Salinity reduction in well water using zeolite

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Abstract. Saline water intrusion is one of the global issues, which increases the demand for freshwater around the coastal region. The saline content in drinking water makes so many health impacts on human beings. There are many new technologies available for reducing salinity such as desalination, membrane technologies, reverse osmosis, etc. But these are expensive too. There is a need for cost-effective treatment which is suitable for domestic purpose in coastal regions. In this paper, a new technique is introduced which reduces the saline content in groundwater by installing this barrier device in wells of coastal regions. A non-woven Geo textile along with natural zeolite is used as a filter cum adsorption unit. Tests results show a decrease in electrical conductivity and total dissolved solids with an increase in filter thickness for all selected salt concentrations irrespective of the adsorbent materials used viz., natural zeolite and thermally activated natural zeolite. This indicated a reduction in chloride ions as the only salt added to the water samples tested was commercial salt. Authors suggest that a thermally activated zeolite filter could be a possible cost-effective, efficient and easy solution for increasing saline water intrusion issues in coastal drinking water wells.

1. Introduction
Saltwater intrusion, which is the induced flow of saline or brackish water into freshwater, is an ever-increasing problem in coastal areas. Seawater intrusion is often regarded as the only factor causing saltwater contamination. But, there are seven other causes of salinity in groundwater like tidal and storm surges, pollution from agricultural land, etc [1]. Once saltwater intrusion occurs, the changes in the aquifer may be permanent or may take many years to recover.

Saline water intrusion impacts are associated primarily with losses of freshwater resources and contamination of water supply wells, and only a few studies consider adverse ecological impacts directly linked to saline water intrusion. Environmental degradation arising from this is commonly linked to the application of high salinity groundwater in agriculture, resulting in modified soil chemistry and reduced soil fertility [2]. While the direct and indirect intrusion of salinity in fresh groundwater affects human well-being, its serious implications on population health must be clearly understood. Owing to the use of saltwater, numerous diseases including skin ailments, hair fall, diarrhoea, gastric diseases, and high blood pressure are suffered.

A lot of techniques have been used to manage/control salt/seawater intrusion and protect groundwater resources. The principle is basically to reduce the volume of saltwater intrusion and increase the volume of freshwater. Mahesha [3] and Rastogi et al. [4] combined the methods of injection of freshwater and extraction of saline water to increase the volume of freshwater and to reduce the volume of saltwater pose effective but the setback is the cost factor involved in the construction and maintenance of the wells. Several of these methods are costly and some might not be
applicable in certain cases especially with the growing population and increasing demand for water [5-6]. Another technique of control is maintaining a seaward hydraulic gradient and a proportion of the natural freshwater recharge flowing into the sea. The movement may be insignificant, but in collaboration with other methods, it is possible to eradicate saltwater intrusion [7]. Application of a geotextile material along with sand, as a new absorbent has been reported for fluoride and other salts removal [8].

Extensive researches have been carried out to investigate saline water intrusion in coastal aquifers. However, a limited number of researches have been directed to study the control of saline water intrusion into a coastal well in a cost-effective manner. Hence this project aims to provide a better method to reduce saline water intrusion by introducing a filter unit inside the well.

2. Materials used

2.1. Natural zeolite
Natural zeolites, a hydrated alumino silicate mineral, in fine grade powder form used in this study was collected from Sam Industries, Gujarat. Natural zeolites are well known for their adsorption behaviour, cation exchange capacity, low density and high porous structure. The physical and chemical properties of the zeolite used in the study are provided in Table 1.

