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Removal of zinc ions as zinc chloride complexes from strongly acidic aqueous solutions by ionic exchange[+]

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Abstract: The aim of this study was to compare several anion exchangers and to investigate the capacity of Amberlite IRA410 to remove zinc as chloride $[ZnCl_3]^-$ from hydrochloric solutions (1 M). Influence of the process parameters such as stirring rate, resin quantity and zinc initial concentration over the removal process, was considered. The highest experimental ionic exchange capacity between the considered anionic exchangers, in the same working conditions (500 rpm, 5 g resin and 500 mg L^{-1}), was obtained for Amberlite IRA410, 8.34 mg g^{-1}. With an increase of zinc ions concentration, ionic exchange capacity increased up to 19.31 mg g^{-1} (1100 mg L^{-1}). The experimental data were analysed using Langmuir, Freundlich, Temkin and Dubinin-Radushkevich isotherm models. The results were also analyzed using sorption kinetics models, pseudo-first-, pseudo-second-order, intra-particle and film diffusion models. From the Dubinin-Radushkevich and Temkin isotherm models the mean free energy and heat of sorption were calculated to be 7.45 kJ mol^{-1}, respectively 1×10^{-4} kJ mol^{-1}, which indicates that zinc sorption is characterized by a physisorption process. Kinetic studies showed that the adsorption followed a pseudo-second-order kinetic model.

Keywords: *Anion exchangers • Zinc • Isotherm models • Kinetics • Hot-dip galvanising*

1. Introduction

People have used metals for many centuries and in our days the mass usage of metals has become a great concern [1]. Several industrial activities, in particular metallurgical industries, are important sources of environmental pollution due to their high content of several heavy metals ions that are toxic for living organisms including human beings [2].

One of the main problems of metallurgical industries are the wastes containing zinc generated from process such as galvanizing, casting, scrap recycling and smelting [3]. Hot dip galvanizing processes offer a simple and effective way for corrosion protection of steel [4-7]. The steps of a hot dip galvanizing process are as follows: alkaline or acidic degreasing, rinsing with water, pickling with dilute hydrochloric or sulfuric acid, rinsing with water, fluxing in aqueous $ZnCl_2/NH_4Cl$ baths, drying and dipping into molten zinc at temperatures of about 450ºC for a defined period [6,7]. The pickling step generates effluents containing, among other substances, high concentrations of $ZnCl_2$, $FeCl_2$ and HCl [6].

Even if zinc is a key element for humans, free zinc ions in solution can cause serious issues to the environment [8] because of its acute toxicity and non-biodegradability [9] and its presence in water is a potential risk for the public health. Therefore, it is necessary to use feasible processes to minimize the pollution caused by zinc discharges and to reduce the risks associated with its presence in the environment [2].

For years, many techniques have been developed to remove heavy metals from wastewaters including: chemical precipitation, reverse osmosis, evaporation, adsorption, electrolytic and membrane methods, ionic

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Table 1. Characteristics of the investigated anion exchangers (product data sheet).

Resin	Type	Matrix/functional group	Total exchange capacity (eq L^{-1})	Maximum temperature, (°C)	Colour of spherical beads	Moisture content, (%)
Amberlite IRA410	Cl^-	Styrene divinylbenzene copolymer/$N^+(CH_3)_2C_2H_4OH$	1.25	35	Pale yellow translucent	45 - 51
Purolite A103S	Cl^-	Polystrene crosslinked with divinylbenzene/$NH(CH_3)_2OH$	1.60	100	Opaque white	48 - 55
Purolite A400MBOH	Cl^-	Styrene-Divinylbenzene/ $R\text{-}N^+(CH_3)_3$	1.30	60	Clear golden	48 - 54
Purolite NRW700	OH^-	Gel polystyrene crosslinked with divinylbenzene/ $N(CH_3)_3OH$	1.15	60	Golden	42 - 47

exchange, oxidation, biodegradation, *etc*. [2,9,10,11]. Among these methods, ionic exchange has several advantages like: recovery of valuable metal, selectivity, less sludge produced, low operational costs and high efficiency [10]. Also, ionic exchange is an effective and common method, which allows handling of large volumes of wastewaters containing relatively low concentration of heavy metals.

