

Scientific paper

Samarium(III) Removal by Weak Acid Exchanger Amberlite IRC-50 in (H^+) and (Na^+) Forms

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Abstract

Adsorption of samarium(III) on a weakly macroporous cation exchanger Amberlite IRC-50 (H^+) and (Na^+) forms is studied as a function of the initial pH of the aqueous solution, time and temperature, initial samarium(III) ion concentration, and the amount of resin at a fixed temperature (20 ± 1 °C).

The concentration range was between 0.1–5 mmol/L, the pH range was between 1.8 and 10.5; the stirring time was between 2 and 60 min; and the amount of resin was between 0.025 and 0.15 g. Both the film and particle diffusion equations are applied to explain the kinetic data. The rate constant values for samarium(III) adsorption were calculated for both film and particle diffusion processes. It is observed to follow the order (Na^+) > (H^+). Temperature is found to have an insignificant effect on both diffusional processes. Various thermodynamic parameters (ΔH° , ΔS° , and ΔG°) from samarium(III) exchange on the resin were calculated. The optimum conditions were found to be a concentration of 1 mmol/L, pH of 9.3, stirring time of 20 and 5 min for Amberlite IRC-50 (H^+) and (Na^+) forms, respectively, and 0.15 g of resin. The equilibrium extraction of samarium was 22.2 mg/g for Amberlite IRC-50 (H^+) and 21.9 mg/g for Amberlite IRC-50 (Na^+) at an initial concentration of 1 mmol/L. The results obtained show that the Amberlite IRC-50 weak cation-exchange resin performed well for the removal and recovery of samarium(III). The optimization procedure provides access to industrial-scale Sm(III) removal processing.

Keywords: Samarium, adsorption, ion exchange, Amberlite IRC-50, metal removal, kinetics study

1. Introduction

In recent years, rare earth elements (REE) have been regarded as important components from an industrial point of view. The major causes for this stem from the high application interest of the REE in many fields, as these elements and their compounds find various commercial applications, knowing that a large deposit of REEs, which is located in Ihouhouan in Algeria, is not yet exploited.

The recovery of REE from large quantities of processing solutions and industrial wastewater is of particular importance to protect the environment and meet the demand for green and sustainable products in energy production. REE can be introduced in small quantities into the human body with water or at the workplace when the work is connected to the relative production dealing with REEs. Being heavy metals, rare-earth elements can accumulate in biological systems, replacing calcium.

Samarium is primarily used in the production of samarium–cobalt permanent magnets, which are used in lightweight electronic equipment where size or space is a limiting factor and where functioning at high temperatures is of great concern. Because of its weak spectral absorption band, samarium is used in the filter glass on Nd:YAG solid-state lasers to surround the laser rod to improve efficiency by absorbing stray emissions. Stable samarium–titanate compounds with useful dielectric properties are suitable for coatings and capacitors at microwave frequencies. The specific applications of samarium in different fields of technology have turned it into an industrial material of outstanding significance.^{1,2} However, samarium(III) is also toxic to health and, at the same time, precious and expensive; therefore, it must be recovered through recycling processes to protect the environment and reduce costs. In addition, it is essential to separate and

recover Sm(III) ions from refuse because samarium is one of the most important rare earth elements.³

Many removal techniques have been proposed for the removal of samarium(III), including solvent extraction, molecular imprinting, ion exchange, co-precipitation, membrane processes, oxidation, and adsorption. Among these methods, ion exchange is highly popular and has been widely practiced for metal ion removal.^{4–7} Furthermore, organic ion exchange resins are more suitable for the removal of toxic elements because of their faster kinetics, ease of regeneration, and high exchange capacity.⁸ While several studies have been reported for the exchange removal of monovalent and divalent metal cations from aqueous solutions,⁹ very little is reported about the exchange of trivalent metal cations such as Sm³⁺ and La³⁺.^{10–13} Other research indicates that solutions containing Sm³⁺ ions were treated with different resins, and the results obtained showed that the resin has a strong affinity for these ions.^{14,15}

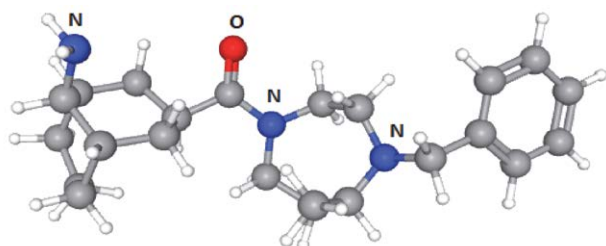
Synthetic resins are readily available, biodegradable, and extendable. These resins, Amberlite IRC-50, are small, synthetic, porous, crystalline solids. Negative charge compensation cationic systems give the adsorbent cationic polymer resin exceptional properties that lead to many applications, especially in the areas of catalysis, absorption, and as a cationic exchange-acid.^{16,22}

A review of the pertinent literature indicates the absence of studies regarding the activation of this resin at its basic level. Hence, this aspect has been thoroughly investigated and elaborated upon in this paper.

The main goal of this study was to examine the factors that affect ion exchange, such as the initial solution pH, agitation time, concentration of samarium(III) ions, temperature, and amount of resin. In addition, equilibrium, kinetics, and thermodynamic parameters were determined on the basis of measurements of ion exchange.

