

Adsorptive Removal of Al, Zn, Fe, Cr and Pb from Hydrogen Peroxide Solution by IR-120 Cation Exchange Resin

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ABSTRACT: Adsorption of cations Al, Zn, Fe, Cr and Pb from aqueous solution of hydrogen peroxide using IR-120 cation-exchange resin was studied. The removal percentage of the cations was examined by varying experimental conditions (such as pH of the hydrogen peroxide solution, temperature, contact time and dosage of adsorbent) in a stirred-batch system. Under the optimal conditions (pH=1, T=25°C, contact time=150 min, adsorbent dosage=5g), it was found that more than 98% removal was achieved. The cations adsorption was studied on the basis of Langmuir, Freundlich and linear isotherms in the concentration range of 0-50 mg/L. Adsorption of the cations on the resin followed first-order, pseudo-first-order (Lagergren) and intraparticle diffusion kinetic models in the cations range of 10-20 mg/L. The best fitted model for kinetic model was obtained as Lagergren model. The obtained studies showed that IR-120 cation-exchange resin was successfully used as an efficient adsorbent for removal of the cations from aqueous solution of hydrogen peroxide.

KEY WORDS: Adsorption isotherms; Adsorption kinetics; IR-120 Cation exchange resin; Hydrogen peroxide.

INTRODUCTION

High purity Hydrogen Peroxide (HP) is used in the electronic industry for cleaning of germanium and silicon semiconductor wafers and etching printed circuit boards. With the rapid development of electronic and semiconductor applications, the demand for HP with high purity and total cationic impurity levels below 10 µg/L is increased [1]. Depend on equipments and production methods used, various cationic impurities are entered into the industrial grade of HP [2]. These are: Al, Zn, Fe, Cu, Mn, Ni, As, Ti, Pb and Cr. Industrial or commercial

grade of HP solutions does usually not contain all the cations. It usually contains some of them.

Luan *et al.* reviewed different methods for removal of cations from HP solution. They concluded the methods can not remove the cations, lonely. The combination of the methods may remove the cations. Cation exchange resin is usually used in the all combinative methods due to high removal efficiency, simplicity and easy operation [3].

In ion-exchange systems, polymeric resins are usually employed [4-7]. In the present study, Amberlite IR-120

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Table 1: Characteristics properties of IR-120 cation exchange resin (information provided by the manufacturer)

Characteristics	Values
Physical form	Amber beads
Shipping weight	833 kg/m ³
Color	yellow
Harmonic mean size	0.6 to 0.8 mm
Uniformity coefficient	1.9 maximum
Screen analysis	3% maximum on 16 mesh, 2% maximum through 50 mesh
Matrix	Styrene divinylbenzene copolymer
Functional groups	Sulphonic acid
Ionic form, as shipped	Sodium
Total exchange capacity	2.0 meq/ml minimum (Na ⁺ form)
Moisture holding capacity	45 to 50% (Na ⁺ form)
Ionic conversion	Na ⁺ →H ⁺ : approximately 10%

cation-exchange resin was used for removal of Al, Zn, Fe, Cr and Pb from aqueous solution of HP. The parameters that influenced on adsorption were investigated. The main objective of this study was to investigate the equilibrium and kinetic parameters of this ion-exchange resin for removal of the mentioned cations from HP solution. The obtained results will be useful for design, scale up and fabrication of HP purification plant.

THEORITICAL SECTION

The concentration of the cations on the resin is calculated as the difference between the initial concentration in the solution and the concentration in solution, after contact or at equilibrium time. The mass balance may be expressed as:

$$m(q_{i,e} - q_{i,o}) = V(C_{i,o} - C_{i,e}) \quad (1)$$

and $q_{i,o} = 0$; therefore,

$$q_{i,e} = \frac{V(C_{i,o} - C_{i,e})}{m} \quad (2)$$

in which

m : the mass of adsorbent

$q_{i,e}$: equilibrium concentration of cation i on adsorbent

$q_{i,o}$: initial concentration of cation i on adsorbent

V : the solution volume

$C_{i,o}$: solution phase concentration of cation i at initial state

$C_{i,e}$: solution phase concentration of cation i at equilibrium state

EXPERIMENTAL SECTION

Materials

Cation-exchange resin IR-120 (purchased from Rohm and Haas Co.) was used in this study. Physical properties and specifications of the resin as reported by the supplier are shown in Table 1. Prior to use, the resin was washed by deionized water to remove possible organic and inorganic impurities. A hydrogen peroxide solution (35% wt) containing Al, Zn, Fe, Cr and Pb cations was used as feed in all experiments.