Zinc ions can form various chloride complexes in hydrochloric acid solutions in cationic and anionic form and this tendency can be utilized to separate zinc from chloride solution, which also contain other metals, such as iron [12,13].

In literature, ionic exchange resins like Purolite C-100 MH [8], Dowex HCR S/S [9], Chelex 100, Amberlite IRC748, Purolite S930, Lewatit TP207 [14], Amberlite IR120 [15], have been extensively applied for zinc removal in cationic form. On the other hand research papers did not cover removal of zinc in anionic form. Literature mentions palladium removal from various chloride solutions onto anion exchange resins such as Varion (ATM, ADM, ADAM) [16].

Taking into consideration these aspects and also the fact that removal of zinc as $[ZnCl_3]^-$ allows separation from solutions containing other metals, in this paper we studied removal of zinc-chloride complexes formed in hydrochloric acid solution using anion exchanger resins. Several anion exchangers were considered. Influence of the process parameters such as stirring rate, resin quantity and zinc initial concentration were considered to examine the performance of an anion exchanger for zinc removal from acidic solution. Equilibrium data were modelled using Langmuir, Freundlich, Temkin and Dubinin-Radushkevich (D-R) isotherms. The results were also analyzed using sorption kinetics models, pseudo-first-, pseudo-second-order, intra-particle and film diffusion models.

2. Experimental procedure

2.1. Resins and solutions

Strongly basic anion exchanger resins like Amberlite IRA410, Purolite A103S, Purolite A400MBOH and Purolite NRW700 were considered for investigations. Their characteristics are summarized in Table 1.

Analytical reagent and other inorganic chemicals such as HCl, $ZnCl_2$ were purchased from Merck Co. Initial zinc solutions were prepared by dissolving $ZnCl_2$ salt in hydrochloric acid 1M. All used chemicals were of analytical purity. HCl concentrations were chosen taking in account $ZnCl_3^-$ formation constant (K = 0.58) in order to ensure formation of this anionic species [12].

2.2. Apparatus and analytical procedure

The sorption experiments were performed in batch conditions, contacting various quantities of anion exchanger (1-5 g) with zinc solutions (100 mL) at different initial concentrations ranging from 300 to 1100 mg L^{-1} at room temperature. The stirring rate was varied within 100-500 rpm range using a magnetic stirrer. An experiment run lasted for 300 min (preliminary tests showed that equilibrium was reached up to 300 min in all cases). Samples of 1 mL were taken from solution at previously established time intervals and the concentration of zinc in solutions was determined using an atomic absorption spectrophotometer Avanta PM GBC (Australia).

The amount of sorbed zinc per unit mass of anion exchanger (ionic exchange capacity) was calculated using Eq. 1, while removal efficiency (percent of sorption) was calculated using Eq. 2.

$$q_e = \frac{(C_0 - C_e)}{m} \cdot \frac{V}{1000} \qquad (1)$$

$$E(\%) = \frac{C_0 - C_e}{C_0} \cdot 100 \qquad (2)$$

where, C_0, C_e are the initial and equilibrium zinc ion concentrations (mg L^{-1}); q_e is the ionic exchange capacity (mg g^{-1}); V is the volume of zinc ion solution (mL); m is the mass of resin (g) [2,8].

3. Results and discussion

3.1. Ionic exchange capacity of anion exchanger resins

Four anion exchanger resins were tested in the same conditions by contacting the resin (5 g) with the metal solution (500 mg L^{-1}) and stirred for 300 min (500 rpm).

The results presented in Fig. 1 showed that the percentage of zinc removed increased with increasing contact time. In the first 100 min a steep increase was observed, followed by a slower increase with time up to 300 min (equilibrium). The maximum percent of sorption about 87% was obtained for Amberlite IRA410 and the minimum percent of sorption about 79% for Purolite A400MBOH. The following series was depicted based on removal efficiencies: Amberlite IRA410 > Purolite A103S > Purolite NRW700 > Purolite A400MBOH. The experimental ionic exchange capacities were calculated to be: 8.34 mg g^{-1} for Amberlite IRA410 and 7.83 mg g^{-1} for Purolite A400MBOH. Based on these data the following tests were made by using Amberlite IRA410 resin.

