliminating heavy metals, ammonia, and other impurities. Because of its water problems, Jordan is a good place to install zeolite-based systems with cutting-edge desalination equipment. A realistic way to achieve sustainable water security is to combine natural resources with contemporary technologies, particularly in arid and semi-arid areas like Jordan.

Margeta et al. (2013) and Barloková (2008) have examined the effectiveness of using natural zeolite in water treatment. A review of modified zeolite as a material for wastewater purification was provided by Widiastuti et al. (2008), Hamed et al. (2022), and Shoumkova (2024). Nizam et al. (2021) investigated the application of natural zeolite to treat greywater, focusing on removing ammonia and heavy metals to improve water quality in fish ponds. Similarly, Onyutha et al. (2024) demonstrated using zeolite in household water treatment to remove arsenic, lead, and fluoride, following turbidity reduction through slow sand filtration. Using natural zeolite as a cost-effective adsorbent for removing ammonium from drinking water was explored by Eberle et al. (2022).

In another study, Mnyango et al. 2010, used clinoptilolite functionalized with the cationic surfactant hexadecyl trimethyl ammonium (HDTMA) to control nitrate concentrations in drinking water. Salman et al. (2017) examined the static absorption of heavy metals V^{+5}, Ni^{+2}, Zn^{+2}, and Pb^{+2} using natural zeolite sourced from southern Syria. Their research focused on ascertaining the adsorption capability of inexpensive zeolite used to extract heavy metals from crude oil desalter effluent, which poses significant risks to human and ecological health if discharged untreated. Margeta et al. (2013) also discussed the removal of arsenic from water using both natural and modified clinoptilolite.

MATERIALS AND METHODS

Scientific literature and theoretical studies confirm the positive effects of the zeolite mineral in reducing water hardness and removing various impurities and chemical compounds that are foreign to water's natural composition (H_2O). These impurities are typically introduced through external environmental factors encountered during the water's natural cycle.

The methodology of this work is structured as follows:

1. **Treatment Objective:** Seawater from the Gulf of Aqaba was treated using natural zeolite stones to reduce the **concentration** of dissolved salts, which contribute to water hardness, to the lowest possible level.
2. **Application Scope:** The study aimed to evaluate the feasibility and effectiveness of the treated water for various societal uses, including human consumption, animal use, agriculture, and industry.
3. **Location:** Gulf of Aqaba
4. **Duration:** The experimental period was extended from November 5, 2022, to March 5, 2023, to ensure scientifically reliable results supported by laboratory test reports from accredited laboratories in Jordan.
5. **Zeolite Samples:** Three types of natural zeolite stones were used, identified as Z1, Z2, and Z3. These were sourced from different officially licensed extraction sites in Jordan.
6. **Water Samples:** After studying the conditions of the sea (the Gulf of Aqaba) in terms of tides, and noting that two high tides and two low tides occur every 24 hours, sampling was synchronized with these tidal variations across several days (Table 1). Geographic variability was incorporated by selecting sampling points at different depths and distances from the shoreline.
7. **Experimental Procedure:** A structured setup was implemented for the treatment and testing processes.
8. **Data Verification and Analysis:** Data collected from different samples were analyzed and validated to ensure reliability and accuracy.

Chemicals and Toxic Compounds: Toxic substances and chemicals must be absent from water intended for use. If present, their concentrations must remain within acceptable limits, as defined by international standards. Table 2 outlines the permissible concentration limits (in mg/L) for various toxic and chemical substances in water.

Table 1: Seawater sampling information and timings.

Sample name	Sample collection time	Sea condition	Sample quantity (L)	Sample collection date
A	9.30 am	After the first high tide	100	6/11/2022
B	2.00 pm	Near the first low tide	100	6/11/2022
C	8.20 pm	At the peak of the second high tide	100	8/11/2022
D	2.30 am	At the second low tide	100	9/11/2022

Table 2: Permissible limits of toxic and chemical substances in water.

Material	Ratio mg/L	Material	Ratio mg/L
Lead	1.0	Copper	5.1
Arsenic	50	Manganese	5
Zinc	15	Iron	1
Phenol	200	Nitrates	Max 45
Sulfates	400	Fluorides	Max 8
Chlorides	600	Mercury	0-100
Magnesium	150	Cadmium	10
Calcium	200	Cyanide	50
pH	6.5- 9.2	Lead	1.0

Specifications of Potable Water According to the WHO

The WHO has established 62 criteria for safe drinking water, including chemical, physical, microbiological, and sensory criteria that people may detect with their senses.