Procedure and analysis

In order to change Na⁺ form of resin to H⁺ form, the resin was washed with a strong acid (such as HCl solution). H⁺ form cation exchange IR-120 resin was washed with deionized water to remove all the excess acid [8]. Na⁺ will be exchanged with H⁺ in the resin.

To determine the optimum conditions for purifying industrial grade of HP solution by Amberlite IR-120 resin, certain amounts of industrial HP solution and Amberlite IR-120 resin were mixed in a glass bottle. The solutions were agitated for predetermined period in a shaking incubator (Heidolph Co.). The resin was separated and the filtrate was analyzed by an inductively coupled plasma spectrometer (Varian Vista ICP-AES) for the cations contents.

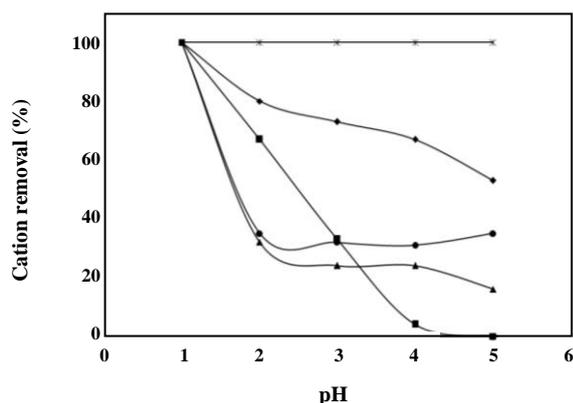


Fig. 1: Effect of pH on removal of Al, Zn, Fe, Cr and Pb from HP solution by ion exchange resin IR-120: -*-Pb, -♦-Al, -■-Zn, -●-Cr, -▲-Fe (Conditions: $T=25^{\circ}\text{C}$, agitation time = 1 h, resin dosage = 5 mg/100 mL, $C_{Al,0}=0.15\text{ppm}$, $C_{Zn,0}=0.03\text{ppm}$, $C_{Fe,0}=0.12\text{ppm}$, $C_{Cr,0}=0.13\text{ppm}$, $C_{Pb,0}=0.14\text{ppm}$).

The pH of the solution was adjusted by using 0.1N dilute sodium hydroxide solutions. The solution pH was determined by pH meter (model CG819, Schott Gerate Co.).

Adsorption isotherm and kinetic studies were carried out with different initial concentrations of the cations while maintaining the resin dosage at a constant level. In order to correct for any adsorption of Al, Zn, Fe, Cr and Pb on the container surface, control experiments were carried out in the absence of resins. These experiments indicated that no adsorption by the container walls was detectable.

RESULTS AND DISCUSSION

Preliminary tests showed that pH, temperature, agitation time (or contact time) and resin dosage were the effective parameters on adsorption of the cations on cation exchange resin IR-120.

Effect of pH on adsorption

The pH of a solution is an important parameter affecting on adsorption processes because of pH dependency of complexation reactions and electrostatic interactions at the adsorbent surface [9]. The effect of pH on the cations adsorption was investigated in pH range of 1–5 by addition of NaOH or HCl (Fig. 1).

It should be noted that the removal efficiency decreases with increasing pH and shows a maximum removal value at pH=1. This is due to the fact that the hydrogen atoms in the hydroxyl groups of sulfonic acid

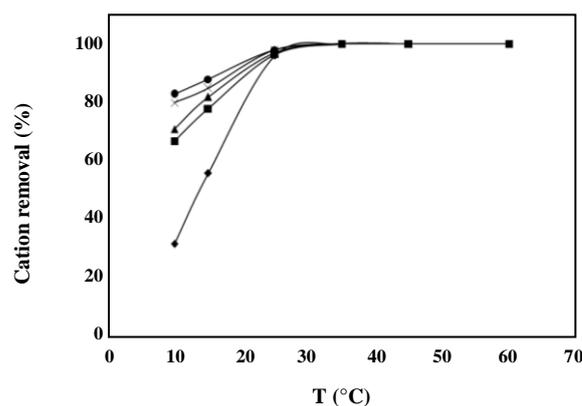


Fig. 2: Effect of temperature on adsorption of Al, Zn, Fe, Cr and Pb from HP solution by ion exchange resin IR-120: -♦-Zn, -■-Cr, -▲-Pb, -x-Al, -●-Fe (Conditions: pH=1, agitation time = 1 h, resin dosage = 5 mg/100 ml, $C_{Al,0}=0.15\text{ppm}$, $C_{Zn,0}=0.03\text{ppm}$, $C_{Fe,0}=0.12\text{ppm}$, $C_{Cr,0}=0.13\text{ppm}$, $C_{Pb,0}=0.14\text{ppm}$).

are replaceable by the cations and form stable complexes with Al, Zn, Fe, Cr and Pb. At higher pH, the negatively charged sulfonic acid surface sites do not favor the adsorption of Al, Zn, Fe, Cr and Pb oxyanions due to electrostatic repulsion. Conclusively, IR-120 resin is more effective for the removal of Al, Zn, Fe, Cr and Pb at lower solution pH. This phenomenon was observed by Hu [10]. Of course, it is necessary to pointed that high pH will lead to more decomposition of HP. So it is preferred to conduct the experiments at lower pH values.

