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Removal Of Cations And Anions From Wastewater Using Zeolite Filter

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Abstract: Zeolite adsorbs large amounts of dissolved ions in waters, its porous structure and high ionic exchange capacity makes it capable of removing impurities from wastewaters. Solutions were prepared by dissolving the respective compounds in the required amounts of distilled water and were filtered through a packed column of zeolite of known mass and volume. The initial concentration of each of the metals was as follows: Zn^{2+} (50 mg/L), Mn^{2+} (20 mg/L), Pb^{2+} (50 mg/L), Fe^{2+} (150 mg/L), Ca^{2+} (200 mg/L), Cu^{2+} (150 mg/L), NH^{+}_{4} (100 mg/L), PO^{3-}_{4} (80 mg/L) and NO^{-}_{3} (20 mg/L). Removal capacity of zeolite in removing co-existing Zn^{2+} , Mn^{2+} and Pb^{2+} was found to be 6.46, 3.3 and 13.84 (g metal ion/ kg zeolite) respectively and for removing co-existing Fe^{2+} , Ca^{2+} and Cu^{2+} was 21.96, 40.26 and 24.7 (g metal ion/ kg zeolite) respectively whereas for removing co-existing NO^{-}_{3} , NH^{+}_{4} and PO^{3-}_{4} was 4.75, 17.8 and 20.57 (gm group-ion/ kg zeolite) respectively. In this study zeolite was proved to be an effective material in removing co-existing metals ions and ion-groups from wastewater.
Keywords: calcium, lead, iron, nitrate, phosphate, Zeolite.

Introduction

Zeolites are aluminosilicate minerals (natural or manufactured) usually with a 3-D structure with a cage-like structure suitable for ion exchange due to isomorphous replacement of structural Si^{4+} with Al^{3+} cations. They have a unique structure and characteristics that make them adsorb effectively a wide range of environmental pollutants. Their deep and wide pore openings are just one of few characteristics which enable zeolites to remove various water or atmospheric contaminants. Another characteristics of zeolite is their large surface area (20-50 m^2/g by natural species, however above 1000 m^2/g by synthetic ones). Both physisorption and chemisorption adsorption may occur within the zeolite voids during the removal of pollutants. The most important benefit of the manufactured zeolite is that interior cavities can be sized during the manufacturing to target ions of a particular size.

Many toxic metals are discharged into the environment, as industrial wastes, causing serious soil and water pollution. If they happen to enter living organisms biological system they can cause muscular and cardiovascular disorders, brain damage as well as liver and kidney disorders. Different techniques are used to remove metals from wastewater, such as precipitation, solvent extraction, membrane filtration, biodegradation and advanced oxidation. These techniques lack the advantages of being fast, economical and/or eco-friendly. However, adsorption has proven to be effective and serves as an alternative treatment technique for the removal of hazards from wastewaters (Elmorsi et al., 2019). Zeolites have shown capability to adsorb large amounts of dissolved ions in waters. The chemical and structural features of zeolites make them very effective for the removal of toxic metal ions (Erdem et al., 2004, Halimoon and Yin, 2010, Peric et.al., 2004, Lotfy, 2006 and Wingenfelder et al., 2005) radionuclides as well as ammoniacal nitrogen (ammonia and ammonium) from wastewater (Leinonen and Lehto, 2001, Hedström and Amofah, 2008, Mažeikien et al. 2010). Hydroxylated surfaces of metal oxides at the edges of zeolite develop charges and exchange with anions in water. Moreover, hydrogen bonding between anions and H^+ of zeolitic water makes them form complexes with anionic groups (E. Tarlan and V. Önen, 2010).

The aim of this study is to use the zeolite as a filter media and to evaluate its capacity in removing cations and anions simultaneously from wastewater. The targeted ions are Cu^{2+}, Zn^{2+}, Mn^{2+}, Fe^{2+}, Pb^{2+}, Ca^{2+}, NH^+_4, PO^{3-}_4 and NO^-_3. The initial concentration of each of the ions was as follows: Zn^{2+} (50 mg/L), Mn^{2+} (20 mg/L), Pb^{2+} (50 mg/L), Fe^{2+} (150 mg/L), Ca^{2+} (200 mg/L), Cu^{2+} (150 mg/L), NH^+_4 (100 mg/L), PO^{3-}_4 (80 mg/L) and NO^-_3 (20 mg/L). The removal efficiency of zeolite was calculated for each.

