

Pre-Evaluation of Strong Base Exchange, Amberlite IRA-958 Resin for Nitrate Removal

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Abstract

High concentration of nitrate in water either in surface or groundwater is an effect from agricultural activities, domestic use and industrial activities. Hence, removing enormous nitrate from water is necessary because it hazardous to the human health and aquatic life. The ion exchange resin is the most widely technology used in removing nitrate from water source. In this study, commercial strong anion exchange resin, Amberlite IRA 958 was used to study the efficiency of nitrate removal from aqueous solution in a fixed-bed column experiment. The influence of resin dosage (0.05 to 0.20 g), contact time (1 to 4 hours) and initial nitrate concentration (20, 50, 100 and 200 mg/L) were examined. More than 87% of nitrate removal achieved at 0.1 g of resin dosage, 3 hours of contact time and 20 mg/L of initial nitrate concentration. This promising result make that Amberlite IRA-958 can become an attractive candidate as adsorbent for nitrate removal.

Keywords: Anion exchange resin, nitrate removal, adsorbent, adsorption, Amberlite IRA 958

1. Introduction

Water is a source of life in all parts of the world and the most common water source obtained from surface and groundwater. According to the Saimy and Yusof [1], increasing in human population, uncontrolled developments, industrial and water expansion resulting water demand increasing. Based on statistic by the Food and Agricultural Organisation (FAO) reported by Saimy and Yusof [1] the highest water usage is from agricultural sector with 62% compared with industrial 21% and domestic uses 17%. However, in the last few years, there are rising concern on the quality of water due to existing of toxic pollutants. The agricultural sector is the most sector that consume the highest fertilizer for the growth which contain high concentration of nitrate. Elevated nitrate concentration into the water bodies can cause various damage to humans and promote heavy algal growth using eutrophication [2]. In addition, the presence higher nitrate concentration also will affect the living of aquatic life and cattle by reducing the concentration of oxygen in water bodies and uptake of carcinogenic nitrate [3].

Since billions of people keep demanding a clean, fresh and safe drinking water, nitrate can become untraceable contaminant if the water-treating system is shallow and poorly constructed. Nitrate ions were identified as a easy soluble and stable in the water body [4]. Due to this circumstance, an efficient solution to remove nitrate is quiet challenging. Many researchers were enthusiastically seeking the best method to be implemented in the system such as catalytic reduction, precipitation, chemical denitrification, reverse osmosis, electrolytic denitrification and biological denitrification [5-8]. As eloquently stated by Song et al. [9], these

methods show excellent removal of nitrate from water, but unfortunately these technologies will bring enormous disadvantages to the system. Some exemplary examples of this are catalytic reduction method and distillation method. Prior research indicated that a fast removal of nitrate ions could be achieved by using a catalytic reduction method and distillation method is simple to operate however both methods may demand higher capital and operation cost [10]. A few methods have limitations and are incompatible for practical application. According to Matos et al. [11], even though biological denitrification method has the capabilities to remove a very selective and specific nitrate by converting nitrate into nitrogen using microorganism, however this method is not recommendable because of the biological treatment may affect the water quality. Moreover, another extensive post treatment such as filtration and germicidal treatment are needed to be applied in the system to remove germs and metabolic substances [12]. Other than that, Weinetova et al. [10] indicated that reverse osmosis and electrodialysis also showed great performance of water desalination but it was reported that both methods are not favourably to be used because the process of demineralizing water were too deep which are not suitable for drinking water.