Effect of temperature

Effect of temperature on the cations uptake was investigated by varying the temperature of the solution at pH=1. The data in Fig. 2 shows that the adsorption capacity increases with increasing temperature to a plateau which represents the maximum adsorption capacity of the resin. However, HP solution will be decomposed dramatically when the temperature is arised. Hence, in the subsequent studies, experiments were performed at 25 °C.

Effect of agitation time

The feed solution in contact with IR-120 resin was mixed by a stirrer at high agitation speeds. Agitation time or contact time varied in the range 0–230 min. Fig. 3 shows the effect of agitation time on the removal of Al, Zn, Fe, Cr and Pb by IR-120 cation-exchange resin.

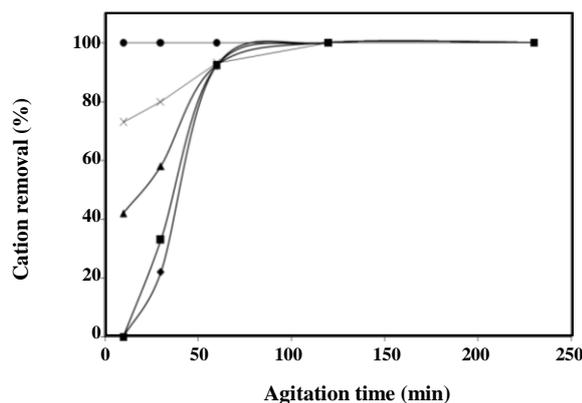


Fig. 3: Effect of agitation time on the adsorption of Al, Zn, Fe, Cr and Pb from HP by ion exchange resin IR-120: -◆-Cr, -■- Zn, -▲-Fe, -×-Al, -●-Pb (Conditions: pH=1, resin dosage = 5 mg/100 ml, T= 25°C, $C_{Al,0}=0.15\text{ppm}$, $C_{Zn,0}=0.03\text{ppm}$, $C_{Fe,0}=0.12\text{ppm}$, $C_{Cr,0}=0.13\text{ppm}$, $C_{Pb,0}=0.14\text{ppm}$).

The removal amount of the cations increased rapidly during the first few minutes, and then increased slowly until the equilibrium state was reached.

The initial adsorption rate was very high, and this may be due to the greater number of resin sites available for the adsorption of cations. With decrease in the remaining vacant surface sites, the adsorption rate slowed down due to the formation of repulsive forces among the cations on the solid surface and in the liquid phase.

Removal of Al, Zn, Fe, Cr and Pb cations was increased with time and attained equilibrium at 10 min for Pb, 120 min for Al, 120 min for Fe, 90 min for Zn and 80 min for Cr. The curves of cation removal versus time were single, smooth and continuous indicating monolayer adsorption of the cations on the surfaces of the IR-120 resin [11].

Effect of resin dosage on adsorption

The resin dosage was varied from 0 to 25 g/100 mL and equilibrated for 1 h. Fig. 4 represents the removal of Al, Zn, Fe, Cr and Pb as a function of IR-120 resin dosage in a solution at pH= 1. The removal percent of Al, Zn, Fe, Cr and Pb was enhanced by increasing the resin dosage. Cations removal is nearly the same by using the resin. So, the curves have been overlapped.

Results showed that for the quantitative removal of the cations from 100 ml solution, a minimum resin dosage of 4 mg was required. The results also clearly indicated that the removal efficiency increases up to