Experimental

The type of zeolite used in this study is a synthetic zeolite named OXYSIV 5 Adsorbent, which was used in medical oxygen concentrators that employ a pressure swing cycle for the generation of high purity (90 – 95%) oxygen. This particular zeolite has the following specifications:

Particle form	Beads
Particle size (mm)	0.6
Density (kg/m^3)	705

A reflectometer and a spectrometer were used to measure the ions concentrations. The filtration rate was kept at 3.5 L/h. Three filtration columns were set-up with a simple layout. The filtration columns were then packed with zeolites. The first column was packed with 2.168 Kg zeolite, the second filtration column with 2.186 Kg and the third filtration column with 2.022 kg zeolite. Metal solutions were prepared by dissolving their respective salts in the required amounts of distilled water. The initial concentration of each of the metals was as follows: Zn^{2+} (50 mg/L), Mn^{2+} (20 mg/L), Pb^{2+} (50 mg/L), Fe^{2+} (150 mg/L), Ca^{2+} (200 mg/L), Cu^{2+} (150 mg/L), NH^+_4 (100 mg/L), PO^{3-}_4 (80 mg/L) and NO^-_3 (20 mg/L). A solution of Zn^{2+}, $Pb^{2+}$and Mn^{2+} was filtered through the first filter (2.168 Kg of zeolite) whereas, a solution of Fe^{2+}, Ca^{2+} and Cu^{2+} was filtered through the second filter (2.186 Kg of zeolite) and a solution of NH^+_4, NO^-_3 and PO^{3-}_4 was filtered through the third filter (2.022 Kg of zeolite) . An electrical motor pump was used to pump water from the wastewater container into the column filters. The following figure shows the set-up of the filters:

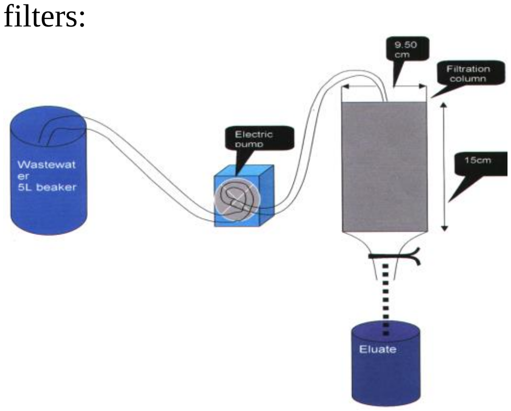

Fig.1: A schematic diagram of the experimental set-up.

Results And Discussions

The following figures are the removal graphs for the ions Zn^{2+} , Pb^{2+} , Mn^{2+}, Cu^{2+}, Ca^{2+},Fe^{2+}, NH^{+}_{4}, NO^{-}_{3}, PO^{3-}_{4}. Data for each ion filtered were recorded and removal graphs were drawn. The percentage removals were calculated using the following formula:

Percentage removal (%)

$$= \frac{\text{initial concentration} - \text{final concentration}}{\text{Initial concentration}} \times 100$$

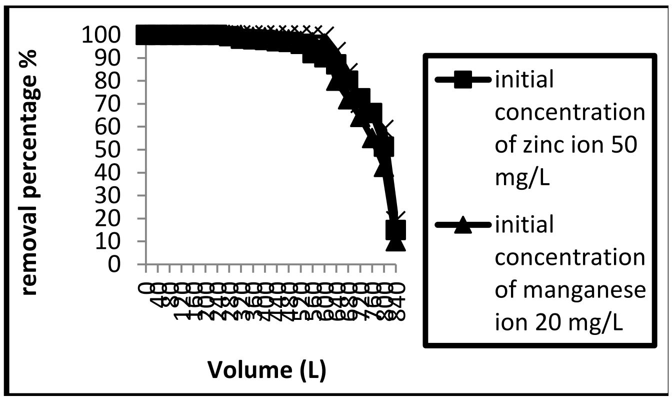

Fig. 2. The percentage removal graph of zinc, manganese and lead ions using the first filter.