2. Materials and Methods

Amberlite IRC-50 (H⁺) (C₂₃H₃₇Cl₂N₃O, *M* = 442.5 g/mol; Scheme 1) (supplied by Fluka) is a macroporous weak acid cation-exchange resin with a methacrylic acid-DVB structure and is available in the form of spherical beads. The maximum temperature it can tolerate is 120 °C. It works in the pH range of 5–14. The particle size varies



Scheme 1: Chemical structure of Amberlite IRC-50.

from 0.297 to 1.190 mm. The exchange capacity of the resin is 9.5 mg/g. The moisture content is 10% by weight.¹⁰

2. 1. Conversion of Amberlite IRC-50 (H⁺) into (Na⁺)

A 100 g sample of the hydrogen ion form of Amberlite IRC-50 was treated with a solution of sodium hydroxide at 85 g/L in Erlenmeyer flasks. After stirring intermittently for 2 h, the resin was filtered off, re-treated with a fresh sodium hydroxide solution, filtered again, thoroughly washed with water, and desiccated.²³

2. 2. Ion Exchange Studies

The removal of Sm(III) with Amberlite IRC-50 as a function of contact time was investigated. An exactly weighed amount (0.1 g) of Amberlite IRC-50 in (H⁺) and (Na⁺) forms was mixed with 5 mL of Sm₂(CO₃)₃ solution dissolved in 4 mL nitric acid and diluted with distilled water to obtain a concentration of 1 mmol/L, which had attained the desired temperature (293–313 K). The stirring rate was 1000 rpm. The concentration of Sm(III) in the aqueous phase was analyzed with a SPECORD 210 plus spectrophotometer using the method described in the literature.²⁴

The percent Sm(III) extraction (%) was determined as follows:

$$\text{Extraction yield (\%)} = \frac{(C_0 - C)}{C_0} \cdot 100 \quad (1)$$

The adsorption amount was calculated as follows:

$$q_t = \frac{V(C_0 - C)}{W} \quad (2)$$

where q_t is the adsorption amount (mg/g), w is the weight of the Amberlite IRC-50 (g), M is the molar mass (g/mol), V is the volume of solution (L), and C_0 and C are the concentrations (mol/L) of samarium ions before and after adsorption, respectively.

The effect of solution pH on the equilibrium uptake of samarium(III) from aqueous solution by Amberlite IRC-50 resin in (H⁺) and (Na⁺) forms was investigated between pH 1.8 and 10.5 for 15 min. The experiments were performed by adding a known weight of the resin (0.1 g) into six 10 mL Erlenmeyer flasks containing 5 mL of samarium(III) solution. Dilute nitric acid or sodium hydroxide was used to adjust the pH of the samarium solutions using a pH meter (model WTW, PH 3310 SET 2, Germany). The flasks were shaken for 15 min at 1000 rpm and 20±1 °C.

Kinetic experiments were carried out by agitating 5 mL of samarium(III) solution of concentration ranging from 0.01 to 5 mmol/L with 0.1 g of Amberlite IRC-50 resin (H⁺) and (Na⁺) forms in a 10 mL Erlenmeyer flask at 20±1 °C at pH 9.3 and at constant agitation speed of 1000 rpm.

The effect of the adsorbent amount was studied with a 5 mL solution of 1 mmol/L samarium(III) solution and varying amounts of adsorbent from 0.025 to 0.15 mg at equilibrium time.

3. Results and Discussion

3.1. Effect of pH

In the adsorption operation, the solution pH plays an important role in controlling the high adsorption capacity and selectivity of the target lanthanide ions.^{25–27} This is partly because hydrogen ions themselves are strongly competitive with adsorbents.²⁸

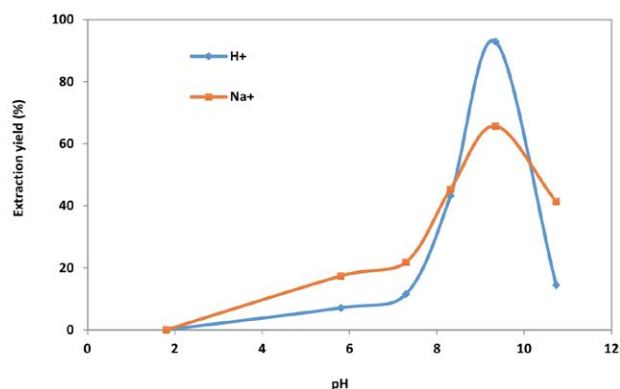


Figure 1: Effect of initial pH on efficient extraction of samarium(III). Amount of resin 0.1 g, volume of ion-exchange medium 5 mL, T 20 ± 1 °C, stirring time 1000 rpm, initial concentration of Sm(III) 1 mmol/L, and contact time 15 min.

To determine the optimum pH for the adsorption of Sm(III) ions onto Amberlite IRC-50, the percentage removal of Sm(III) ions as a function of hydrogen ion concentration was examined at an initial concentration of 1 mmol/L. In Fig. 1, both adsorbents show a decrease in the removal rate of Sm(III) ions at lower pH conditions. At lower pH, hydrogen ions occupy most of the adsorption sites on the surface of the adsorbent, resulting in very low adsorption of Sm(III) ions due to electrostatic repulsion. However, increasing the pH of the solutions results in a decrease in the competition of hydrogen ions with Sm(III) ions for adsorption sites, thus facilitating a higher rate of removal of Sm(III) ions. The optimum pH for both beads was found to be 9.3, with maximum percentage removal of 63% and 88% onto Amberlite IRC-50 in (H⁺) and (Na⁺) forms, respectively. Moreover, increasing the pH to above 9.3 resulted in the precipitation of insoluble samarium hydroxide, causing a decrease in the removal of Sm(III) ions.²⁷ Thus, this pH was selected for our subsequent investigations in the following experiments.²⁶

3.2. Kinetic Curves

Figure 2 shows the results of the study on how quickly samarium adsorbs to different types of resin Amberlite