3.2. Effect of stirring rate

The purpose of these tests was to determine the optimal stirring conditions for the ionic exchange process. The experiments were carried out using Amberlite IRA410 (5 g), which was contacted with zinc solution (100 mL) for 300 min at three different stirring rates 100, 300 and 500 rpm. Results are presented in Fig. 2. The curves obtained showed that the sorption process was strongly intensified by an increase of stirring rate from 100 to 300 rpm in the first 150 min, a further increase up to 500 rpm lead to a smaller increase. Therefore liquid film diffusion limitations are diminished. Percent of sorption increased from 86 to 87% while ionic exchange capacity reached a maximum value of 8.34 mg g^{-1} for 500 rpm.

3.3. Effect of resin quantity

In order to study the effect of resin quantity on zinc removal, the weight of resin added to 100 mL solution was varied from 1 to 5 g. All experiments were carried out at the same stirring rate (500 rpm). The results are given in Fig. 3. An increase in resin quantity will lead to a more rapid concentration drop in the first 50 min and an

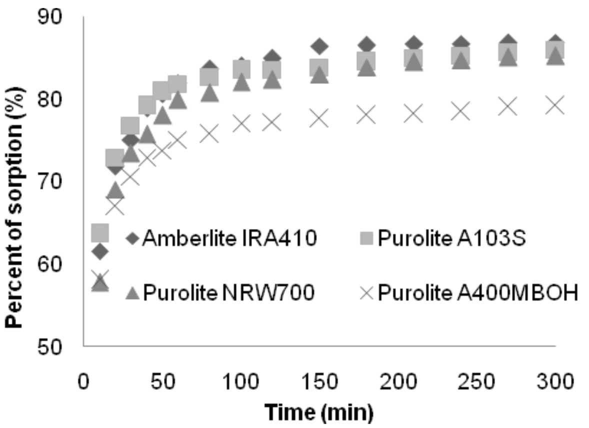

Figure 1. Removal efficiency for zinc sorption on different anion exchangers; C_0 = 500 mg L^{-1}, m = 5 g, V = 100 mL, 500 rpm.

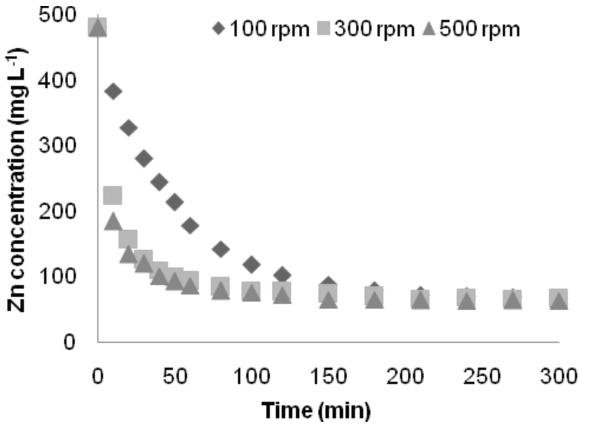

Figure 2. Effect of stirring rate on zinc sorption by Amberlite IRA410; C_0 = 500 mg L^{-1}, m = 5 g, V = 100 mL.

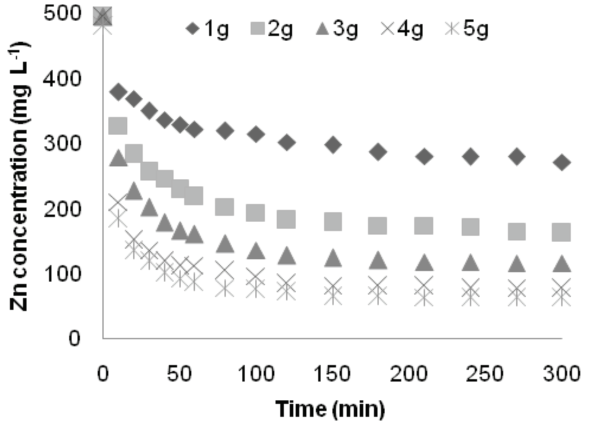

Figure 3. Effect of resin quantity on zinc sorption by Amberlite IRA410; C_0 = 500 mg L^{-1}, V = 100 mL, 500 rpm.