Among them, adsorption method involving of ion-exchange resin has been chosen widely to remove selective nitrate ions from water bodies due to its most versatile, flexible, effective, simple and relatively low cost [13]. In fact, the ion exchange resin is an environmentally sound technology since it does not have any side effect either to the process or to the consumers. It deals only elements already occurring in water. The term of 'ion exchange' does means the process has the capability to exchange particular ions within the resins with ions in a solution that is passed through them. The resins are made up by polymers which are insoluble in the water bodies. They play an important role as a medium of the exchanging ions which may consist either positive or negative charged functional groups. The functional groups would attract the charged ion from the solution. The positively charged ion exchanger would attract negatively charge anions and vice versa. Competing anions for instance sulphate, chloride and bicarbonate do present in the water but their existence is not a hindrance to the process. As indicated by Samatya et al. [7], a report has proved that nitrate specific resin has affinity for the following ions- $\text{NO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{HCO}_3^-$. Since their affinity are less than nitrate ion, these competing anions would not be an issue due to high selectivity removal more towards to nitrate ion and the removal of other competing anions also will be covered during the process. In his study, Song et al. [9] managed to prepare and has utilized the NDP-5 resin and has proved in his research that this resin able to remove high efficiency of nitrate from solution even in a presence of competitor ions. Besides, many of commercialized resin also have been developed and tested for example Perolite A 520E which it has showed a great promising result of efficient selectivity toward nitrate ions from the ground water [7].

The overall goal of this study is to identify the capability and performance of a commercialized resin, Amberlite IRA 958-Cl to remove nitrate ion from the water bodies. The ion exchange process was accomplished by loading the nitrate water to pass through the designed fixed-bed containing the strong anion adsorbent. In this study, Amberlite IRA 958-Cl was examined for the efficiency in removing nitrate based on nitrate concentration, contact time within the adsorbent and the solution and the amount of resin as parameters study.

2. Materials and Methods

2.1 Materials

Amberlite IRA 958-Cl resin is a macroreticular strong base anion exchange resin obtained from Sigma Aldrich. The properties of Amberlite IRA 958-Cl Table 1. Sodium hydroxide (NaOH) use to soften the resin was obtained from R&M Chemicals with purity of 99%. Synthetic nitrate solution was prepared by dissolving sodium nitrate (NaNO₃) in distilled water was purchased from Sigma Aldrich which 97% purity.

Table 1: Properties of Amberlite IRA 958 [14]

Physical form	White spherical beads
Matrix	Crosslinked acrylic macroreticular structure
Functional group	Quaternary ammonium
Ionic- form	Chloride
Moisture holding capacity	66 to 72% (Cl ⁻ form)
Particle size:	
• Uniformity coefficient	≤ 1.8
• Harmonic mean size	630-850 μm

2.2 Fixed- bed Column Studies

The experiments conducted by packing the syringe with varies dosage of resin (0.05 to 0.2 g) and equilibrated with 20 mL of 0.5 mol/L NaOH for 30 minutes. After 30 minutes the solution was drained out and rinsed two times using distilled water. 20 mL of synthetic NaNO₃ solution (20, 50, 100 and 200 mg/L) was introduced into the syringe at varies contact times (1 to 4 hours). The effluent nitrate concentration was analysed based on APHA 4500- NO₃ method and the functional group that present at the surface of resin was characterized using FTIR.

2.3 Determination of Adsorption Capacity

The nitrate reduction/ rate of nitrate removal R in percent calculated using the equation:

$$R = \frac{C_o - C_r}{C_o} \times 100\% \quad (1)$$

Where, C_o specified the initial nitrate concentration (mg/L) and C_r is the nitrate concentration after the treatment [21]. The amount of NO₃⁻ adsorbed per mass unit of adsorbent was calculated from the following expression:

$$q_t = \frac{(C_o - C_t)}{m} \times V \quad (2)$$

Where, q_t (mg/g) indicated the resin capacity at the given time, C_o and C_t (mg/L) were designated as an initial and final nitrate concentrations in the aqueous solution, V (mL) was the volume of the experimental solution and m (g) was the dose of the resin used [20].

2.4 Characterization

The functional group presence in the resin was determined using the Spherical Diamond ATR Nicolet iS50 (Thermo Scientific) Fourier transform infrared spectroscopy analysis (FTIR). In this method, the resin was brought into contact with the diamond window. The spectrum was scanned with a resolution of 4 cm^{-1} , an average of 32 scans were taken for each sample.