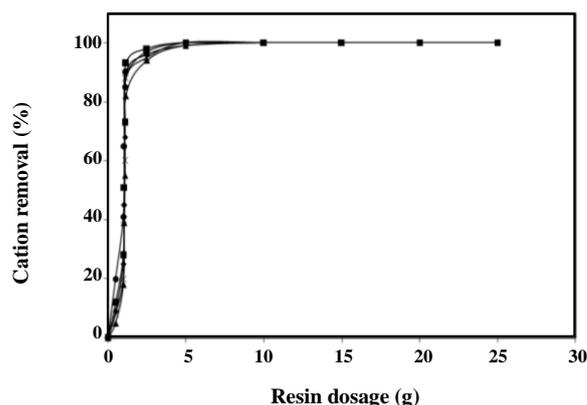


Fig. 4: Effect of the resin dosage on the adsorption of Al, Zn, Fe, Cr and Pb from HP by ion exchange resin IR-120: -▲- Zn, -×-Cr, -◆-Pb, -■-Al, -●-Fe (Conditions: pH=1, T= 25°C, agitation time = 1h, $C_{Al,0}=0.15\text{ppm}$, $C_{Zn,0}=0.03\text{ppm}$, $C_{Fe,0}=0.12\text{ppm}$, $C_{Cr,0}=0.13\text{ppm}$, $C_{Pb,0}=0.14\text{ppm}$).

the optimum dosage beyond which the increase in removal efficiency is negligible. It is apparent that the equilibrium cation concentration decreases with increasing resin dosage for a given initial cation concentration. This is to be expected because, at a fixed initial solute concentration, increasing the adsorbent doses provides greater surface area or adsorption sites.

Adsorption isotherm

Adsorption data are usually described by adsorption isotherms, such as the linear, Langmuir and Freundlich isotherms. These isotherms relate cation uptake per unit weight of adsorbent q_e to the equilibrium adsorbate concentration in the bulk fluid phase C_e . The linear model describes accumulation of solute by sorbent as directly proportional to the solution concentration:

$$q_{i,e} = K_{D,i}C_{i,e} \quad (3)$$

The constant of proportionality or distribution coefficient $K_{D,i}$ is often referred to as the partition coefficient for cation i .

The Langmuir model represents one of the first theoretical treatments of non-linear sorption, and has been successfully applied to a wide range of systems that exhibit limiting or maximum sorption capacities. The model assumes uniform energies of adsorption onto the surface and no transmigration of the adsorbate in the plane of the surface. The Langmuir isotherm is given by:

$$q_{i,e} = \frac{(Q_i b_i C_{i,e})}{(1 + b_i C_{i,e})} \quad (4)$$

where Q_i and b_i are Langmuir constants related to adsorption capacity and energy of adsorption for component i , respectively. Equation (4) is usually linearised by inversion to obtain the following form:

$$\frac{1}{q_{i,e}} = \frac{1}{Q_i} + \frac{1}{b_i Q_i} \times \frac{1}{C_{i,e}} \quad (5)$$

Equation (5) is used to analyze batch equilibrium data by plotting $1/q_{i,e}$ versus $1/C_{i,e}$, which yields a linear plot if the data conform to the Langmuir isotherm.

The Freundlich isotherm is the most widely used non-linear sorption model and given by the general form:

$$q_{i,e} = K_{F,i} C_{i,e}^n \quad (6)$$

Where $K_{F,i}$ relates to sorption capacity and n to sorption intensity. The logarithmic form of Eq. (6) is usually used to fit data from batch equilibrium studies:

$$\log q_{i,e} = \log K_{F,i} + n \log C_{i,e} \quad (7)$$

Equations (3), (5) and (7) are usually used for the analysis of equilibrium batch experiment data assuming the validity linear, Langmuir and Freundlich isotherms, respectively [12-14].

Figs. 5, 6 and 7 present the linear, Langmuir and Freundlich isotherm plots for the adsorption of mentioned cations on the ion exchange resin.

The equilibrium data was fitted very well to all three sorption isotherms in the concentration range. These plots were used to calculate the isotherm parameters given in Table 2 for all the cations. As it is shown, Zn, Fe, Al and Pb cations are fitted well by linear isotherm. However, Cr cation is fitted well by Langmuir isotherm.

Experiments for studying the adsorption kinetics were carried out at 25°C and at higher agitation speeds (for example at least 400rpm) in order to minimize the effect of bulk diffusion and film diffusion on the adsorption process.

Kinetics models

First-order adsorption kinetic model

Experiments were directed at an attempt to understand the kinetics of the removal by the IR-120 resin. It is a well-established fact that the adsorption of cations

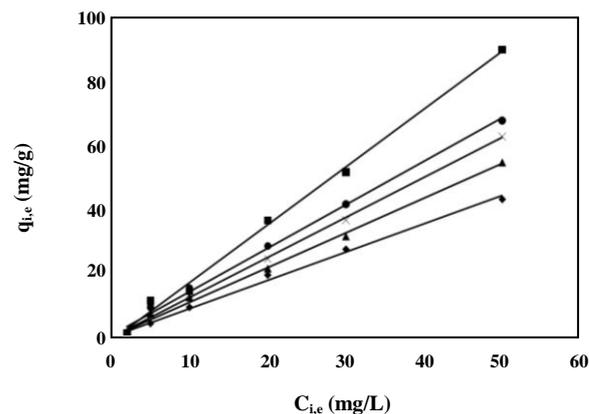


Fig. 5: Linear isotherm plot for the adsorption of the cations on IR-120 cation exchange resin (-♦-Cr, -▲-Fe, -×-Al, -●-Pb, -■-Zn).