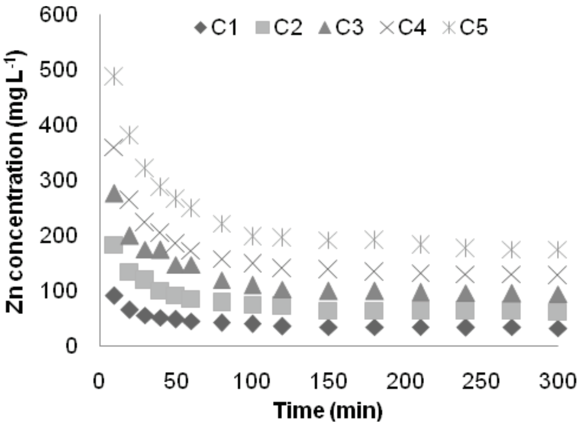

Figure 4. Effect of initial concentration on zinc sorption by Amberlite IRA410; C1 = 300 mg L^{-1}, C2 = 500 mg L^{-1}, C3 = 700 mg L^{-1}, C4 = 900 mg L^{-1}, C5 = 1100 mg L^{-1}, m = 5 g, V = 100 mL, 500 rpm.

increase of the percent of sorption from 45 to 87% for 1 and 5 g, respectively.

For an industrial application an optimisation of the resin quantity should be realised in order to find a balance between removal efficiency and ionic exchange capacity for the specific operating conditions.

3.4. Effect of the initial concentration

The experiments were carried out using a fixed anion exchanger quantity (5 g) and stirring rate (500 rpm) but varying the initial zinc concentration (300 - 1100 mg L^{-1}). The obtained results for the sorption of zinc by Amberlite IRA410 starting from different initial concentrations are presented in Fig. 4. In this range of concentration, zinc sorption was rapid in the first 10 min, after that, the sorption rate slowly decreases as the process reaches equilibrium. It was noted that zinc ionic exchange capacity at 300 mg L^{-1} was 5.61 mg g^{-1} (89% efficiency) and 19.31 mg g^{-1} (85% efficiency) at 1100 mg L^{-1}.

3.5. Isotherm models

The sorption isotherms are characterised by certain constants whose values express the surface properties and affinity of the sorbent sorption is established when the concentration of sorbate in solution is in dynamic balance with that at the sorbent interface and are used to analyze the data obtained from the sorption process [17].

In order to obtain the ion exchange equilibrium the resin, Amberlite IRA410 (5 g) was placed in conical flasks and contacted with zinc solution (100 mL) with desired concentration (300 – 1100 mg L^{-1}). The rotation speed was kept constant at 500 rpm for 300 min until equilibrium was reached. The equilibrium data were analysed using the most common isotherms model (Langmuir, Freundlich, Dubinin-Radushkevisch and Temkin).

3.5.1. Langmuir isotherm

This isotherm represents the equilibrium distribution of zinc ions between the solid and liquid phases [2] and its equation, valid for monolayer adsorption onto specific homogenous sites [8] is given below [18]:

$$\frac{1}{q_e} = \frac{1}{q_{max} \cdot K_L \cdot C_e} + \frac{1}{q_{max}} \qquad (3)$$

where, K_L is the Langmuir adsorption constant (L mg^{-1}); q_{max}, q_e are the maximum and equilibrium adsorption capacities (mg g^{-1}), C_e is the equilibrium zinc concentration in the solution (mg L^{-1}).

The essential features of the Langmuir isotherm may be expressed by the separation factor R_L [18]:

$$R_L = \frac{1}{1+K_L C_0} \qquad (4)$$

where, C_0 is the initial zinc ion concentration (mg L^{-1}).

R_L value indicates the nature of the isotherm, linear if R_L = 1, irreversible if R_L = 0, favourable if its value lie between 0 and 1 and unfavourable if R_L > 1 [2,18,21]. The calculated R_L values at different initial concentration (300 - 1100 mg L^{-1}) are ranging between 0.01 - 0.004 indicating that the equilibrium sorption was favourable. Fig. 5a shows the Langmuir plots for adsorption of zinc onto Amberlite IRA410 at different concentrations. Isotherm parameters q_{max} and K_L obtained from the slope and intercept of the plot $1/q_e$ *vs.* $1/C_e$ are presented in Table 2.