3. Results and Discussion

3.1 Effect of Resin Dosage

The effect of amount of resin for removing nitrate ions were investigated thoroughly. The quantity of resin is one of the important control to determine the capacity of an ion exchange under a fix operating conditions [15]. These experiment were carried in a fixed-bed process by using 50 mg/L of nitrate solution. Figure 1 demonstrated the adsorption efficiency of nitrate ion with the increasing amount of Amberlite IRA 958-Cl resin at 0.05, 1.00, 0.15 and 0.20 respectively. The removal of nitrate ion was increased from 85.7 to 87.6% with the increasing of resin dosage from 0.05 to 0.1 g of resin. This fact can be explained by when the resin provides more sorption sites, resulting in higher removal efficiencies as proposed by Samatya et al. [7]. Optimum resin dosage was found 0.1 g resin by taking consideration that even at higher resin dosage, the removal rate of nitrate is not appreciably higher with the differences between these values are not significant. As reported by Xu et al. [15], the conditions are happened when the amount of resin then is the optimum resin amount.

However, adsorption capacity of ions nitrate decreased with increasing of Amberlite IRA 958-Cl dose. The values of adsorption capacity decreased from 17.2 to 4.4 mg/g with increasing of resin dosage from 0.05 to 0.2 g at initial concentration of 50 mg/L nitrate. This can be explained by the gradient between the concentration of nitrates in bulk solution and that at the surface of the anion exchange resin as reported by Lazar et al. [16].

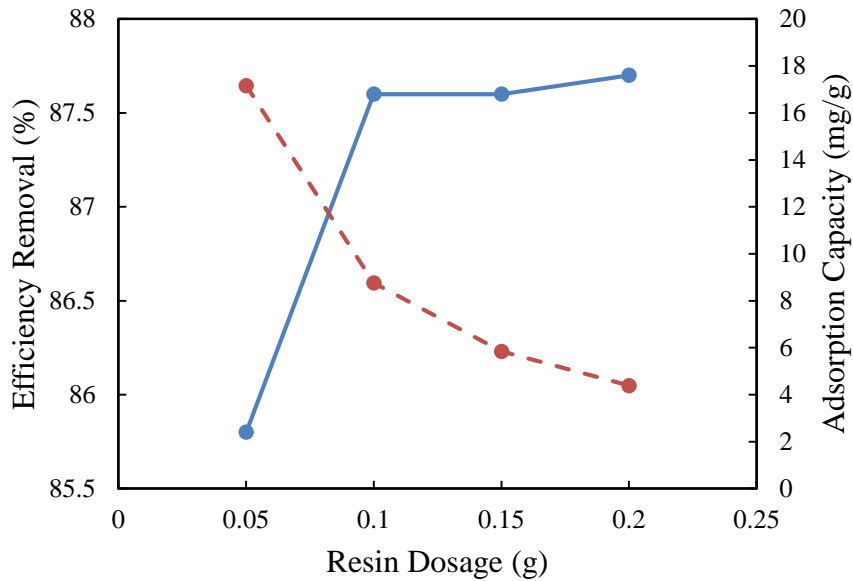


Figure 1: Effect of different resin dosages on efficiency removal and adsorption capacity of nitrate from aqueous solution

3.2 Effect of Contact Time

In this parameter study, the equilibrium time for maximum adsorption of nitrate was examined. The aqueous solution of nitrate was treated with resin Amberlite IRA 958-Cl as the function of contact time varies from 1 to 4 hours. Figure 2 indicated the result of the experiments. The uptake of nitrate was rapid from 85.8% (17.2 mg/g of adsorption capacity) and reached its equilibrium within 4 h with the 87% (17.4 mg/g of adsorption capacity) efficiency of removal rate. The uptake of nitrate solution begins slowly after 4 hours. These conditions due to the greater viability of binding site at the initial condition and the viability of the site is decrease as the increase in times [17]. The sufficient contact time to achieve adsorption equilibrium state for 0.1 g resin and 50 mg/L nitrate solution was in 4 hours with the sorption capacities 17.4 mg/g.