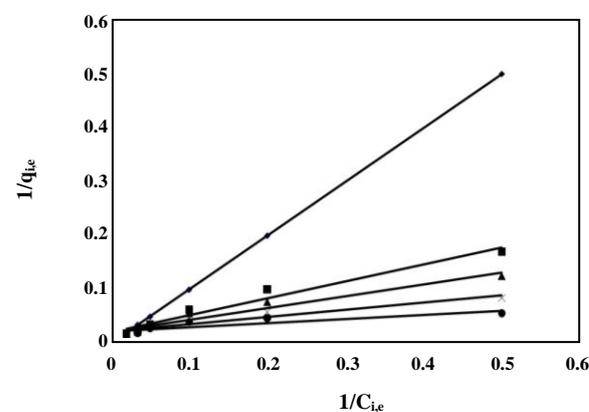


Fig. 6: Langmuir isotherm plot for the adsorption of the cations on IR-120 cation exchange resin (-●-Pb, -×-Al, -▲-Fe, -■-Zn, -♦-Cr).

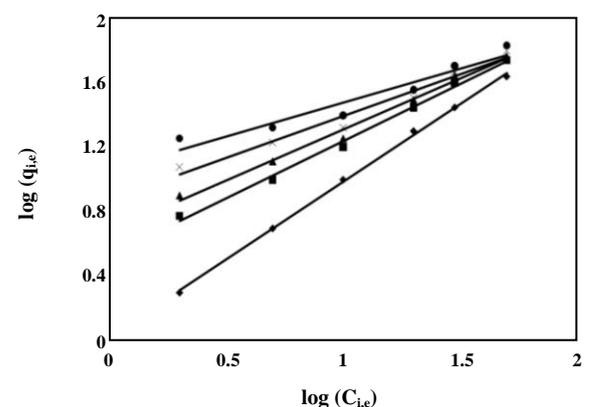


Fig. 7: Freundlich isotherm plot for the adsorption of the cations on IR-120 cation exchange resin (-♦-Cr, -■-Zn, -▲-Fe, -×-Al, -●-Pb).

Table 2: Isotherm parameters for the adsorption of the cations on IR-120 ion exchange resin.

Cation	Linear		Langmuir			Freundlich		
	$K_{D,i}(1/g)$	R^2	$Q_i(mg/g)$	$b_i(1/g)$	R^2	$K_{F,i}$	n	R^2
Cr	0.866	0.970	1000	0.0010	0.999	1.05681	0.963	0.990
Zn	1.088	0.990	47.619	0.0675	0.970	3.3962	0.707	0.980
Fe	1.241	0.990	45.454	0.1009	0.980	4.7973	0.630	0.965
Al	1.347	0.990	45.454	0.1670	0.980	7.4817	0.518	0.960
Pb	1.795	0.999	45.454	0.2894	0.980	11.4025	0.420	0.960

in an aqueous system follows reversible first-order kinetics, when a single species is considered on a heterogeneous surface [11]. It must be remembered that the two important physico-chemical aspects for parameter evaluation of the sorption process, as a unit operation, are the kinetics and the equilibria of the system. The kinetic of sorption describing the solute uptake rate which, in turn, governs the residence time of the sorption process is one of important characteristics that defines the sorption efficiency. Hence, in the present study, the kinetics of the cations removal was carried out to understand the behavior of this adsorbent.

The sorption of a cation from liquid phase to solid phase may be expressed as:



in which $M_{(aq)}$ and $M_{(ad)}$ are cation concentration in aqueous phase and cation concentration in adsorbed phase, respectively. Also, $K_{C,i} = (k_{i,1}/k_{i,2})$ in which $k_{i,1}$ is the forward rate constant and $k_{i,2}$ the backward rate constant for cation i .