3.5.2. Freundlich isotherm

This isotherm is used to describe the adsorption characteristics for the heterogeneous surface and it can be expressed in the linear form as follows [2]:

$$\log q_e = \log K_F + \frac{1}{n} \log C_e \qquad (5)$$

where, K_F and n are isotherm constants that indicate the capacity and intensity of the adsorption; 1/n is a function of the strength of adsorption. If n value is below 1 it indicates a normal adsorption, > 1 indicates cooperative adsorption and if 1< n < 10 indicates a favourable adsorption process [2].

From the data presented in Table 2, the value of n is 1.29 indicating that the sorption of zinc onto Amberlite IRA410 is cooperative and the sorption data fitted well to Freundlich model. Isotherm constant K_F, n and correlation coefficients were obtained from the slope and the intercept of the linear plot $\log q_e$ vs. $\log C_e$ at different concentrations (Fig. 5b).

3.5.3. Dubinin-Radushkevich isotherm

This isotherm expresses the adsorption mechanism with a Gaussian energy distribution onto a heterogeneous surface. The linear form of this isotherm equation can be expressed as [2]:

$$\ln q_e = \ln q_m - \beta\varepsilon^2 \tag{6}$$

where, q_m is the theoretical adsorption capacity (mg g^{-1}),β is Dubinin Radushkevich model constant (mol² kJ^{-2}); ε is equal to:

$$\varepsilon = RT\ln(1+\frac{1}{C_e}) \tag{7}$$

where, R is the gas constant (8.314 J mol K^{-1}) and T is absolute temperature (K).

Free energy E per molecule, Eq. 8, of adsorbate, which helps to distinguish between the physical and chemical adsorption of metal ions is given below:

$$E = \frac{1}{\sqrt{-2\beta}} \tag{8}$$

The isotherm constants q_m and β were obtained from the intercept and the slope of the plot $\ln q_e$ *vs.* ε^2.

If E value is between 8 and 16 kJ mol^{-1}, the sorption process is chemically and if E < 8 kJ mol^{-1}, the sorption process is physically [19]. In our case the mean free energy was 7.45 kJ mol^{-1} (Table 2) indicating a physisorption process.

3.5.4. Temkin isotherm

This isotherm assumes that heat of adsorption of all molecules in the layer would decrease linearly rather than logarithmic with coverage. The equations of this model are given below [2]:

$$q_e = B\ln A_T + B\ln C_e \tag{9}$$

$$B = \frac{RT}{b_T} \tag{10}$$

where, A_T is the Temkin isotherm equilibrium constant (L g^{-1}); b_T is Temkin isotherm constant; B is a constant related to heat of sorption (J mol^{-1}). From the q_e *vs.* $\ln C_e$ plot, A_T and B constants were determined.

Taking into consideration the calculated value of the constant related to heat of sorption, B, which has a value smaller than 20 kJ mol^{-1} [20] (Table 2), we concluded that according to this isotherm the sorption process takes place as physisorption. This result confirms the result obtained from Dubinin-Radushkevich isotherm.

3.6. Kinetics studies

To analyse kinetics of the sorption process, different reaction kinetic models were applied to determine the reaction order and rate constant of the ion exchange. These models take into consideration the property of the sorbent, sorbate and experimental conditions [8]. Intra-particle diffusion rate coefficients, liquid film diffusion rate coefficients and pore diffusion coefficients were also determined using the appropriate models.