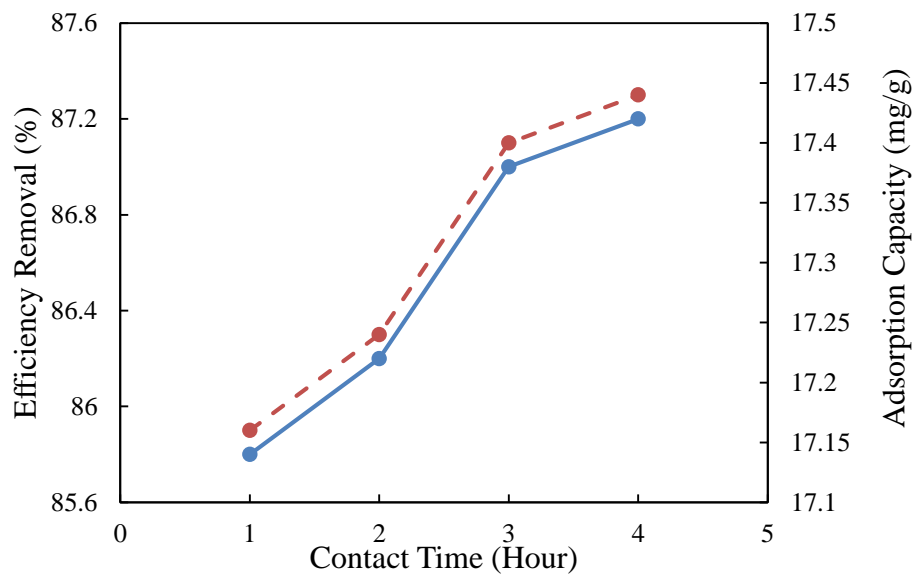


Figure 2: Effects of different contact times on efficiency removal and adsorption capacity of nitrate from aqueous solution

3.3 Effect of Initial Nitrate Ions Concentration

Figure 3 shows how several preliminary nitrate concentration affect the adsorption process of the resin. The aqueous solution of nitrate were prepared and varied at different concentration such as 20, 50, 100 and 200 mg/L respectively. Additionally, each of experiment was conducted using a fixed amount of resin at 0.1g with a room temperature at 25°C and undergoes 4-hour contact time. As depicted form Figure 3, it can be seen clearly that the trend of adsorption capacity of nitrate declined with the rising of concentration of nitrate ions during the process. Within 4 hours of the ion exchange process, the adsorption capacities of Amberlite IRA 958-Cl resin for removing nitrate ion from 20 mg/L and 200 mg/L of nitrate ions were 5.4 and to 72.5 mg/g respectively. The increasing of initial concentration of ions nitrate resulting decreasing of efficiency of nitrate ions removal from 87 to 59%.

This variation could be briefly explained with higher ratio between the number of nitrate ions from aqueous solution and the limited number of available sorption sites on the surface of Amberlite IRA 958-Cl resin. This opposite trend is drive by the circumstance that at greater nitrate ions concentration, the most superficial functional groups are already engaged with ions, and the diffusion of nitrate ions to unreacted functional groups is blocked [18].

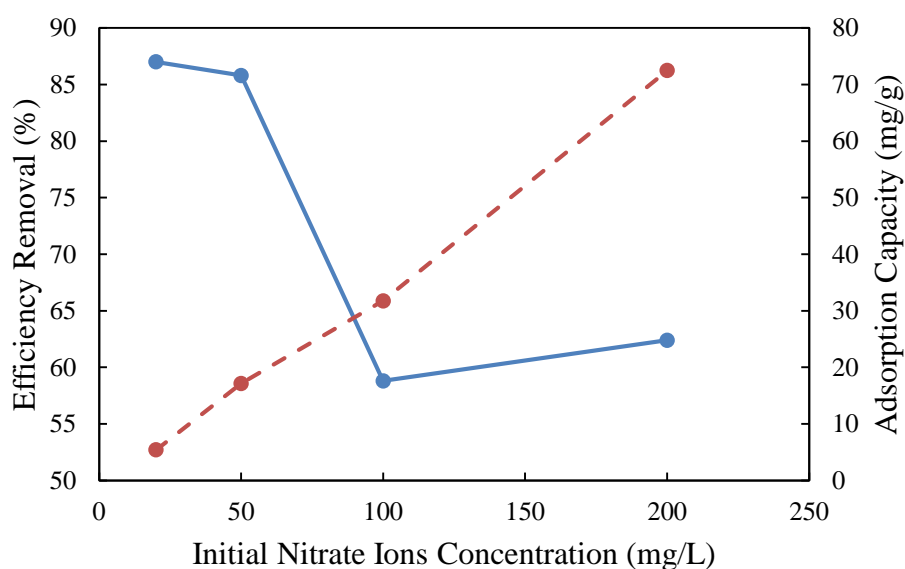


Figure 3: Effect of initial nitrate ions concentrations on efficiency removal and adsorption capacity of nitrate from aqueous solution