If a_i is the initial concentration of the cation i and x_i the amount transferred from liquid phase to solid phase for cation i at any time t , then

$$-r_i = \frac{-d(a_i - x_i)}{dt} = k_i(a_i - x_i) \quad (9)$$

or

$$k_i = \left(\frac{1}{t}\right) \ln\left(\frac{a_i}{a_i - x_i}\right) \quad (10)$$

where k_i is the overall adsorption rate constant. Since $k_{i,1}$ and $k_{i,2}$ are the rate constants for the forward and reverse process, the rate can be expressed as:

$$\frac{dx_i}{dt} = k_{i,1}(a_i - x_i) - k_{i,2}x_i \quad (11)$$

If $X_{i,e}$ represents the concentration of cation i adsorbed at equilibrium, then at equilibrium, $k_{i,1}(a_i - X_{i,e}) - k_{i,2}X_{i,e} = 0$, because under these conditions:

$$\frac{dx_i}{dt} = 0 \quad \text{or} \quad K_{C,i} = \frac{X_{i,e}}{a_i - X_{i,e}} = \frac{k_{i,1}}{k_{i,2}} \quad (12)$$

where $K_{C,i}$ is the equilibrium constant. Now by considering the equilibrium conditions, the rate becomes:

$$\frac{dx_i}{dt} = [k_{i,1}(a_i - x_i) - k_{i,2}x_i] - [k_{i,1}(a_i - X_{i,e}) - k_{i,2}X_{i,e}] \quad (13)$$

$$\frac{dx_i}{dt} = (k_{i,1} + k_{i,2})(X_{i,e} - x_i) \quad (14)$$

Eq. (14) is in the form $\frac{dx_i}{dt} = k_i(a_i - x_i)$. Therefore,

$$k_{i,1} + k_{i,2} = \left(\frac{1}{t}\right) \ln\left(\frac{X_{i,e}}{X_{i,e} - x_i}\right) \quad (15)$$

$$\ln\left(\frac{1}{1 - \left(\frac{x_i}{X_{i,e}}\right)}\right) = (k_{i,1} + k_{i,2})t \quad (16)$$

$$-\ln\left(1 - \frac{x_i}{X_{i,e}}\right) = (k_{i,1} + k_{i,2})t \quad (17)$$

Equation (17) can be written in the form:

$$\ln(1 - U_{i,t}) = -(k_{i,1} + k_{i,2})t = -k_i t \quad (18)$$

where $U_{i,t} = \frac{x_i}{X_{i,e}}$ and k_i the overall rate constant.

Further,

Table 3: Rate constants for the removal of the cations with IR-120 cation exchange resin by first-order adsorption kinetic model at initial cations concentrations of 15 mg/L.

Cation	Overall rate constant $k_t=k_{i,1}+k_{i,2}(\text{min}^{-1})$	Forward rate constant, $k_{i,1}(\text{min}^{-1})$	Backward rate constant, $k_{i,2}(\text{min}^{-1})$	R ²
Cr	0.036	0.0355	0.0005	0.986
Zn	0.054	0.0534	0.0006	0.982
Fe	0.107	0.1062	0.0008	0.989
Al	0.144	0.1432	0.0008	0.991
Pb	0.180	0.1791	0.0009	0.985

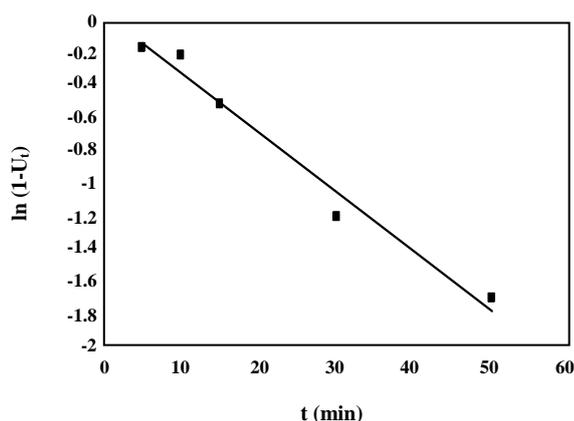


Fig. 8: First-order adsorption kinetic fit for the adsorption of Cr on IR-120 ion exchange resins ($C_{0, Cr} = 15 \text{ mg/L}$).

$$k_i = k_{i,1} + k_{i,2} = k_{i,1} + \frac{k_{i,1}}{K_{C,i}} = k_{i,1} \left(1 + \frac{1}{K_{C,i}}\right) \quad (19)$$

where $U_{i,t}$ can be calculated using the expression:

$$\frac{C_i(o) - C_i(t)}{C_i(o) - C_i(e)} = \frac{x_i}{X_{i,e}} = U_{i,t} \quad (20)$$

$C_{i(o)}$ is the initial concentration of cation i (mg/L), $C_{i(t)}$ the concentration of the cation present at any time t (mg/L), $C_{i(e)}$ the concentration of the cation present at equilibrium condition (mg/L). $U_{i,t}$ is called the fractional attainment of equilibrium of the cation and is calculated by considering the cation adsorption over the resin in a given time range 200 minutes.