| Grade                  | Grade | Natural Zeolite Fine Powdered (Clinoptilolite) |
|------------------------|-------|-----------------------------------------------|
| Type                   | Type  | Adsorbent                                     |
| Formula                | Formula | (Na K)₆(Si₃₀Al₆O₇₂)H₂O                      |
| Si / Al Ratio          | Si / Al Ratio | 4 – 5                                    |
| Main Cation            | Main Cation | Na, K, Ca                           |
| Cation Exchange Capacity| Cation Exchange Capacity | 2-2.6 meq/g                            |
| Specific Gravity       | Specific Gravity | 1.89                                   |
| Pore Diameter          | Pore Diameter | 4 - 7 angstroms                        |
| Specific Surface Area  | Specific Surface Area | 40 m²/g                                |
| Specific Weight        | Specific Weight | 2.20 – 2.44 g/cm³                       |

2.2. Thermally activated natural zeolite
The natural zeolite in powder form was thermally activated by heating in a hot air oven to a temperature of 225°C for 3 hours. Thermal activation will increase the adsorption efficiency of natural zeolite.

2.3. Sand
Sand-filled behind the filter unit inside the L-shaped tank was procured from Manali river, Amballur, Kerala. It had a specific gravity of 2.67 and an effective particle size of 0.35mm, while the uniformity coefficient and coefficient of curvature were 3.7 and 1.07 respectively. The maximum and minimum dry unit weights were 16.28kN/m³ and 13.73 kN/m³ respectively. The river sand was washed several times, sun-dried and sieved through 1.18 mm IS sieve to get the required gradation and was filled behind the filter unit in the L-shaped tank.

2.4. Geotextile fabric
Non-woven needle punched monofilament geotextile made of polypropylene used in the study was purchased from Sri Raghavendra Textiles, Thiruvallur, Tamilnadu and the material specifications are listed out in Table 2. The geotextile acts as a separation layer and prevents the intermixing of sand and
adsorbent during the flow process. The geotextile having an apparent opening size of 0.065mm was found to satisfy the permeability criteria and retention criteria to be satisfied by a filter fabric with respect to the gradation of zeolite filled inside it.

### Table 2. Properties of Geotextile fabric

| Type                                      | Non-Woven Needle Punched Monofilament Polypropylene |
|-------------------------------------------|-----------------------------------------------------|
| Thickness                                 | 1 – 2 mm                                            |
| Application                               | Filtration                                          |
| Min. Grab Elongation                      | 20 %                                                |
| Gab Tensile                               | 150 lbs                                             |
| Puncture Resistance                       | 45 lb                                               |
| UV Resistance                             | 70 % at 2500 hr                                     |
| Tear Strength                             | 135 N                                               |
| Pore Size                                 | 0.5 mm                                              |
| Mass / Unit Area                          | 156 g/cm²                                           |
| Apparent Opening Size                     | 0.065 mm                                            |
| Porosity                                  | 85.4 %                                              |
| Permittivity                              | 2.50 s⁻¹                                            |

2.5. Saltwater

TDS values are usually highest during the summer season indicated by a rise in Chloride, Sodium and Hardness according to the rise of TDS concentration. The values of the highest and lowest TDS measurements from some of the previous studies were noted and test solutions were prepared by dissolving commercial salt into freshwater at three different concentrations 35 g/L, 4.8g/L, 0.87g/L to attain high, medium, low concentration level. The pH of these solutions ranged between 6.5 to 6.7 and the electrical conductivity and TDS values were as shown in Table 3.

### Table 3. Characteristics of saltwater used for the study

| Salt Water Solution | EC (mS) | TDS (ppt) |
|---------------------|---------|-----------|
| High concentration  | 59.14   | 32.50     |
| Medium concentration| 11.10   | 6         |
| Low concentration   | 3.40    | 2         |

3. Methodology

3.1. Filter unit

The filter unit consisted of a non-woven geotextile bag filled with the adsorbent at a density of 1.2 g/cm³. It had variable thickness (5cm, 7cm, 9cm, 12cm, 15cm) and a cross-section of 10cm x 10cm across which the flow would occur in a horizontal direction. To retain the desired size and rectangular shape, the entire filter assembly was set inside a frame made up of aluminium sheets by stitching the geotextile fabric onto the frame. The aluminium frame was chosen as it is non-corrodible when in contact with saltwater. A sponge of 3cm thickness was also provided at the outlet side of the filter unit to draw out clear water and rubber bushes were provided to avoid leakage of flow.