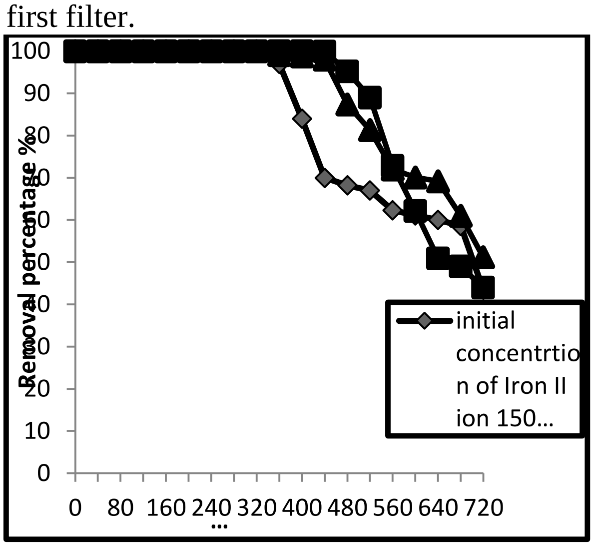

Fig. 3. The percentage removal graph of iron, calcium and copper ions using the second filter.

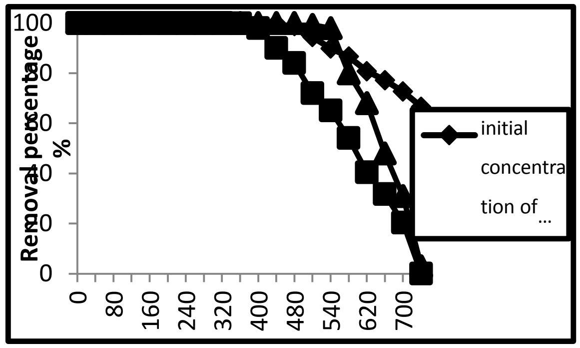

Fig. 4. The percentage removal graph of nitrate, ammonium, phosphate ions using the third filter.

Removal of Zn^{2+} , Mn^{2+} and Pb^{2+} :-

In the removal of Zn^{2+} , Mn^{2+} and Pb^{2+} (Fig.2) the initial concentration of Zn^{2+} in the solution = 50 mg/L
Zeolite weight in the column = 2.168 Kg
Total volume of the solution, containing Zn^{2+} , filtered = 840L
Amount of filtrate in which 100% of zinc was removed = 280L
Total amount of Zn^{2+} filtered (in 100% removal): 50mg/L X 280L= 14000mg
The zeolite capacity in removing 100% of Zn^{2+} = 6.46 g/Kg

Initial concentration of Mn^{2+} in the solution = 20mg/L
Zeolite weight in the column = 2.168Kg
Total volume of the solution, containing Mn^{2+} , filtered = 840L
Amount of filtrate in which 100% of manganese was removed = 360L
Total amount of Mn^{2+} filtered (in 100% removal): 20mg/L X 360L = 7200mg
The zeolite capacity in removing 100% of Mn^{2+} = 3.3 g/Kg

Initial concentration of Pb^{2+} in the solution = 50mg/L
Zeolite weight in the column = 2.168Kg
Total volume of the solution, containing Pb^{2+}, filtered = 840L
Amount of filtrate in which 100% of lead was removed = 600L
Total amount of Pb^{2+} filtered (in 100% removal): 50mg/L X 600L = 30000mg
The zeolite capacity in removing 100% of Pb^{2+} = 13.84 g/Kg

Removal of Fe^{2+}, Ca^{2+} and Cu^{2+} :-

In the removal of Fe^{2+}, Ca^{2+} and Cu^{2+} (Fig.3) the initial concentration of Fe^{2+} in the solution = 150 mg/L
Zeolite weight in the column = 2.186 Kg
Total volume of the solution, containing Fe^{2+}, filtered = 720L
Amount of filtrate in which 100% of iron was removed = 320L
Total amount of Fe^{2+} filtered (in 100% removal): 150mg/L X 320L = 48000mg
The zeolite capacity in removing 100% of Fe^{2+} = 21.96 g/Kg