In the present study, a concentration of the cations over the range 10–20 mg/L was examined. Using the kinetic equations, the overall rate constant, the forward and backward rate constants were calculated. Since the plots are similar in general schematic for all cations, so one sample is given for Cr cation in Fig. 8. By plotting

$\ln(1-U_{Cr,t})$ versus t , the overall rate constant k_{Cr} for a given concentration of Cr was calculated by considering the slope of straight line in Fig. 8. Using Eqs. (12) and (18), the equilibrium constant $K_{C, Cr}$, forward and backward rate constants $k_{1, Cr}$ and $k_{2, Cr}$ were calculated, as shown in Table 3. From Table 3, it can be seen that the forward rate constants for the removal of the cations were much higher than the backward rate constants, namely the desorption process.

Pseudo-first-order adsorption kinetic model

The rate constant of adsorption can also be determined from the following pseudo first-order rate expression given by Lagergren & Svenska [11]. The differential equation is as follows:

$$\frac{dq_i}{dt} = k_{ad,i} (q_{i,e} - q_i) \quad (21)$$

Integrating Eq. (21) for boundary conditions $t = 0$, $q_i = 0$ to $t = t$ and $q_i = q_i$, gives:

$$\log\left(\frac{q_{i,e}}{q_{i,e} - q_i}\right) = \left(\frac{k_{ad,i}}{2.303}\right)t \quad (22)$$

Which is the integrated rate law for pseudo-first-order reaction, Eq. (22) can be rearranged to obtain a linear form:

$$\log(q_{i,e} - q_i) = \log q_{i,e} - \left(\frac{k_{ad,i}}{2.303}\right)t \quad (23)$$

Where q_i and $q_{i,e}$ are amounts of cation i adsorbed (mg/g) at time t (min) and at equilibrium, respectively. $k_{ad,i}$ is the rate constant for adsorption (1/min).

For different cations concentrations, the straight line plot of $\log(q_{i,e} - q_i)$ versus t indicates the applicability of Eq.(23). As it was before stated, since the plots are similar

Table 4: Lagergren rate constants and intraparticle diffusion values for different initial concentrations of the cations at initial cations concentrations of 15 mg/L.

Cation	Lagergren rate constant, k_{ad} (min^{-1})	R^2 for Lagergren kinetic model	Intraparticle rate k_{id} ($\text{mg/g min}^{0.5}$)	R^2 for intraparticle kinetic model
Cr	0.035	0.993	0.437	0.982
Zn	0.055	0.995	0.585	0.994
Fe	0.108	0.997	0.695	0.986
Al	0.145	0.995	0.738	0.980
Pb	0.182	0.999	0.898	0.985

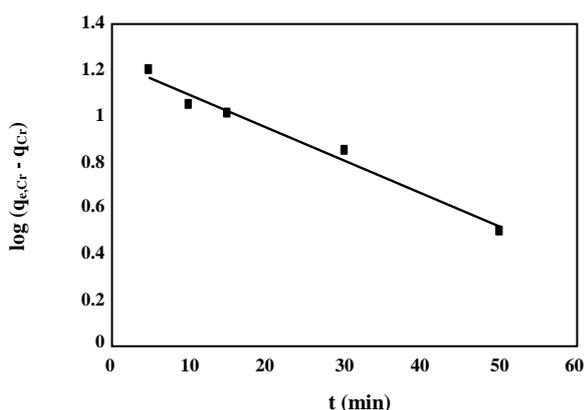


Fig. 9: Lagergren plot for the adsorption of the Cr on IR-120 cation exchange resin ($C_{0,Cr} = 15 \text{ mg/L}$).

in general schematic for all cations, so one sample is given for Cr cation in Fig. 9.

The values of $k_{ad,i}$ were calculated from the slope of the linear plots and are presented in Table 4.

Intraparticle diffusion model

The rate constant for intraparticle diffusion ($k_{id,i}$) is given by *Weber & Morris* [15]:

$$q_i = k_{id,i} t^{0.5} \quad (24)$$

where q_i is the amount of adsorbed cation (mg/g) at time t (min). Plots of q_i versus $t^{0.5}$ are shown in Fig. 10 for Cr cation. The plots for other cations are similar to Cr cations in schematic form. So, the graph is given for Cr cation.