IRC-50 at 293 K. The maximum percent Sm(III) extractions were 93% and 90% obtained at 20 and 5 min for the (H⁺) and (Na⁺) forms, respectively, which are suitable contact times for samarium(III) adsorption. Thereafter, it becomes slower near equilibrium. Amberlite IRC-50, being a good exchanger, has the fastest kinetics for Sm(III) adsorption in the (Na⁺) form, followed by the (H⁺) form. Between these final and initial stages of adsorption, the rate is virtually consistent. This is obvious from the fact that numerous vacant surface sites are available for adsorption during the initial stage, and after a period of time, the residual vacant sites are difficult to occupy due to repulsive forces between the solute molecules in the solid and bulk phases. No significant change in samarium removal was observed after approximately 20 and 5 min by the two types of Amberlite IRC-50 in (H⁺) and (Na⁺) forms, respectively.

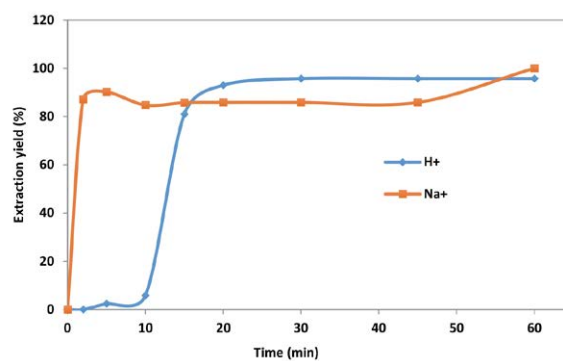


Figure 2: Effect of contact time on the ion exchange of Sm(III) using Amberlite IRC-50 in the (H⁺) and (Na⁺) forms. The initial concentration of Sm(III) 1 mmol/L, the amount of resin 0.1 g, the volume of ion-exchange medium 5 mL, T 20 ± 1 °C, stirring time was 1000 rpm, and the initial pH was 9.3.

The results of the kinetic study are presented in Figure 3. The equilibrium is attained within 20, 60, and 30 min at 293, 313, and 333 K, respectively. The extraction of samarium sorbed after equilibrium is 97% at 333 K using Amberlite IRC-50 in the (H⁺).

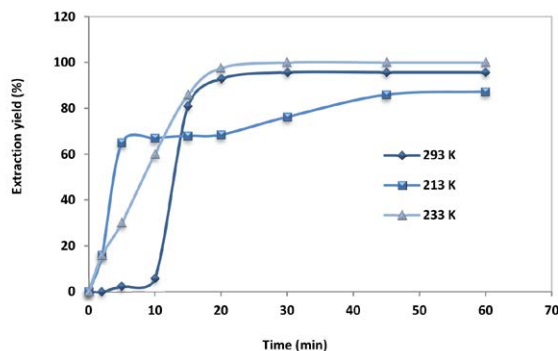


Figure 3: Effect of contact time on the ion exchange of Sm(III) using Amberlite IRC-50 in the (H⁺) form at different temperatures. The initial concentration of Sm(III) 1 mmol/L, the amount of resin 0.1 g, the volume of ion-exchange medium 5 mL, $T = 20 \pm 1$ °C, stirring time was 1000 rpm, and the initial pH was 9.3.

The kinetics of samarium adsorption on Amberlite IRC-50 (H^+) can be described using two types of equations: film diffusion and particle diffusion equations. The expression for the film diffusion equation is given as follows:²⁹

$$-\ln(1 - F) = K_u t \quad (3)$$

where F is the ratio of the amount adsorbed after time t to the amount adsorbed at equilibrium, and K_u is the rate constant. According to Eq. (3), when the kinetic data obtained for a series of F values are plotted against t , a straight line is obtained with a slope equal to the rate constant, as shown in Fig. 4. This indicates that on Amberlite IRC-50 (H^+) resin, the mechanism of samarium adsorption is the diffusion of samarium through a thin covering liquid film. Similarly, for the particle diffusion equation, the B_t values can be calculated using the following equations:

$$B_t = -2.30258 \log(1 - F) - 0.49770 \quad (4)$$

$$B_t = 6.28318 - 3.2899F - 6.28318(1 - 1.0470F)^{1/2} \quad (5)$$

where B_t is equal to $D\pi^2/r^2$, D is the particle diffusion coefficient and r its radius.

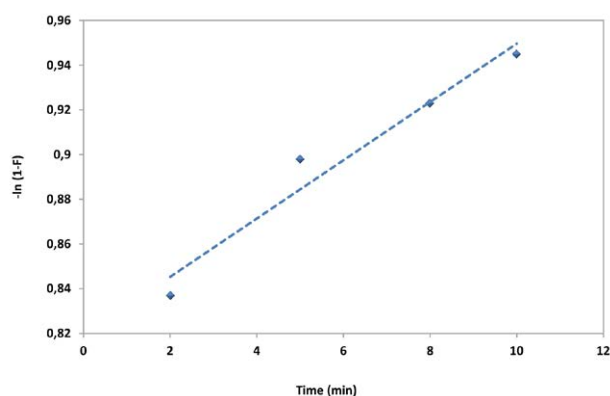


Figure 4: Film diffusion plots for Sm(III) adsorption on Amberlite IRC-50 (H^+) at 293 K. The initial concentration of Sm(III) 1 mmol/L, the amount of resin 0.1 g, the volume of ion-exchange medium 5 mL, $T 20 \pm 1^\circ\text{C}$, stirring time was 1000 rpm, and the initial pH was 9.3.