3.4 Characterization

The Amberlite IRA 958-Cl is commercially designed as a macroporous-strong basic anion exchange and it contains quaternary ammonium as a functional group presents in a cross-linked acrylic polymer matrix [14]. Figure 4 depicts the FTIR spectrum of the Amberlite IRA 958 resin before and after nitrate sorption. It can be observed that the most important changes are observed in the spectra region where the present the N-H stretching vibration ($3364\text{-}2943\text{ cm}^{-1}$) and the C-N stretching vibrations ($1430\text{-}1390\text{ cm}^{-1}$) from amines. The special peak at 1633

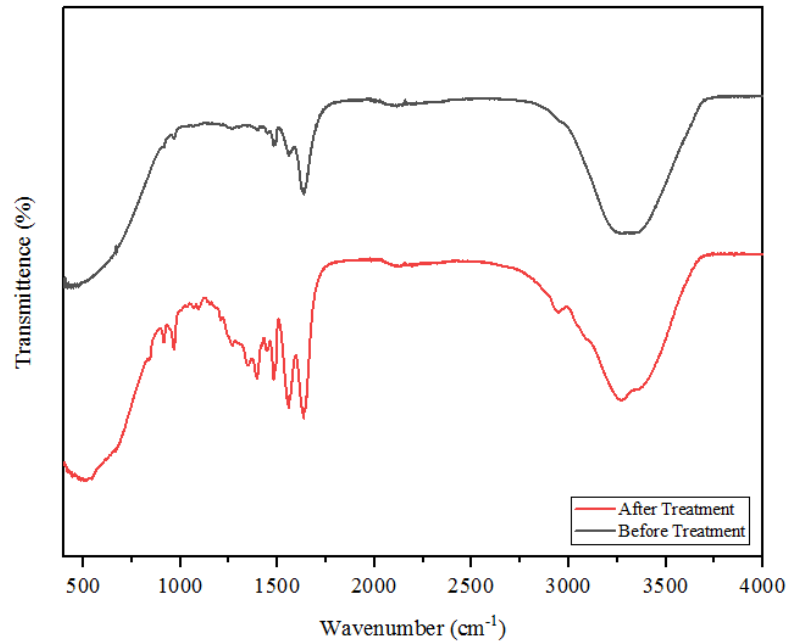


Figure 4: FTIR spectroscopy adsorption of resin before and after the process

cm^{-1} was allocated to amide $\text{C}=\text{O}$ stretching vibration. As a matter of a fact, there were electrostatic ion exchange interactions between the amines group from the Amberlite IRA 95-Cl with the aqueous solution as the Figure 4 exposed the intensity of adsorption bands has increased after the process interaction the sorption of nitrate [16]. Certainly, the sorption process of nitrate was successfully occurred [19].

4. Conclusion

The performance of a commercialized resin, Amberlite IRA 958-Cl was finally being explored in order to identify the effectiveness to remove nitrate ion from the aqueous nitrate-solution. In summary, the impact of contact time between resin and the solution, the dosage used for resin in experiments and the initial nitrate concentration on adsorption were studied as the primary parameters. It were identified that, the efficient removal of nitrate ions from the water bodies rose effectively as the amount of resin used and the contact time between resin and the solution increased. On the other hand, the increasing of initial concentration of ions nitrate resulting declining of efficiency of nitrate ions removal from 87 to 59% respectively. From the result, Amberlite IRA 958-Cl managed to achieve standard removal of nitrate ions even in small amount of resin. Undoubtedly, Amberlite IRA 958-Cl will be an attractive and promising candidate adsorbent for ion metal removal specifically for nitrate ions removal.

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