As it is shown, the initial curved portion followed by linear portion to the intraparticle diffusion and the plateau to the equilibrium. k_{id} values were obtained from the slope of the linear portion of the curves for each concentration of cation (Table 4). The value for k_{id}

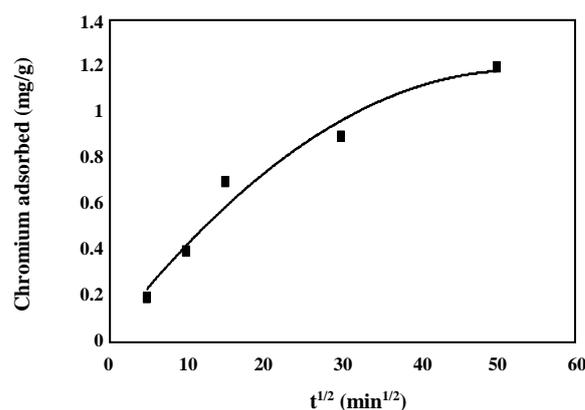


Fig. 10: Intraparticle diffusion plots for the adsorption of Cr on IR-120 cation exchange resin ($C_{0,Cr} = 15 \text{ mg/L}$).

was higher at higher concentration. As it is shown in Table 3 and Table 4, the kinetic data are fitted well by Lagergren kinetic model.

CONCLUSIONS

IR-120 cation exchange resin was used in treatment of hydrogen peroxide contaminated with Al, Zn, Fe, Cr and Pb cations. The results showed that the resin can efficiently remove traces of the all cations present in aqueous hydrogen peroxide solution. Under the optimal conditions ($\text{pH}=1$, $T=25^\circ\text{C}$, contact time=150 min, adsorbent dosage=5g), it was found that more than 98% removal was achieved. Equilibrium removal by the resin followed Freundlich, Langmuir and linear adsorption isotherms. The kinetics of the cations adsorption by the resin followed first-order, pseudo-first-order (Lagergren) and intraparticle diffusion models. The low value of k_2 (desorption process) indicates that the adsorbed cations are relatively stable on the adsorbent. The adsorption of the cations on the resin showed the Lagergren model as the best kinetic model.

It should be considered that the initial concentration of the cations in hydrogen peroxide must be less than 0.2 ppm, because higher concentrations decomposes hydrogen peroxide catalytically and in turn changes (or lowers) simultaneously the hydrogen peroxide concentration. So the largest limitation in this research is working with the metal concentrations less than 0.2 ppm. This is the most important limitation in this research.

The results of this investigation will be applicable in design of purification unit for hydrogen peroxide used in electronic industries. Also, it will be applied for hydrogen peroxide storage in any military and civil industries. It is recommended the future research on the scale up of process, study on hydrogen peroxide purification in continuous process, modeling the regeneration of ion exchange resin and etc.

Nomenclature

a_i	Initial concentration of the cation i , mg/L
b_i	Langmuir constant related to energy of adsorption for component i , L/mg
$C_{i,e}$	Solution phase concentration of cation i at equilibrium, mg/L
$C_{i,o}$	Solution phase concentration of cation i at initial state, mg/L
$C_{i(o)}$	Initial concentration of cation i , mg/L
$C_{i(t)}$	Concentration of cation i present at any time t , mg/L
$C_{i(e)}$	Concentration of cation i present at equilibrium condition, mg/L
HP	Hydrogen peroxide
$k_{i,1}$	Forward rate constant for cation i in first-order adsorption kinetic model, min^{-1}
$k_{i,2}$	Backward rate constant for cation i in first-order adsorption kinetic model, min^{-1}
k_i	Overall adsorption rate constant, min^{-1}
$k_{ad,i}$	Adsorption rate constant in Lagergren and Svenska, min^{-1}
$k_{id,i}$	Rate constant for intraparticle diffusion for cation i , $\text{mg g}^{-1} \text{min}^{0.5}$
$K_{C,i}$ [-]	Equilibrium constant
$K_{D,i}$	Constant of proportionality or distribution coefficient for cation i , L/g
$K_{F,i}$	Freundlich constant, mg/g
m	The mass of adsorbent, g
n	Freundlich constant, -

$q_{i,e}$	Equilibrium concentration of cation i on adsorbent, mg/g
$q_{i,o}$	Initial concentration of cation i on adsorbent, mg/g
q_i	Concentration of cation i on adsorbent, mg/g
Q_i	Langmuir constant related to adsorption capacity for component i , mg/g
t	Time, min
$U_{i,t}$	Fractional attainment of equilibrium of cation i at any time t , -
V	The solution volume, L
x_i	Amount transferred from liquid phase to solid phase for cation i at any time t , mg/L
$X_{i,e}$	Concentration of cation i adsorbed at equilibrium, mg/L

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