Eq. (4) is used for values of F from 0 to 0.85 and Eq. (5) is used for values of F from 0.86 to 1 according to the simplification given by Reichenberg.³⁰ The B_t values calculated from Eqs. (4) and (5) are plotted against t , and again, a straight line is obtained. The values of the rate constant B_t are calculated from the slope in Fig. 5. The plot of B_t versus t was linear, and a correlation coefficient of 0.953 indicated that the adsorption processes were controlled by film diffusion for the adsorption of samarium(III), as indicated by R^2 values ($R^2 = 0.968$).

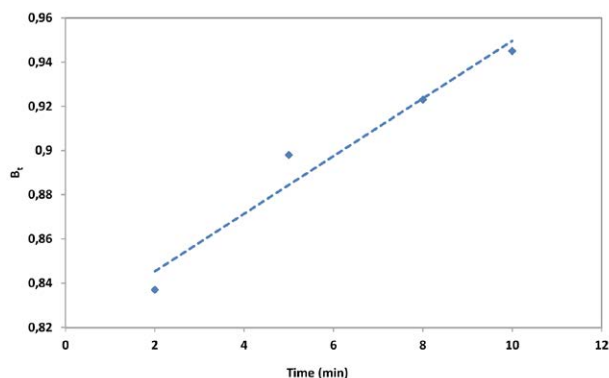


Figure 5: Particle diffusion plots for Sm(III) adsorption on Amberlite IRC-50 (H^+) at 293 K. The initial concentration of Sm(III) 1 mmol/L, amount of resin 0.1 g, volume of ion-exchange medium 5 mL, $T 20 \pm 1^\circ\text{C}$, stirring time was 1000 rpm, and initial pH 9.3.

Figure 6 shows how the contact time affects the batch adsorption of samarium on the resin Amberlite IRC-50 (Na^+) at 293 K. It is obvious that with an increase in contact time, the percentage removal of Sm(III) was enhanced significantly. Initial rapid adsorption gives a very slow approach to equilibrium. The nature of the adsorbent and its available adsorption sites affected the time required to reach equilibrium. The desorption of samarium at 333 K for a time interval of 5 to 15 min may be due to resin shrinkage at high temperatures and for a long time of contact, which limits Sm^{3+} adsorption. The equilibrium times for the adsorption of Sm(III) were 5 min at 293, 313, and 333 K.

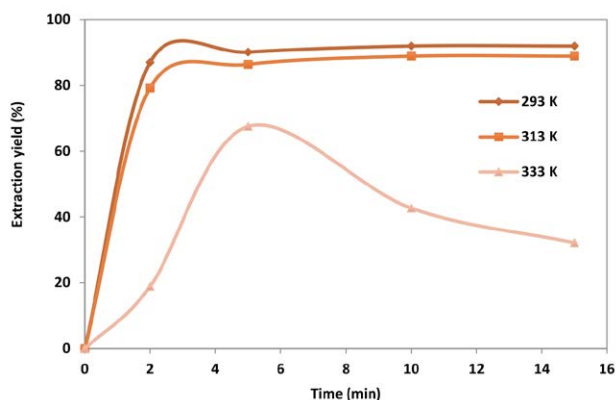


Figure 6: Effect of contact time on the ion exchange of Sm(III) using Amberlite IRC-50 in the (Na^+) form at 293 K. The initial concentration of Sm(III) 1 mmol/L, the amount of resin 0.1 g, the volume of ion-exchange medium 5 mL, $T 20 \pm 1^\circ\text{C}$, stirring time was 1000 rpm, and the initial pH was 9.3.

Film and particle diffusion kinetic models were applied against the kinetic data, and it was observed that both film and particle diffusion models were the best choices for explaining the kinetic parameters. The ion exchange adsorption of metal cations has been reported in the lit-

erature^{31,32} to be controlled either by the film, particle diffusion, or both. According to equation (3), when $\ln(1-F)$ is plotted against t , the intercepts of the plots do not equal zero, as shown in Fig. 7. Similarly, for the particle diffusion equation, the B_t values are calculated using equations (4) and (5).

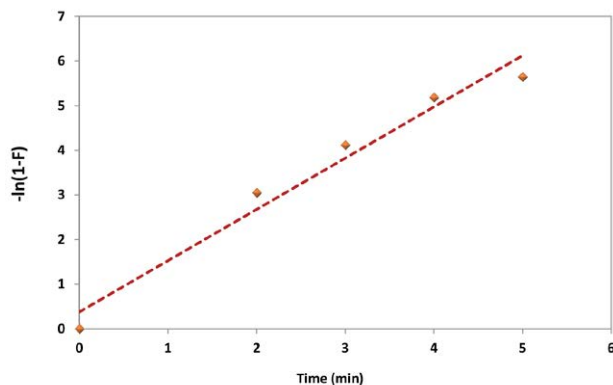


Figure 7: Film diffusion plots for Sm(III) adsorption on Amberlite IRC-50 (Na^+) at 293 K. The initial concentration of Sm(III) 1 mmol/L, the amount of resin 0.1 g, the volume of ion-exchange medium 5 mL, $T 20 \pm 1^\circ\text{C}$, stirring time was 1000 rpm, and the initial pH was 9.3.

Unfortunately, these simplifications are commonly used as “different” methods to determine K_u or incorrectly used to determine the rate-limiting step without considering the surface coverage range for which the approximations were originally derived. Eq. (3) is commonly used as a litmus test to determine the rate-limiting mechanism. If plotting $-\ln(1-F)$ vs. t , Eq. (3), yields a linear relation through the origin; this is seen as evidence for mass transfer control.