3.2. Experimental setup

The experimental setup comprised of three tank units made with transparent acrylic sheets of different dimensions and shape. The schematic diagram of the test setup is shown in figure 1(a). The first unit,
which was the feeding tank unit, comprised of two rectangular tanks of dimensions, 40 x 30 x 30 cm with a capacity of 36 L and 30 x 20 x 20 cm with a capacity of 12 L. It was provided with a regulating valve to control the saltwater inflow and to maintain a constant head throughout the test. The second tank unit was an L-shaped tank filled with sand into which the filter unit can be inserted in the slot towards the outlet end as shown in figure 1(b). The water coming out through the filter unit was collected in the third tank (collection tank) and was tested for required properties.

**Figure 1.** (a) Schematic diagram of the experimental setup (b) L-shaped tank with filter unit

### 3.3. Test details

A preliminary batch adsorption study was conducted before the detailed tests on filter units to ensure the effectiveness of natural zeolite as an adsorbent material and to understand its adsorption behaviour. Jar test apparatus was used to ensure proper mixing and contact period between the saltwater (high concentration) and natural zeolite. After 100 revolutions in the jar test apparatus, the solution was kept undisturbed and allowed to settle. Samples were taken from the middle of the solution after 15 minutes and 45 minutes to conduct tests on Electrical conductivity (EC) and Total Dissolved Solids (TDS) as these two parameters indicate the salt concentration in water. The batch adsorption study ascertained that an increase in adsorbent dosage and contact period improves the salt removal efficiency. But the contact period cannot be increased beyond a certain limit in the case of a filter unit designed for coastal wells. So as an alternative, the natural zeolite was thermally activated so that the contact time can be modified accordingly. The adsorption mechanism of natural zeolite can be well explained by the Electrical Double Layer theory.

The preliminary study was followed by a detailed experimental analysis to determine the salt removal efficiency of the two filter units viz., Natural zeolite filter unit and Thermally activated natural zeolite filter unit. Tests were conducted at different filter thicknesses (5cm, 7cm, 9cm, 12cm, 15cm) and input salt concentrations (high, medium, low). The 5cm, 7cm, 9cm, 12cm and 15cm thick filters had adsorbent dosages in the order of 100g, 150g, 200g, 250g, 350g respectively. The head of flow was kept constant throughout the filtration process. The effect of filter thickness on the salt removal efficiency at different salt concentrations was analyzed based on Electrical conductivity and TDS test results of the filtered saltwater coming out from the filter unit. The performance of both the filter units was compared and the results are presented in the following sections.

### 4. Results and Discussions

#### 4.1. Batch adsorption study

Figure 2 (a) and (b) shows the percentage reduction in EC and TDS with an increase in adsorbent dosage at different contact periods for high concentration salt solution (with initial values of
59.14mS and 32.50ppt for EC and TDS respectively). The percentage reduction in EC and TDS was found to increase with an increase in zeolite dosage with a maximum value of 20.41% for EC and 27.60% for TDS. Thus, it is clear that by increasing adsorbent dosage salt removal efficiency can be increased. The efficiency can still be increased by providing a sufficient contact period for adsorption. The above conditions can be achieved in a filter unit by increasing its thickness while remaining within the limitations on the thickness of a filter unit that can be installed in a well. The test results are tabulated in Table 4.