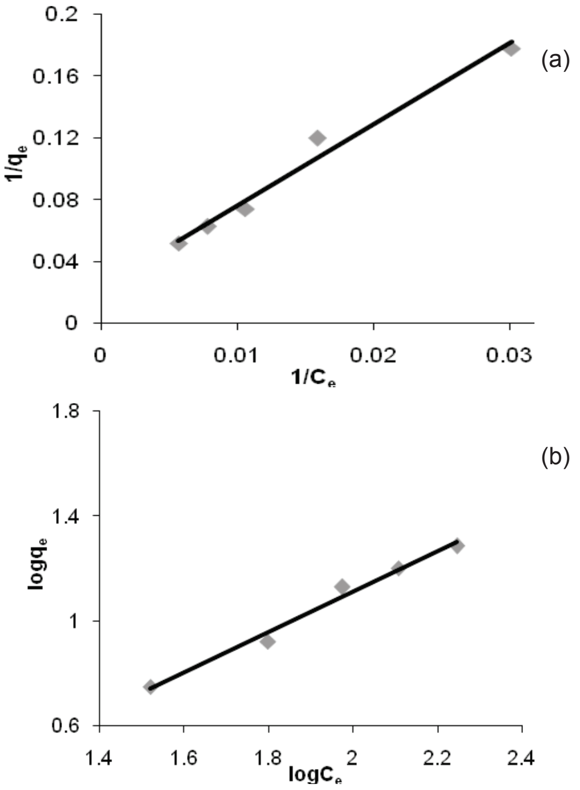

Figure 5. Langmuir (a) and Freundlich (b) adsorption isotherm for zinc sorption on Amberlite IRA410; C_i = 300 - 1100 mg L^{-1}, m = 5 g, V = 100 mL, 500 rpm.

Table 2. Isotherm constants for zinc sorption on Amberlite IRA410.

Langmuir			**Freundlich**		
q_{max} (mg g^{-1})	K_L (L mg^{-1})	R^2	n	K_F ($mg^{(1-1/n)}$ $L^{1/n}$ g^{-1})	R^2
43.47	0.18	0.980	1.29	0.37	0.984
Dubinin-Radushkevich			**Temkin**		
β (mol² kJ^{-2})	E (kJ mol^{-1})	R^2	A_T (L g^{-1})	B (J mol^{-1})	R^2
9×10^{-9}	7.45	0.984	2.15	1×10^{-4}	0.966

3.6.1. Pseudo-first-order

Mathematical expression for pseudo-first-order suggested by Lagergren [19] is:

$$\ln(q_e - q_t) = \ln q_e - k_1 t \tag{11}$$

Table 3. Pseudo-first-order and pseudo-second-order reaction kinetics constants and ionic exchange values for zinc sorption on Amberlite IRA410.

C_0 (mg L^{-1})	$q_{e,exp}$ (mg g^{-1})	Pseudo-first-order			Pseudo-second-order		
		k_1 (min^{-1})	$q_{e,calc}$ (mg g^{-1})	R^2	k_2 (g mg^{-1} min^{-1})	$q_{e,calc}$ (mg g^{-1})	R^2
300	5.61	0.010	0.62	0.381	0.056	5.68	1
500	8.34	0.015	1.54	0.554	0.025	8.54	1
700	13.47	0.014	2.44	0.602	0.015	13.39	0.99
900	15.92	0.012	2.71	0.609	0.013	16.39	1
1100	19.31	0.017	5.05	0.655	0.008	20.00	1

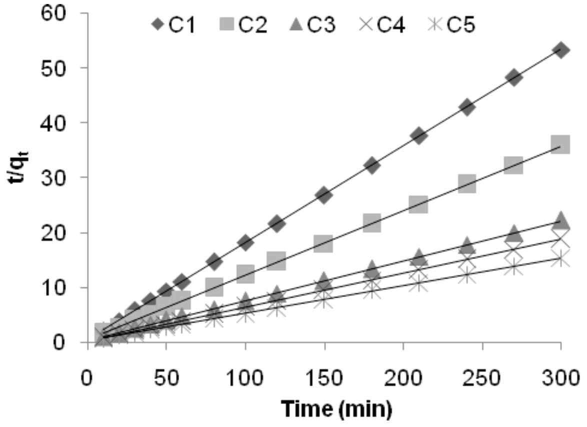

Figure 6. Plot of pseudo-second-order reaction kinetics models for zinc sorption on Amberlite IRA410; C1 = 300 mg L^{-1}, C2 = 500 mg L^{-1}, C3 = 700 mg L^{-1}, C4 = 900 mg L^{-1}, C5 = 1100 mg L^{-1}, m = 5 g, V = 100 mL, 500 rpm.

where, q_e and q_t (mg g^{-1}) are the amount of zinc adsorbed at equilibrium and time t (min); k_1 is the first-order rate constant (min^{-1}).