It can be judged from Figs. 7 and 8 that the film diffusion equation ($R^2 = 0.968$) is well-fitted to the data with relatively high R^2 values and low intercepts compared to the particle diffusion equation ($R^2 = 0.933$). This indicates that the film diffusion process is the rate-limiting step during Sm(III) adsorption. The values of K_u and B_t obtained from both diffusional equations at 293 K are presented in Table 1.

3. 3. Effect of Samarium Concentration

Figure 9 shows Sm^{3+} removal efficiency and adsorption capacity for Amberlite IRC-50 in (H^+) and (Na^+) forms. It is clear that the (%) removal efficiency of

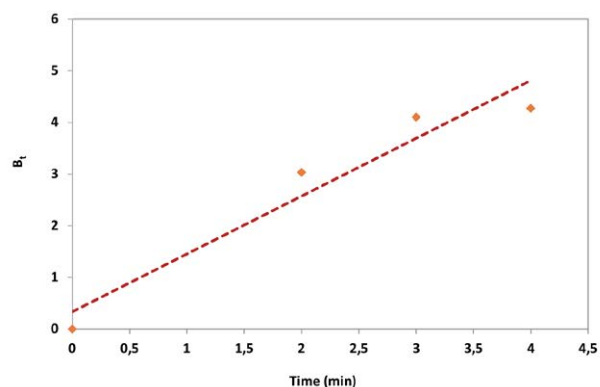


Figure 8: Particle diffusion plots for Sm(III) adsorption on Amberlite IRC-50 (H^+) at 293 K. The initial concentration of Sm(III) 1 mmol/L, the amount of resin 0.1 g, the volume of ion-exchange medium 5 mL, $T 20 \pm 1^\circ\text{C}$, stirring time was 1000 rpm, and the initial pH was 9.3.

Sm^{3+} increases with increasing initial concentration of samarium(III). This may be due to the presence of more active adsorption sites for Sm^{3+} . The extraction of samarium sorbed after equilibrium is 22.2 and 21.9 mg/g for Amberlite IRC-50 (H^+) and (Na^+) forms, respectively, at an initial concentration of 1 mmol/L.

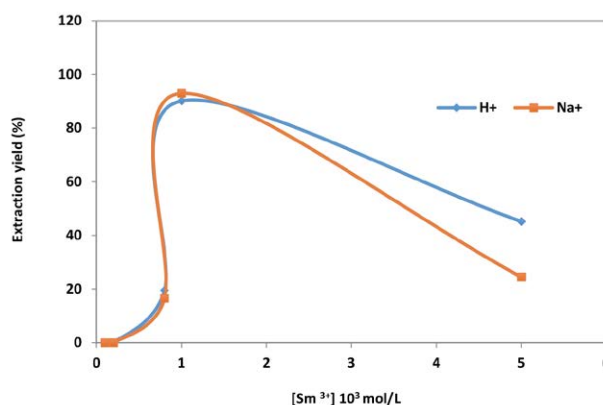


Figure 9: Effect of the initial concentration of Sm(III) adsorption on Amberlite IRC-50 in (H^+) and (Na^+) forms. Amount of resin 0.1 g, volume of ion-exchange medium 5 mL, $T 20 \pm 1^\circ\text{C}$, stirring time 1000 rpm, initial pH 9.3, contact time 20 min for (H^+) and 5 min for (Na^+).

Figure 9 also demonstrates that Sm^{3+} adsorption capacity decreases as the initial concentration increases. This effect can be explained as follows: at low metal/sorbent ratios, there are several adsorption sites in the Amberlite

Table 1. Values for film and particle diffusion processes on Amberlite IRC-50 in the (H^+) and (Na^+) forms

Temperature (K)	(H ⁺) form		(Na ⁺) form	
	Rate constants (min ⁻¹)			
	Film diffusion (<i>K_u</i>)	Particle diffusion (<i>B_t</i>)	Film diffusion (<i>K_u</i>)	Particle diffusion (<i>B_t</i>)
293	0.01	1	0.9	0.01

IRC-50 structure. As the metal/sorbent ratio increases, adsorption sites become saturated, resulting in a decrease in adsorption efficiency.³³

3. 4. Effect of the Resin Dosage

The resin amount is an important parameter for determining the quantitative uptake of metal ions. The retention of the metals was examined in relation to the amount of resin. Fig. 10 shows the removal of Sm(III) as a function of resin dosage using Amberlite IRC-50 in the (H⁺) and (Na⁺) forms. The resin amount varied from 0.025 to 0.15 g and was equilibrated for 20 and 5 min at an initial metal ion concentration of 1 mmol/L solution. The equilibrium concentration in the liquid phase and the contact time required to reach equilibrium decrease with increasing resin doses for a given initial metal concentration. These results were anticipated because increasing the adsorbent dose could provide a large surface area or ion-exchange sites for a fixed initial solute concentration.

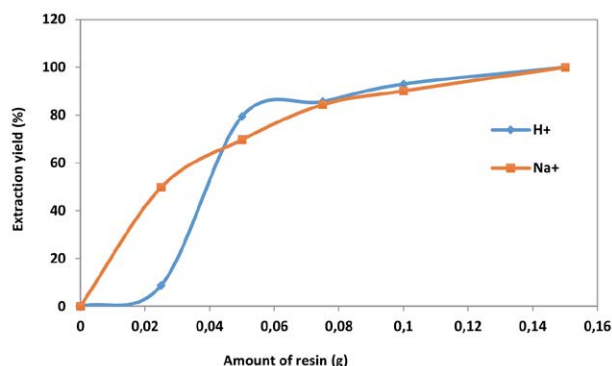


Figure 10: Effect of resin amount on ion exchange Sm(III) adsorption on Amberlite IRC-50 in (H⁺) and (Na⁺) forms. Amount of resin 0.1 g, volume of ion-exchange medium 5 mL, $T 20 \pm 1$ °C, stirring time 1000 rpm, initial pH 9.3, contact time 20 min for (H⁺) and 5 min for (Na⁺).