- Color: Acceptable and not exceeding 50 units on the scale of platinum cobalt.
- Taste: It should be pleasant and palatable.
- Odor: Should be odorless.
- Turbidity: Should be clear, with a maximum of 5 Jackson units for treated water and up to 52 units for groundwater.
- Dissolved Oxygen (O_2): 5–8 mg/L at 25°C.
- Dissolved Carbon Dioxide (CO_2): 2–3 mg/L at 25°C.
- Electrical Conductivity**:** 0.0004 μmho/cm² at 18°C.
- Thermal Conductivity**:** 1.555 W/m·K at 40.8°C.
- Refractive Index: 1.33 at 20°C.
- Vapor Pressure: 17.62 mm Hg at 20°C.
- Specific Heat: 0.99 kJ/kg·°C at 20°C.
- Density: 1.00 g/cm³ at 4°C and 0.99823 g/cm³ at 20°C.

Table 3: Results of Sample A Treated with Zeolite (Z1, Z2, Z3).

Sample name	Sample type	Color	TDS	pH
A	Filtered seawater	clear	35,000	7.8
AZ1-1	Sample treated after 1 hour	clear	33,020	6.8
AZ1-2	Sample treated after 2 hours	clear	31,150	5.6
AZ1-3	Sample treated after 3 hours	clear	29,820	4.5
AZ1-6	Sample treated after 6 hours	clear	22,320	4.8
AZ1-12	Sample treated after 12 hours	clear	20,120	5.2
AZ1-24	Sample treated after 24 hours	clear	18,500	7.7
AZ2-1	Sample treated after 1 hour	clear	32,800	6.9
AZ2-2	Sample treated after 2 hours	clear	30,110	6.1
AZ2-3	Sample treated after 3 hours	clear	28,150	5.1
AZ2-6	Sample treated after 6 hours	clear	21,000	5.8
AZ2-12	Sample treated after 12 hours	clear	19,550	6.4
AZ2-24	Sample treated after 24 hours	clear	17,420	7.6
AZ3-1	Sample treated after 1 hour	clear	33,500	7.2
AZ3-2	Sample treated after 2 hours	clear	31,100	6.6
AZ3-3	Sample treated after 3 hours	clear	28,850	5.2
AZ3-6	Sample treated after 6 hours	clear	20,440	6.1
AZ3-12	Sample treated after 12 hours	clear	17,820	6.8
AZ3-24	Sample treated after 24 hours	clear	15,250	7.9

- Freezing Point: 0°C
- Boiling Point: 100°C
- Latent Heat of Vaporization: 584.9 cal/g at 20°C
- Surface Tension: 72.75 dynes/cm at 20°C

RESULTS AND DISCUSSION

The tidal times in the Gulf of Aqaba were studied over 30 days to determine tidal levels. The sampling time was set to the time of highest tide (because the seawater was at its lowest salinity after testing), and the sampling time was set to the time of lowest ebb tide (when the water was at its highest salinity after testing) because there are no freshwater outlets in the Gulf. It is considered one of the coastal areas with the highest percentage of dissolved salts because it is relatively enclosed, except where it meets the Red Sea.

The experimental procedure began with physical testing of raw seawater, particularly assessing Total Dissolved Solids (TDS), color, and pH. Then, the water was passed through natural zeolite mineral stones using a controlled approach to determine the effectiveness of zeolite in reducing hardness and improving water quality. Three different types of natural zeolite (Z1, Z2, and Z3) were tested simultaneously. After each treatment interval, the same tests were conducted to measure changes in water characteristics. The performance of each zeolite type was monitored over varying durations of 1, 2, 3, 6, 12, and 24 hours. Further adjustments, such as pH balancing using chemical additives, were made to align the treated water's quality with recognized natural water standards, particularly for taste and usability.

Sample "A" Measurements

Table 3 presents the results of treating different Sample "A" using the three zeolite types over various time intervals.