Pseudo-first-order parameters and correlation coefficients (R^2) obtained by plotting $\ln(q_e - q_t)$ *vs.* t are presented in Table 3. The correlation coefficients for the pseudo-first-order equation obtained for all the studied concentrations were low and calculated q_e values are very different from the experimental values. This suggests that pseudo-first-order cannot be used to describe the sorption process.

3.6.2. Pseudo-second order

The pseudo-second-order kinetic model proposed initially by Ho and McKay [19] is given by following equation:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \qquad (12)$$

where, k_2 is the second order rate constant (g mg^{-1} min^{-1}).

The values of pseudo-second-order equation parameters together with correlation coefficients calculated from the slope and intercept of t/q_t *vs.* t (Fig. 6) are given in Table 3. The high values of the correlation coefficients obtained and the fact that calculated q_e values are almost similar with the experimental values suggests that sorption of zinc ions on Amberlite IRA410 is best described by the pseudo-second-order model.

3.6.3. Intra-particle diffusion model

Several steps are involved in the sorption of a molecule by a sorbent. The first step is represented by the transport of the solute molecules from the aqueous phase to the surface of the solid particulates (bulk and liquid film diffusion) and the second step is diffusion of the solute molecules into the interior of the pores, which is usually a slow process [17].

The rate constant for intra-particle diffusion can be obtained from the Weber and Morris equation [17] and is given below:

$$q_t = k_{ip} t^{1/2} \qquad (13)$$

where, k_{ip} is the rate constant, mg g^{-1} min$^{-1/2}$.

It was observed that the data present multi-linear plots, Fig. 7a. The first region is represented by the external surface adsorption or instantaneous adsorption stage, the second region is the gradual adsorption stage, where intra-particle intercepts (diffusion is rate-controlling step and the third region is the equilibrium stage [21]). The rate coefficients k_{ip} (slope) and intercepts (0 intercept values indicate that diffusion is rate determining step), together with the correlation coefficients obtained by plotting q_t *vs.* $t^{1/2}$ are listed in Table 4.

The pore diffusion coefficient, D (cm^2 s^{-1}) for the sorption of zinc ions was also calculated using the following equation:

$$D = 0.003 \cdot \frac{r_0^2}{t_{1/2}} \qquad (14)$$

where, r_0 is the particle diameter (cm); $t_{1/2}$ is the time for half adsorption (s) and was estimated using the

Table 4. Intra-particule diffusion rate coefficients for zinc sorption on Amberlite IRA410 at different initial concentrations.

C_o (mg L^{-1})	D (cm^2 s^{-1})	Region 1 10-40 minutes k_{ip} (mg g^{-1} $min^{-1/2}$)	R^2	Region 2 40-100 minutes k_{ip} (mg g^{-1} $min^{-1/2}$)	R^2	Region 3 100-300 minutes k_{ip} (mg g^{-1} $min^{-1/2}$)	R^2
300	$8.14 \cdot 10^{-7}$	1.20	0.925	1.82	0.973	3.08	0.773
500	$5.28 \cdot 10^{-7}$	0.83	0.952	1.23	0.941	2.07	0.666
700	$5.39 \cdot 10^{-7}$	0.52	0.917	0.75	0.973	1.28	0.991
900	$5.62 \cdot 10^{-6}$	0.43	0.945	0.64	0.985	1.08	0.977
1100	$4.28 \cdot 10^{-6}$	0.37	0.979	0.53	0.999	0.89	0.929
Intercept values		3.73 – 9.24		4.89 – 14.3		5.47 – 18.06	

Table 5. Liquid film diffusion rate coefficients for removal of zinc on Amberlite IRA410 at different initial concentrations.

C_o (mg L^{-1})	k_{fd} (min^{-1})	Intercept	R^2
300	52.66	2.12	0.895
500	37.72	1.39	0.982
700	41.72	1.55	0.972
900	47.47	1.69	0.958
1100	33.69	1.08	0.933

following equation, based on the pseudo-second-order [22,23]:

$$t_{1/2} = \frac{1}{k_2 q_e} \tag{15}$$

Pore diffusion is assessed to be less significant due to relatively higher values of the coefficients, in contrast to the rate-limiting range (10^{-11} - 10^{-13} cm^2 s^{-1}) [22].