It may also be concluded that the removal efficiency increases and the ion-exchange density decreases with increasing adsorbent dose. The decrease in ion-exchange density can be attributed to the fact that some of the ion exchangers remain unsaturated during the adsorption process, whereas the number of available ion-exchange sites increases with resin dosage, resulting in an increase in removal efficiency.³⁴ It is clear from Fig. 10 that for the quantitative removal of 1 mmol/L samarium in a 5 mL solution, a minimum resin dosage of 0.15 g in the (H⁺) and (Na⁺) forms is required. For this amount of resin, the adsorption values were 99%.

3. 6. Thermodynamic Studies

Thermodynamic parameters, such as the Gibbs energy (ΔG°), enthalpy (ΔH°), and entropy (ΔS°), are deter-

mined using the following equations:^{10,35}

$$K_d = q_e/C_e \quad (6)$$

$$\Delta G^\circ = -RT \ln K_d \quad (7)$$

$$\ln K_d = \Delta S^\circ R - \Delta H^\circ RT \quad (8)$$

where R (8.3145 J/mol K) is the ideal gas constant, T (K) is the absolute temperature, and K_d is the thermodynamic equilibrium constant. The values of changes in enthalpy (ΔH°) and entropy (ΔS°) are calculated from the slopes and intercepts of the plot of $\ln K_d$ vs. $1/T$ using Eq. (8).

The calculated values of the thermodynamic parameters are given in Table 2. The negative value for the Gibbs energy change for the two resins shows that the adsorption process is feasible and thermodynamically spontaneous. Furthermore, the decrease in ΔG° values with increasing temperature indicates that adsorption is not favorable at higher temperatures.

Table 2. Gibbs free energy, enthalpy, and entropy changes for Sm(III) adsorption on Amberlite IRC-50

Resin	$\Delta H^\circ \cdot 10^4$	ΔS°	$\Delta G^\circ \cdot 10^5$ (kJ/mol)		
	(kJ/mol)	(J/K mol)	293 K	303 K	333 K
Amberlite IRC-50 (H ⁺)	+21	+95	-8	-10	-12
Amberlite IRC-50 (Na ⁺)	-19	+32	-9	-9	-8

The enthalpy of the adsorption, ΔH° , is a measure of the energy barrier that must be overcome by reacting molecules.²⁵ The values of ΔH° for the adsorption of Sm³⁺ by Amberlite IRC-50 in (H⁺) are positive, indicating that the extraction procedure of samarium is endothermic in nature, unlike the values of ΔH° for the adsorption of Sm³⁺ by Amberlite IRC-50 in (Na⁺), which indicate the exothermic nature of the adsorption process of Sm(III) at 20–60 °C.

The value of ΔS° can be used to identify whether the adsorption reaction is attributed to an associative or dissociative mechanism. Generally, entropy change $\Delta S^\circ > -10$ J/mol K implies a dissociative mechanism.²⁰ Before adsorption occurs, the heavy metal ions near the surface of the adsorbent will be more ordered than in the subsequent adsorbed state, and the ratio of free heavy metal ions to ions interacting with the adsorbent will be higher than that in the adsorbed state. As a result, the distribution of rotational and translational energy among a few molecules will increase with increasing adsorption by producing a positive value of ΔS° and randomness will increase at the solid-solution interface during the process of adsorption. The entropy changes in this work are all positive for the

two resins, implying that the dissociative mechanism is involved in the adsorption processes.

The negative values of ΔG° also indicate that the process of extraction by the two resins is spontaneous.

3. 7. Probabilities of the Mechanism

Samarium ions may exist in the aqueous phase in different ionic forms. Any of these forms will predominate over other forms of samarium depending on the total amount of samarium and the pH of the aqueous phase. Sm(III) cation prevails in an acidic or slightly basic solution, whereas different samarium cations dominate in a basic solution. Therefore, in this study, the samarium ion will be in the form of $\text{Sm}(\text{OH})_2^+$, as shown in Fig. 11.

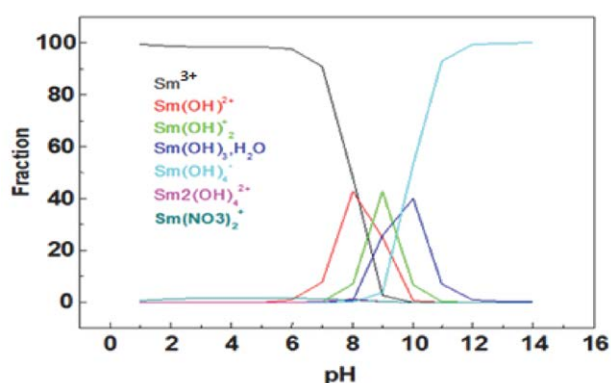
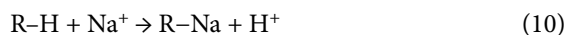
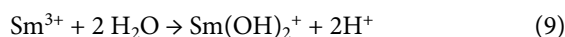


Figure 11: Distribution diagrams of samarium using the Medusa and Hydra programs³⁶

To explain the observed behavior of Sm(III) removal with varying pH, it is necessary to examine various mechanisms, such as electrostatic attraction/repulsion, chemical interaction, and ion exchange, that are responsible for adsorption on sorbent surfaces.