Table 3 shows how zeolite affects the reduction of Total Dissolved Solids (TDS). The initial TDS value of 35,000 mg/L was reduced significantly after 24 hours of treatment:

- AZ1-24: 18,500 mg/L (~47% reduction)
- AZ2-24: 17,420 mg/L (~50% reduction)
- AZ3-24: 15,250 mg/L (~56% reduction)

These results indicate a consistent and effective performance of natural zeolite in reducing salinity and dissolved solids. Notably, the Z3 sample exhibited the highest efficiency, suggesting better adsorptive properties.

It is important to note that the experiment was conducted under static laboratory conditions, where the water remained stationary during contact with the zeolite. In real-world (dynamic) applications, where water is continuously moving, the interaction and mixing rates are higher, potentially improving the efficiency of ion exchange and enhancing the overall purification process.

Fig. 1 illustrates how sample A's pH changed over time. At the initial time point (0 hours), the pH of the filtered seawater was recorded at 7.8 across all three samples. As treatment progressed, a noticeable decrease in pH was observed, particularly within the first 3 to 6 hours. This decline indicates the acidic influence of natural zeolite on the treated water. After 3 hours, the pH values dropped to 4.5, 5.1, and 5.2 for AZ1, AZ2, and AZ3, respectively, suggesting the zeolite samples possess mildly acidic characteristics that lower the water's pH. To ensure the treated water met acceptable acidity standards, minor chemical adjustments were made, raising the pH to approximately 7.0–7.5, aligning the treated water with international potable water guidelines for usability.

Sample "B" Measurements

The results for the different Sample "B," collected near the first low tide, are presented in Table 4. As with Sample A, seawater was treated using three types of natural zeolite (BZ1, BZ2, and BZ3), and measurements were taken over different exposure times ranging from 1 to 24 hours.

Table 4 demonstrates how zeolite affects the reduction

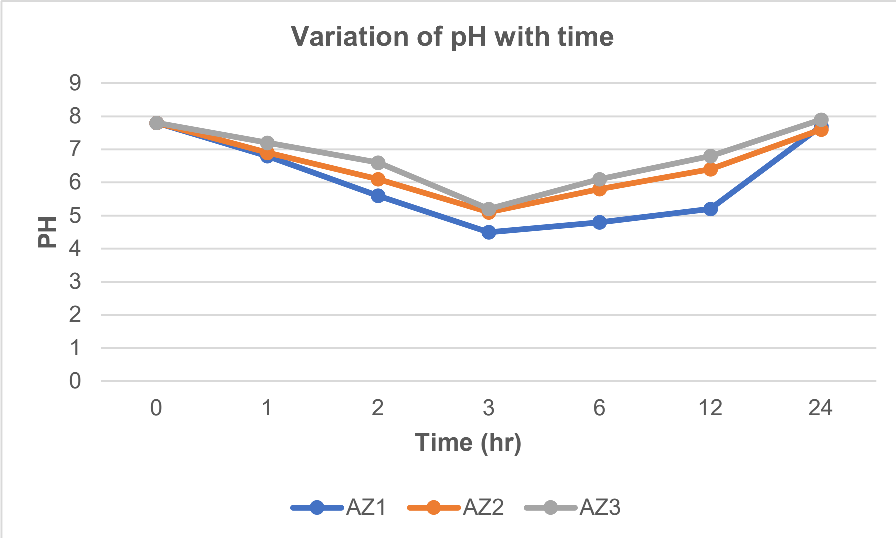

Fig. 1: Variation of pH with time for sample A.

Table 4: Data obtained from Sample B.

Sample name	Sample type	Color	TDS	pH
B	Filtered seawater	clear	38,100	8
BZ1-1	Sample treated after 1 hour	clear	35,200	7
BZ1-2	Sample treated after 2 hours	clear	33,050	6.5
BZ1-3	Sample treated after 3 hours	clear	31,300	6.1
BZ1-6	Sample treated after 6 hours	clear	26,350	5.9
BZ1-12	Sample treated after 12 hours	clear	21,825	6.8
BZ1-24	Sample treated after 24 hours	clear	19,850	7.9
BZ2-1	Sample treated after 1 hour	clear	36,050	7.2
BZ2-2	Sample treated after 2 hours	clear	32,800	6.6
BZ2-3	Sample treated after 3 hours	clear	29,150	5.8
BZ2-6	Sample treated after 6 hours	clear	24,250	6.1
BZ2-12	Sample treated after 12 hours	clear	21,500	6.7
BZ2-24	Sample treated after 24 hours	clear	18,560	7.8
BZ3-1	Sample treated after 1 hour	clear	34,550	7.3
BZ3-2	Sample treated after 2 hours	clear	31,325	6.9
BZ3-3	Sample treated after 3 hours	clear	29,100	5.9
BZ3-6	Sample treated after 6 hours	clear	25,400	6.3
BZ3-12	Sample treated after 12 hours	clear	21,125	7.7
BZ3-24	Sample treated after 24 hours	clear	16,800	8.1