Initial concentration of Ca^{2+} in the solution = 200mg/L
Zeolite weight in the column = 2.186 Kg
Total volume of the solution, containing Ca^{2+}, filtered = 720L
Amount of filtrate in which 100% of calcium was removed = 440L
Total amount of Ca^{2+} filtered (in 100% removal): 200mg/L X 440L = 88000mg
The zeolite capacity in removing 100% of Ca^{2+} = 40.26 g/Kg

Initial concentration of Cu^{2+} in the solution = 150mg/L
Zeolite weight in the column = 2.186 Kg
Total volume of the solution, containing Cu^{2+}, filtered = 720L
Amount of filtrate in which 100% of copper was removed = 360L
Total amount of Cu^{2+} filtered (in 100% removal): 150mg/L X 360L = 54000mg
The zeolite capacity in removing 100% of Cu^{2+} = 24.7 g/Kg

Removal of NO^-_3, NH^+_4 and PO^{3-}_4

In the removal of NO^-_3, NH^+_4 and PO^{3-}_4 (Fig. 4) the initial concentration of NO^-_3 in the solution = 20mg/L
Zeolite weight in the column = 2.022 kg
Total volume of the solution, containing NO^-_3, filtered = 740L

Amount of filtrate in which 100% of nitrate was removed = 480L
Total amount of NO^-_3 filtered (in 100% removal): 20mg/L X 480L = 9600mg
The zeolite capacity in removing 100% of NO^-_3 = 4.75 g/Kg
Initial concentration of NH^+_4 in the solution = 100mg/L
Zeolite weight in the column = 2.022 kg
Total volume of the solution, containing NH^+_4, filtered = 740L
Amount of filtrate in which 100% of ammonium was removed = 360L
Total amount of NH^+_4 filtered (in 100% removal): 100mg/L X 360L = 36000mg
The zeolite capacity in removing 100% of NH^+_4 = 17.8 g/Kg
Initial concentration of PO^{3-}_4 in the solution = 80mg/L
Zeolite weight in the column = 2.022 kg
Total volume of the solution, containing PO^{3-}_4, filtered = 740L
Amount of filtrate in which 100% of phosphate was removed = 520L
Total amount of PO^{3-}_4 filtered (in 100% removal): 80mg/L X 520L = 41600mg
The zeolite capacity in removing 100% of PO^{3-}_4 = 20.57 g/Kg

CONCLUSION

In this study zeolite proved to be an effective material in removing metal ions,

cation-groups and anion-groups simultaneously from wastewater. The negatively charged alumino-silicate structure attracts the positive cations from the wastewater. In addition, hydrogen bonding between anions (NO^-_3 and PO^{3-}_4 in this study) and H^+ of zeolitic water can also remove the anions. Zeolite showed varying removal capacities with respect to different metals and groups as shown below.
The capacity of zeolite in removing co-existing Zn^{2+} , Mn^{2+} and Pb^{2+} is found to be 6.46, 3.3 and 13.84 (g metal ion/ kg zeolite) respectively.
Removal capacity of zeolite in removing co-existing Fe^{2+} , Ca^{2+} and Cu^{2+} is found to be 21.96, 40.26 and 24.7 (g metal ion/ kg zeolite) respectively.

Removal capacity of zeolite in removing co-existing NO^-_3 , NH^+_4 and PO^{3-}_4 is found to be 4.75, 17.8 and 20.57 (gm group-ion/ kg zeolite) respectively.

High cation exchange capacity and large vacant cages are responsible for the high efficiency of zeolite for removing ions. Zeolite can be utilized in any water treatment plant using the same set-up for sand filtraion but replacing sand with zeolite, no special set-up is needed. The zeolites utilized in this study was used before for purifying medical oxygen and it was cleaned by washing with water before using it, so it has the advantage of being able to be re-used when cleaned. Zeolite can be cleaned by back washing process.

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