Therefore, the following mechanisms can be proposed for the adsorption of samarium(III) by Amberlite IRC-50 (Na^+):



Similar competition was observed by Mohan et al.³⁷ and Chanda and Rempel³⁸ while studying Cr(III) adsorption on weak acid exchangers.

4. Conclusions

The present study deals with the adsorption of Sm(III) on Amberlite IRC-50 in (H^+) and (Na^+) forms from

aqueous solutions. The effects of pH, contact time, kinetics, and thermodynamics are examined in batch experiments. Amberlite IRC-50 is a weak cationic resin with good capability and efficiency. The ideal conditions for achieving the highest adsorption capacity of samarium(III) were determined. At a temperature of 293 K, the kinetic analysis indicates that the rate of adsorption is primarily limited by film diffusion.

Acknowledgements

Memorial to the beloved Professor Mohamed Amine DIDI, who passed away on January 17, 2023. You will never be forgotten, dear Professor.

Competing interests

The authors declare that no conflict of interest would prejudice the impartiality of this scientific work.

5. References

1. R.Torkaman, M. A.Moosavian, M.Torab-Mostaedi, J. Safdari, *Hydrometallurgy* **2013**, 137, 101–107. DOI:10.1016/j.hydromet.2013.04.005
2. M. E. Mahmoud, G. M. Nabil, S. M. T. Elweshahy, *Powder Technol.* **2021**, 378, 246–254. DOI:10.1016/j.powtec.2020.09.058
3. A. I. Rasee, E. Awual, A. I. Rehan, M. S. Hossain, R.M. Waliullah, K. T. Kubra, Md. C. Sheikh, Md. S. Salman, Md. N. Hasan, Md. M. Hasan, H. M. Marwani, A. Islam, Md. A.Khaleque, Md. R. Awual, *Surf. Interfaces*. **2023**, 103276. DOI:10.1016/j.surfin.2023.103276
4. S. Kocaoba, G. Akcin, *Desalination*. **2005**, 180, 151–156. DOI:10.1016/j.desal.2004.12.034
5. A. Amara-Rekkab, M. A. Didi, D. Villemin, *Eur. Chem. Bull.* **2015**, 4, 190–195. DOI: 10.17628/ECB.2015.4.190
6. R.Kondaurov, Y. Melnikov, L. Agibayeva, *Polymers* **2022**, 15, 846. DOI:10.3390/polym15040846
7. P. Gaete, L. Molina, F. Valenzuela, C. Basualto, *Hydrometallurgy* **2021**, 203, 105698. DOI:10.1016/j.hydromet.2021.105698
8. G. S. dos Reis, G. L. Dotto, J. Vieillard, M. L. S. Oliveira, S. F. Lütke, A. Grimm, L. F.O. Silva, É.C. Lima, M. Nashed, Ulla Lassi, *J. Alloys Compd.* **2023**, 960, 170530. DOI:10.1016/j.jallcom.2023.170530
9. S. Y. Kang, J. U. Lee, S. H. Moon, K.W. Kim, *Chemosphere* **2004**, 56, 141–147. DOI:10.1016/j.chemosphere.2004.02.004
10. S.Mustafa, K. H. Shah, A. Naeem, M. Waseem, M. Tahir, *J. Hazard Mater.* **2008**, 160, 1–5. DOI:10.1016/j.jhazmat.2008.02.071
11. D. Villemin, M. A. Didi, *Orient. J. Chem.* **2013**, 29, 1267–1284. DOI:10.13005/ojc/290402
12. M. A. Didi, O. Abderrahim, A. Azzouz, D. Villemin, *J. Radioanal. Nucl. Chem.* **2014**, 299, 1191–1198. DOI:10.1007/s10967-013-2855-6
13. E. Benaissa, O. Abderrahim, M. A. Didi, *J. Radioanal. Nucl.*