In case of zinc sorption on Amberlite IRA410, intercept values higher than 0 (Table 4) indicates that intra-particle transport is not the rate-determining step, but it could play an important role at low initial concentrations (small intercepts) [24].

3.6.4. External (film) diffusion

When the adsorption from the liquid to the solid phase is the rate determining step boundary plays the most significant role in adsorption; the liquid film diffusion model can be applied [17,24] as follows:

$$\ln(1-F) = -k_{fd} \cdot t \tag{16}$$

where, F is the fraction at equilibrium ($F = q_t/q_e$) and k_{fd} is the liquid film diffusion rate constant (min^{-1}).

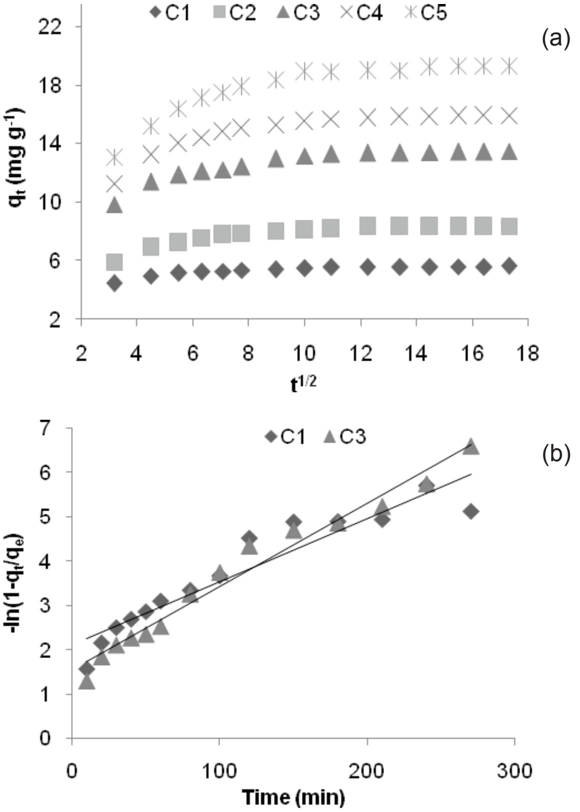

Figure 7. Plots of the intra-particle (a) and film diffusion (b) models for zinc sorption on Amberlite IRA410; C1 = 300 mg L^{-1}, C2 = 500 mg L^{-1}, C3 = 700 mg L^{-1}, C4 = 900 mg L^{-1}, C5 = 1100 mg L^{-1}, m = 5 g, V = 100 mL, 500 rpm.

The rate coefficients k_{fd}, and intercepts, together with the correlation coefficients are listed in Table 5. Analysing the values obtained (Fig. 7b) it can be concluded that neither liquid film diffusion is rate-determining step (intercept values are higher than zero) [24] although plays an important role during the process.

4. Conclusions

A series of anionic exchangers resins were tested for the zinc removal (as chloride anion complexes). The following series was depicted based on removal efficiencies: Amberlite IRA410 > Purolite A103S > Purolite NRW700 > Purolite A400MBOH. An increase of removal efficiency with an increase of stirring rate (limitation of external diffusion influence), resin quantity (increase of the number of sorption sites available) and zinc initial concentration (mass transfer intensified due to an increased concentration difference between solid and liquid phase) was observed.

Experimental data fitted well on the considered isotherm models, suggesting that the sorption process is a very complex one, out of which Freundlich and Dubinin-Radushkevich isotherm models had the highest regression value and hence the best fit. The parameter predicted from the Freundlich isotherm suggests the heterogeneity of the surface of the Amberlite IRA410 resin, while the Dubinin-Radushkevich isotherms indicate a physisorption process. The characteristic parameters for each isotherm and related correlation coefficients have been presented in detail. The kinetics of zinc sorption onto Amberlite IRA410 studied using various models, suggested that the considered sorption process is better described by the pseudo-second-order kinetic model.

According to the obtained results it can be concluded that Amberlite IRA410 is a good ionic exchanger for removal of zinc ions as zinc chloride complexes from strong acidic solutions.

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