![Figure 2. Variation of EC and TDS with adsorbent dosage](image)

**Table 4.** Effect of adsorbent dosage on saltwater removal at different contact time

| Concentration of solution | Adsorbent Dosage (g) | After 15 min. EC (mS) | After 45 min. EC (mS) | % Reduction in EC (%) | After 15 min. TDS (ppt) | After 45 min. TDS (ppt) | % Reduction in TDS (%) |
|---------------------------|----------------------|------------------------|-----------------------|------------------------|--------------------------|--------------------------|------------------------|
|                           | 4                    | 53.05                  | 49.95                 | 10.30                  | 29.70                    | 25.87                    | 15.54                  |
|                           | 6                    | 52.72                  | 49.16                 | 10.86                  | 29.52                    | 25.07                    | 10.86                  |
|                           | 8                    | 51.27                  | 48.38                 | 13.31                  | 27.68                    | 24.19                    | 14.83                  |
|                           | 10                   | 50.84                  | 47.07                 | 14.03                  | 26.43                    | 23.53                    | 18.68                  |

4.2. **Natural zeolite filter unit**

The effect of filter thickness on EC and TDS at three different salt concentrations and varying filter thickness are presented in table 5. The initial values of EC for high concentration, medium concentration and low concentration salt solutions were 59.14mS, 11.10mS and 3.40mS respectively whereas the initial values of TDS were 32.5ppt, 6ppt and 2ppt respectively.

Figure 3(a) shows the variation of electrical conductivity with an increase in filter thickness. It can be observed that the EC decreases with an increase in filter thickness irrespective of the concentration of the saltwater. Another major observation was that the filter unit was most effective for treating low concentration salt solution with a maximum percentage reduction of 38.53% when compared to the medium and high concentration solutions.

TDS also showed a similar trend as that of electrical conductivity (see Figure 3(b)) The TDS removal efficiency increased with an increase in filter thickness. The percentage reduction varied from 16.50% for a filter thickness of 5cm to a value of 40% for a filter thickness of 15cm for a low concentration salt solution.
4.3. Thermally activated natural zeolite filter unit

A study similar to the one done for natural zeolite was done with thermally activated natural zeolite as an adsorbent in the filter unit. EC and TDS tests on treated saltwater coming out from the filter unit were conducted at different filter thicknesses and input salt concentration. Test results are presented in Table 6.

Figure 4 (a) and (b) illustrate the variation of EC and TDS with filter thickness for thermally activated zeolite filter unit. Both the parameters followed a similar trend as in the case of natural zeolite filter unit. The EC and TDS decreased with an increase in filter thickness for all selected salt concentrations. The percentage reduction in EC and TDS varied from 38% to a maximum value of about 48%. A significant observation was that the thermally activated filter unit was effective on all salt concentrations with almost the same maximum percentage reduction attained in all the cases. So, it can be believed that a thermally activated zeolite filter unit of 15cm thickness can be effectively used as a barrier for a wide range of salt concentrations.

Table 5. Effect of natural zeolite filter thickness on EC and TDS

| Concentration of solution | Filter Thickness (cm) | EC (mS) | TDS (ppt) | % Reduction in EC | % Reduction in TDS |
|---------------------------|-----------------------|---------|-----------|------------------|-------------------|
| High concentration        | 5                     | 53.04   | 28.64     | 10.31            | 11.88             |
|                           | 7                     | 50.56   | 27.30     | 14.51            | 16.00             |
|                           | 9                     | 47.40   | 25.59     | 19.85            | 21.26             |
|                           | 12                    | 43.28   | 23.37     | 26.82            | 28.09             |
|                           | 15                    | 37.60   | 20.56     | 36.42            | 36.74             |
| Medium concentration      | 5                     | 10.12   | 5.54      | 8.83             | 7.67              |
|                           | 7                     | 9.73    | 5.18      | 12.34            | 13.67             |
|                           | 9                     | 9.08    | 4.89      | 18.20            | 18.50             |
|                           | 12                    | 8.26    | 4.35      | 25.59            | 27.50             |
|                           | 15                    | 7.05    | 3.65      | 36.49            | 38.50             |
| Low concentration         | 5                     | 3.03    | 1.67      | 10.88            | 16.50             |
|                           | 7                     | 2.89    | 1.61      | 15.00            | 19.50             |
|                           | 9                     | 2.73    | 1.51      | 19.71            | 24.50             |
|                           | 12                    | 2.42    | 1.41      | 28.82            | 29.50             |
|                           | 15                    | 2.09    | 1.23      | 38.53            | 40.00             |