of Total Dissolved Solids (TDS) across all three zeolite types over time. The initial TDS of the filtered seawater was 38,100 mg/L. After 24 hours of treatment, TDS values were reduced to 19,850 mg/L for BZ1-24, 18,560 mg/L for BZ2-24, and 16,800 mg/L for BZ3-24. These reductions represent an approximate 44–52% decrease, indicating a significant purification effect through the zeolite filtration process.

Fig. 2 illustrates the changes in pH levels of Sample B over time during zeolite treatment using the three different types. At 0 hours, all samples showed a consistent pH value of 8.0. The pH declined throughout the treatment, particularly within the 3–6 hour range. This decrease is attributed to the mildly acidic nature of the zeolite materials. After 3 hours of treatment, the pH values dropped to 6.1, 5.8, and 5.9 for BZ1, BZ2, and BZ3, respectively. Although this trend reflects the same behavior observed in Sample A, the reduction in pH for Sample B was slightly less steep. Nonetheless, minor chemical adjustments were applied to raise the pH to near-neutral levels (7.0–7.5) to ensure compliance with water quality standards and make the treated water suitable for practical uses. These results reaffirm zeolite's efficacy in reducing TDS and altering pH and highlight the importance of post-treatment pH correction when considering real-world applications.

Sample "C" Measurements

The results obtained from different "C" samples are presented in Table 5**.** As with previous samples, seawater was treated using three zeolite types (CZ1, CZ2, and CZ3), and measurements were taken at intervals up to 24 hours.

Table 5 demonstrates a gradual and consistent reduction in Total Dissolved Solids (TDS) over time across all zeolite samples. The initial TDS value of the filtered seawater was 33,280 mg/L. After 24 hours of treatment, TDS values were reduced to 15,500 mg/L for CZ1-24, 15,025 mg/L for CZ2-24, and 13,320 mg/L for CZ3-24. These values

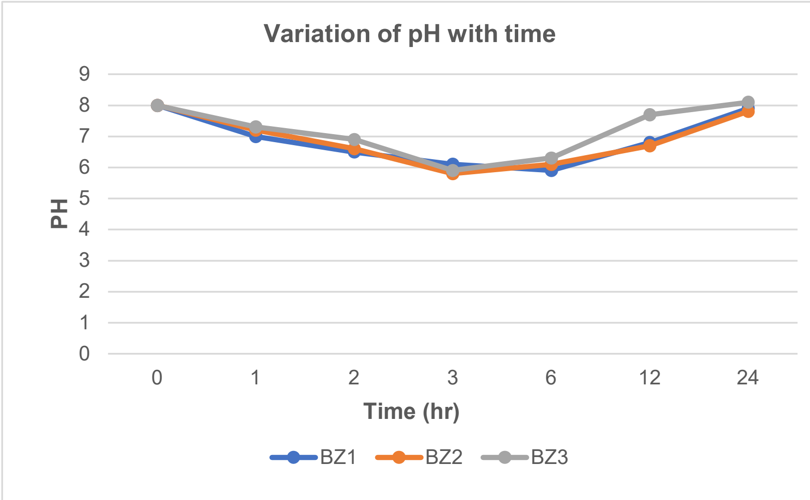

Fig. 2: Variation of pH with time for sample B.

Table 5: The data obtained from different "C" samples.