- Chem.* **2014**, 299, 439–446. <https://link.springer.com/article/10.1007/s10967-013-2766-6>.
14. H. Aghayan, A. R. Mahjoub, A. R. Khanchi, *Chem. Eng. J.* **2013**, 225, 509–519. DOI:10.1016/j.cej.2013.03.092
 15. H. Paudyal, P. Bimala, K. N. Ghimire, I. Katsutoshi, K. Ohto, H. Kawakita, S. Alam, *Chem. Eng. J.* **2012**, 195, 289–296. DOI:10.1016/j.cej.2012.04.061
 16. N. Rahmat, A. Z. Abdullah, A. R. Mohamed, *Sust. Energy Rev.* **2010**, 14, 987–1000. DOI:10.1016/j.sres.2009.11.010
 17. M. Balaraju, V. Rekha, P. S. Sai Prasad, B. L. A. Prabhavathi Devi, R. B. N. Prasad, N. Lingaiah, *Appl. Catal. A – Gen.* **2009**, 354, 82–87. DOI: 10.1016/j.apcata.2008.11.010.
 18. A. Behr, L. Obendorf, *Eng. Life Sci.* **2003**, 2, 185–189. DOI:10.1002/1618-2863(20020709)2:7<185::AID-ELSC185>3.0.CO;2-4
 19. M. Aresta, A. Dibenedetto, F. Nocito, C. Ferragina, *J. Catal.* **2009**, 268, 106–114. DOI:10.1016/j.jcat.2009.09.008
 20. M. A. Dasari, P. P. Kiatsimkul, W. R. Sutterlin, G. J. Suppes, *Appl. Catal. A – Gen.* **2005**, 281, 225–231. DOI:10.1016/j.apcata.2004.11.033
 21. J. A. Melero, G. Vicente, G. Morales, M. Paniagua, J. M. Moreno, R. Roldan, A. Ezquerro, C. Perez, *Appl. Catal. A – Gen.* **2008**, 346, 44–51. DOI:10.1016/j.apcata.2008.04.041
 22. M. J. Climent, A. Corma, P. D. Frutos, S. Iborra, M. Noy, A. Velly, P. Concepcion, *J. Catal.* **2010**, 269, 140–149. DOI:10.1016/j.jcat.2009.11.001
 23. T. Hiroki, K. Masashi, F. Ryusaburo, *React. Funct. Polym.* **1998**, 38, 177–181. DOI:10.1016/S1381-5148(97)00164-8
 24. E. R. Donald, *Thermochim. Acta* **1984**, 79, 117. DOI:10.1016/0040-6031(84)87099-9
 25. Y. W. Lu, B. Keita, L. Nadjo, *Polyhedron* **2004**, 23, 1579–1586. DOI:10.1016/j.poly.2004.03.014
 26. X. Zhao, G. Zhang, Q. Jia, Z. Chengji, Z. Weihong, L. Weijie, *Chem. Eng. J.* **2011**, 171, 152–158. DOI:10.1016/j.cej.2011.03.080
 27. A. Rabiul, K. Tohru, Y. Miyazaki, R. Motokawa, H. Shiwaku, S. Shinichi, O. Yoshihiro, Y. Tsuyoshi, *J. Hazard. Mater.* **2013**, 252, 313–320. DOI:10.1016/j.jhazmat.2013.03.020
 28. E. Igberase, P. Osifo, A. Ofomaja, *J. Environ. Chem. Eng.* **2014**, 2, 362–369. DOI:10.1016/j.jece.2014.01.008
 29. L. Dandan, C. Xijun, H. Zheng, W. Qihui, L. Ruijun, C. Xiaoli, *Talanta* **2011**, 83, 1742–1747. DOI:10.1016/j.talanta.2010.12.012
 30. F. J. Alguacil, M. Alonso, L. J. Lozano, *Chemosphere* **2004**, 57, 789–793. DOI:10.1016/j.chemosphere.2004.08.085
 31. A. Chatterjee, *Chem. Eng. J.* **2014**, 244, 105–116. DOI:10.1016/j.cej.2013.12.017
 32. M. Amara, H. Kerdjoudj, *Desalination* **2004**, 168, 195–200. DOI:10.1016/j.desal.2004.06.187
 33. S. A. Cavaco, S. Fernandes, M. Margarida, Q. M. F. Licinio, *J. Hazard. Mater.* **2007**, 144, 634. DOI:10.1016/j.jhazmat.2007.01.087
 34. Y. Zhihui, Q. Tao, Q. Jingkui, W. Lina, C. Jinglong, *J. Hazard. Mater.* **2009**, 167, 406–412. DOI:10.1016/j.jhazmat.2008.12.140
 35. S. Mustafa, K. H. Shah, A. Naeem, T. Ahmad, M. Waseem, *Desalination* **2010**, 264, 108–114. DOI:10.1016/j.desal.2010.07.012
 36. I. Puigdomenech, “HYDRA (Hydrochemical Equilibrium Constant Database) and MEDUSA (Make Equilibrium Diagrams Using Sophisticated Algorithms) Programs,” Royal Institute of Technology, Sweden. <http://www.kemi.kth.se/medusa>.
 37. D. Mohan, K. P. Singh, V. K. Singh, *J. Hazard. Mater.* **2006**, 135, 280–295. DOI:10.1016/j.jhazmat.2005.11.075.
 38. M. Chanda, G. L. Rempel, *Ind. Eng. Chem. Res.* **1997**, 36, 2184–2189. DOI:10.1021/ie960525t.

Povzetek

Preevalovali smo adsorpcijo samarija(III) na šibki makroporozni kationski izmenjevalec Amberlite IRC-50 v (H^+) in (Na^+) oblikah kot funkcijo začetnega pH vodne raztopine, časa in temperature, začetne koncentracije samarijevih(III) ionov in količine smole pri stalni temperaturi ($20 \pm 1^\circ C$). Koncentracijsko območje je bilo med 0,1 in 5 mmol/L, pH območje med 1,8 in 10,5; čas mešanja med 2 in 60 min; količina smole med 0,025 in 0,15 g. Za razlago kinetičnih podatkov smo uporabili tako filmsko-plastno enačbo kot enačbo za difuzijo delcev. Vrednosti hitrostne konstante za adsorpcijo samarija(III) smo izračunali tako za filmsko-plastni proces kot za difuzijo delcev. Sledi vrstnemu redu (Na^+) > (H^+). Temperatura ima insignifikanten učinek na oba difuzijska procesa. Izračunali smo različne termodinamske parametre (ΔH° , ΔS° in ΔG°) za izmenjavo samarija(III) na smoli. Optimalni pogoji so bili koncentracija 1 mmol/L, pH 9,3, čas mešanja 20 min za Amberlite IRC-50 (H^+) in 5 min za (Na^+) obliko, ter 0,15 g smole. Ravnotežna ekstrakcija samarija je bila 22,2 mg/g za Amberlite IRC-50 (H^+) in 21,9 mg/g za Amberlite IRC-50 (Na^+) pri začetni koncentraciji 1 mmol/L. Pridobljeni rezultati so pokazali, da se šibki kationski izmenjevalec Amberlite IRC-50 dobro obnese za odstranjevanje in ekstrakcijo samarija(III). Z optimizacijo je možno pridobiti pogoje za odstranjevanje Sm(III) v industrijskem merilu.



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