Figure 3. Percentage reduction in (a) EC and (b) TDS in natural zeolite filter unit
4.4. Comparison Between Performance of Natural Zeolite and Thermally Activated Zeolite as Adsorbent

Figure 5 (a) and (b) shows the comparison between the salt removal efficiency of the two filter units in terms of percentage reduction in EC and TDS for medium concentration salt solution. When compared to natural zeolite, thermally activated zeolite was found more effective in reducing the salt concentration in water. Thermally activated zeolite showed a maximum percentage reduction of around 47% for all filter thickness tested. This can be advantageous when it comes to a reduction in filter thickness and size. The increased efficiency might be due to an increase in pore volume resulting from the expulsion of water molecules from the zeolite matrix on thermal activation. Also, the Si/Al ratio increases which enable efficient adsorption of ions on to zeolite particle.

Another significant observation during the study was that the pH of the saltwater solution after passing through the filter unit did not vary much when compared to the value before. The pH ranged between 6.5 to 6.7 before filtration and 6.6 to 6.8 after filtration.

Table 6. Effect of thermally activated natural zeolite filter thickness on EC and TDS

| Concentration of solution | Filter Thickness (cm) | EC (mS) | TDS (ppt) | % Reduction in EC | % Reduction in TDS |
|---------------------------|-----------------------|---------|-----------|-------------------|--------------------|
| High concentration        | 5                     | 36.16   | 20.02     | 38.86             | 38.40              |
|                           | 7                     | 35.20   | 19.46     | 40.48             | 40.12              |
|                           | 9                     | 33.54   | 18.34     | 43.29             | 43.57              |
|                           | 12                    | 32.22   | 17.56     | 45.52             | 45.97              |
|                           | 15                    | 31.13   | 16.90     | 47.36             | 48.00              |
| Medium concentration      | 5                     | 6.61    | 3.62      | 40.45             | 39.67              |
|                           | 7                     | 6.46    | 3.54      | 41.80             | 41.00              |
|                           | 9                     | 6.23    | 3.33      | 43.87             | 44.50              |
|                           | 12                    | 6.10    | 3.26      | 45.05             | 45.67              |
|                           | 15                    | 5.79    | 3.15      | 47.84             | 47.50              |
| Low concentration         | 5                     | 2.01    | 1.16      | 40.88             | 42.00              |
|                           | 7                     | 1.93    | 1.12      | 43.24             | 44.00              |
|                           | 9                     | 1.88    | 1.09      | 44.71             | 45.50              |
|                           | 12                    | 1.84    | 1.07      | 45.88             | 46.50              |
|                           | 15                    | 1.79    | 1.05      | 47.35             | 47.50              |

Figure 4. % reduction in (a) EC and (b) TDS in Thermally activated natural zeolite filter unit
5. Summary and Conclusions
A decrease in electrical conductivity and total dissolved solids was observed with an increase in filter thickness for all selected salt concentrations irrespective of the adsorbent materials used viz., natural zeolite and thermally activated natural zeolite. This indicated a reduction in chloride ions as the only salt added to the water samples tested was commercial salt. The efficiency of salt removal can be easily enhanced by increasing zeolite dosage and contact period which can be achieved by increasing filter thickness. Natural zeolite filter could achieve a maximum percentage reduction of 38.53% and 40% in EC and TDS respectively. By modifying natural zeolite by thermal activation, the EC and TDS can be reduced further. With a 15cm thick filter unit of thermally activated zeolite, it was possible to reduce the EC and TDS by around 47% at all the concentrations of saltwater tested. The filter unit with thermally activated zeolite accompanied by a geotextile separator can be used as a potential barrier for reducing saltwater entry into coastal wells with no significant variation in the pH of water. A thermally activated zeolite filter could be an efficient and easy solution for the saline water intrusion issues in coastal drinking water wells.

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