Sample name	Sample type	Color	TDS	pH
C	Filtered seawater	clear	33,280	7.9
CZ1-1	Sample treated after 1 hour	clear	32,050	7.7
CZ1-2	Sample treated after 2 hours	clear	30,100	7.2
CZ1-3	Sample treated after 3 hours	clear	27,500	6.8
CZ1-6	Sample treated after 6 hours	clear	23,875	6.1
CZ1-12	Sample treated after 12 hours	clear	21,000	6.8
CZ1-24	Sample treated after 24 hours	clear	15,500	7.8
CZ2-1	Sample treated after 1 hour	clear	31,950	7.6
CZ2-2	Sample treated after 2 hours	clear	29,750	7.1
CZ2-3	Sample treated after 3 hours	clear	25,330	6.5
CZ2-6	Sample treated after 6 hours	clear	20,410	5.9
CZ2-12	Sample treated after 12 hours	clear	14,850	6.8
CZ2-24	Sample treated after 24 hours	clear	15,025	7.9
CZ3-1	Sample treated after 1 hour	clear	31,100	7.5
CZ3-2	Sample treated after 2 hours	clear	28,450	7.1
CZ3-3	Sample treated after 3 hours	clear	25,330	6.3
CZ3-6	Sample treated after 6 hours	clear	21,650	6.9
CZ3-12	Sample treated after 12 hours	clear	18,825	7.1
CZ3-24	Sample treated after 24 hours	clear	13,320	7.8

reflect a decrease of approximately 40–46%, confirming the continued effectiveness of zeolite in reducing dissolved salts in seawater.

Fig. 3 shows that at the initial time (0 hr), all samples had the same pH value of 7.9. The pH values decreased over time due to the effect of zeolite, reaching lower values after several hours of treatment. This indicates the acidic influence of the zeolite used.

Sample "D" Measurements

The data obtained from different "D" samples are shown in Table 6.

Table 6, like the previous ones, demonstrates the reduction of Total Dissolved Solids (TDS) by zeolite. The TDS values for DZ1-24, DZ2-24, and DZ3-24 were significantly reduced to 17,500, 18,050, and 16,150 ppm,

Table 6: The data obtained from different "D" samples.

Sample name	Sample type	Color	TDS	pH
D	Filtered seawater	clear	37,900	8
DZ1-1	Sample treated after 1 hour	clear	35,010	7.2
DZ1-2	Sample treated after 2 hours	clear	31,990	6.7
DZ1-3	Sample treated after 3 hours	clear	27,830	6.1
DZ1-6	Sample treated after 6 hours	clear	23,000	5.6
DZ1-12	Sample treated after 12 hours	clear	20,580	6.4
DZ1-24	Sample treated after 24 hours	clear	17,500	7.9
DZ2-1	Sample treated after 1 hour	clear	35,980	7.2
DZ2-2	Sample treated after 2 hours	clear	33,025	6.8
DZ2-3	Sample treated after 3 hours	clear	30,950	5.8
DZ2-6	Sample treated after 6 hours	clear	27,860	6.1
DZ2-12	Sample treated after 12 hours	clear	21,045	6.9
DZ2-24	Sample treated after 24 hours	clear	18,050	7.8
DZ3-1	Sample treated after 1 hour	clear	35,650	7.4
DZ3-2	Sample treated after 2 hours	clear	31,870	6.2
DZ3-3	Sample treated after 3 hours	clear	27,540	5.7
DZ3-6	Sample treated after 6 hours	clear	22,450	6.1
DZ3-12	Sample treated after 12 hours	clear	19,230	6.6
DZ3-24	Sample treated after 24 hours	clear	16,150	7.9

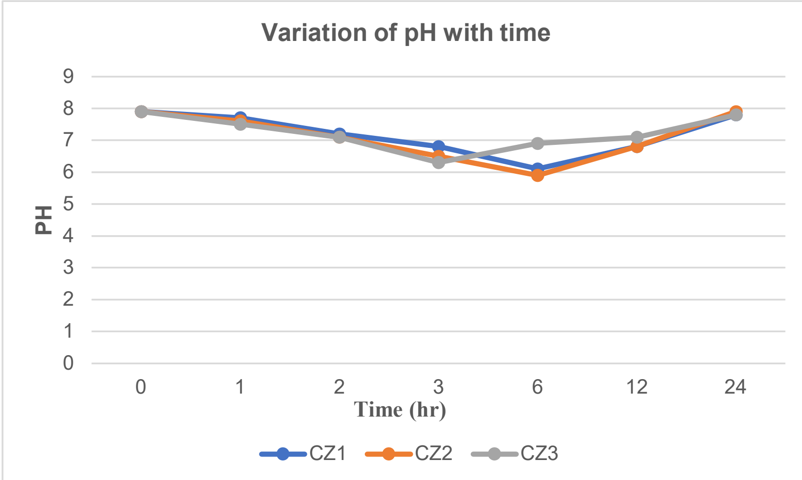

Fig. 3: Variation of pH with time for sample C.

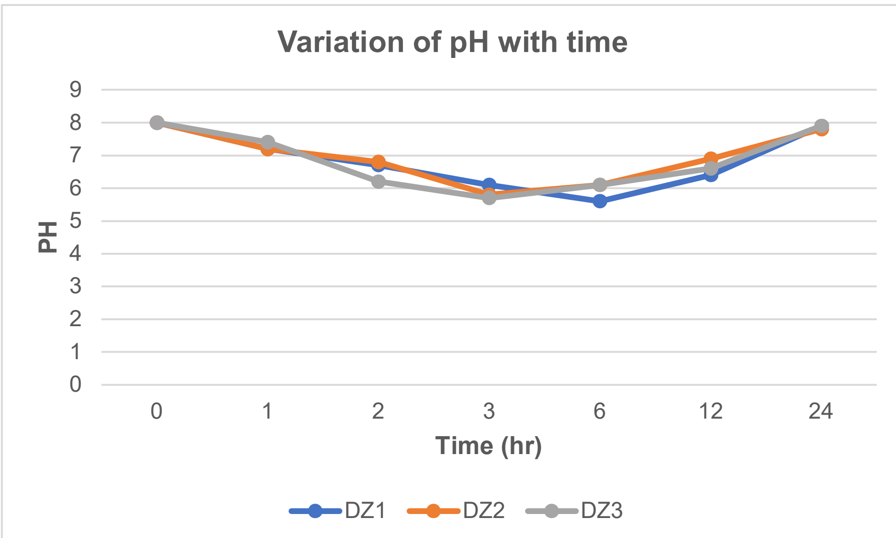

Fig. 4: Variation of pH with time for sample D.

respectively, representing a 42–46% reduction from the initial value of 37,900 ppm.

Fig. 4 shows that at the initial time (0 h), all samples had a pH of 8. Over time, the pH decreased due to the effect of zeolite, indicating its acidic nature. From the experimental data across all sample groups, the results confirm the hypothesis that natural zeolite effectively reduces the hardness and salinity of seawawater. The highest initial TDS values ranged between 33,280 and 38,100 ppm, and zeolite treatment reduced these by approximately 40–50%. The remaining dissolved salts were primarily sodium-based, representing temporary hardness, which can be relatively easily removed using modern treatment methods to make the water suitable for various applications.

Additionally, the decrease in pH values after treatment supports the acidic characteristics of the zeolite used. After treatment, a minor chemical adjustment was applied to restore the pH to a more neutral range (7.0–7.5). It is important to note that these tests were conducted under static conditions in the laboratory. In a dynamic setting, where water is flowing or circulating, the efficiency of zeolite treatment is expected to improve further due to enhanced ionic exchange between water and zeolite particles.

This research was conducted to find solutions and alternatives to the chemicals used in treating hard saline water, which cost high amounts of money and have a short operational life. In addition, zeolite raw materials are natural materials with a sustainable life and are considered environmentally friendly. Their physical value is acceptable, and they can be recycled for agricultural uses when saturated in the water treatment field and do not require destruction. In the field of applications, they have been used in some countries around the world, the most important of which is water treatment after the well-known Chornobyl reactor accident, as well as for greywater treatment in several countries (Germany, Sweden, and Austria).

It should be noted that the work in this study depends on seawater loaded with high levels of salts, which cause permanent hardness, and on the presence of lead (Pb^{2+}), which is often very weak in open water. This is the reason for not considering interactions between Pb^{2+} and functional groups in zeolite.

CONCLUSIONS

The experimental results support the hypothesis that natural zeolite reduces seawater's hardness. Initial TDS values exceeding 38,000 ppm were reduced by more than 50% in several cases. Laboratory tests confirmed that the remaining dissolved salts are primarily sodium-based, contributing to temporary hardness, and can be readily removed using modern treatment technologies. This indicates that natural zeolite can significantly improve seawater quality, making it more suitable for various practical uses.

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