



Kinetics investigation of uranium sorption from alkaline solutions of Calcareous Shale, Um Bogma formation, G. Allouga, Southwestern Sinai, Egypt by Lewatit resin in batch system

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ABSTRACT

Experimental and theoretical studies of the sorption kinetics of uranium carbonate anion from its alkaline solution obtained from um Bogma dissolve liquor on the strong base anion exchange Lewatit Mono Plus M500 (LMP) sorbent was achieved using batch technique. The experimental results using the latter technique were fitted well with pseudo second-order kinetics model. The dependence of the sorption kinetic parameters on the temperature of the solution has been investigated. The pH of solution and agitation speed have dramatic effects on the uptake of uranium carbonate anion by LMP. It was found that pH range from 8.5–9.5 and agitation speed of 300 rpm. The proper conditions for uranium carbonate anion sorption at the present experimental. The fit of experimental data with the homogeneous diffusion model (HDM) equations demonstrated the possibility of using this model for adequate description of the uranium sorption kinetics on the LMP sorbent. Two stages of adsorption with different controlling processes were proposed. Liquid film diffusion controls the process at the early stage of the adsorption followed by matrix diffusion which controls the process in the final stage. Two different equations were used to express each stage.

Keywords: Uranium, Sorption, Um Bogma, Kinetics, Lewatit.

1. Introduction

Uranium is a relatively rare metal element which is often found in association with other elements in the earth's crust. It is the main source to generate the power economically for rapid growth of electricity generation to fulfill the country's ever increasing demands (Fereshte *et al.*, 2017). The sedimentary rocks of Um Bogma Formation, at Gabel Allouga, southwestern Sinai, Egypt, was found to be favorable for uranium mineralization together with some important economic elements. It is located between latitudes 29° 00' 00" and 29° 04' 00" N and longitudes 33° 22' 00" and 33° 27' 00" E (Afifi *et al.*, 2017). Several leaching studies have been performed upon Allouga ore materials. Mahdy *et al.* (2011) and Mahdy *et al.* (1988), have studied the leaching characteristics of both U and Cu from a siltstone ore from the Allouga area. They concluded that both metal values could be almost completely leached by mineral acid under mild agitation or percolation leaching conditions. In the meantime, carbonate leaching of U proved successful separation of U from Cu during the leaching step. The mechanism of leaching behavior of uranium from black carbonaceous shale ore of Allouga area of southwestern Sinai in sodium carbonate/sodium bicarbonate solutions has been briefly studied by Demerdash, (2016). The leaching kinetics studied as a function of alkali concentrations, temperature, particle size and agitation speed indicated that about 89 % of uranium value can be leached under optimum process conditions (Demerdash, 2016).

Ion exchange process was proposed for treating the liquor prepared from the alkaline dissolution of Um Bogma sample in order to separate uranium from other deleterious impurities. However, the application of these systems on industrial scale equipment using fixed column or fluidized bed technology requires a knowledge of the equilibrium and kinetics of the metal extraction processes and the operating hydrodynamic behavior. So, the present work aimed to study the sorption of uranium from alkaline medium solution using the strong base anion exchange Lewatit Mono Plus M500 (LMP)

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resin. Batch shaking sorption experiments were carried out to evaluate the performance of (LMP) anion exchange resin for the uranium adsorption. The adsorption parameters including contact time, pH, initial uranium concentration and temperature have actually been optimized. The determination of kinetic parameters has two objectives: (i) to approach, as accurately as possible, the real physical chemistry of the metal extraction process and (ii) to get an empirical or semi empirical equations for the design of the equipment's. So, this study is aimed to investigate the sorption kinetics of uranium carbonate anion from um Bogma leaching solution using LMP sorbent. Although the kinetics of adsorption of different metals on LMP has extensively been investigated, where the adsorption of uranium carbonate anion on LMP remain limited. For this purpose, homogeneous diffusion model will be examined to simulate the adsorption process of uranyl carbonate anion on LMP resin to attain more knowledge about the mechanism, equilibrium and kinetics of the adsorption process of uranium.

2. Experimental

2.1. Adsorbent characteristics and methods

I. The adsorbent

The polystyrene-DVB-based anion exchanger Lewatit MP L500 (LMP) was applied for the experiments. LMP is a strongly basic, macroreticular anion exchange resin, which derives its exchange activity from the present quaternary ammonium groups. The large fixed porosity of the resin bead structure permits the high adsorptive capacity for large molecules. This resin has high capacity and excellent regeneration efficiency. The resins were preconditioned by repeated treatment with HCl and NaOH solutions to remove any available impurities. After pretreatment, fractions of particle diameters in the range from 0.5–0.7 mm was sieved out for kinetics studies. For equilibrium and kinetic experiments, a certain amount of the resin was centrifuged for 30 min with 1000-fold of g to strip off water adhering at the surface of the beads. The quantities required for each individual experiment were weighed from this issue.

II. Adsorbate characterization

The alkaline dissolution of Black Carbonaceous shale, of um Bogma Formation in G. Allouga at Southwestern Sinai using a mixture of 1 M sodium carbonate/0.1 M sodium bicarbonate solution under the optimum conditions developed by Demerdash, (2016) results in a leaching carbonate solution. The latter was analyzed resulting a 90 ppm U and some elements present in small quantities as shown in Table (1). The chemical composition of the carbonate solution was determined using inductively coupled plasma mass spectrometry (ICP-MS) Table 1.

Element														
Cr	Ni	Cu	Zn	Zr	Rb	Y	Ba	Pb	Sr	Ga	V	Nb	U	Th
ppm														
260	301	3445	121	581	u.d	69	1321	207	239	119	288	37	900	190

2.3. Adsorption studies

The adsorption of U (VI) onto the anion exchanger Lewatit MP L500 (LMP) was investigated as a function of pH, and initial metal ion concentration, temperature, agitation speed, solid/liquid ratio and contact time by means of batch experiments under ambient conditions. In these experiments the parameter under investigation was varied while other experimental parameters were kept constant. To investigate the effect of pH, to LMP screw-cap bottles a specific amount of the adsorbent (1 g) was placed in contact with 25 ml of an aqueous $(\text{UO}_2(\text{CO}_3)_3)^{4-}$ solution of known total metal ion concentration $(\text{U (VI)})_0 = 1.26 \cdot 10^{-3} \text{ M}$ in which pH was varied between 8 and 11. Under these conditions no precipitation of the solubility limiting phase was observed. The mixtures were shaken in a thermostatic shaker at different temperatures (28–60 °C) for 1 h. The pH was adjusted by addition of NaOH (0.1M to 1 M). The pH was measured using a glass electrode (Jenway pH meter.) and the analytical metal ion concentration in solution was determined spectrophotometrically (UV 2401 PC Shimadzu) by means of arsenazo-III dye (Khan *et al.*, 2006). Prior determination of the uranium concentration $((\text{U (VI)}_e))$, aliquot samples were taken from the flask at appropriate time intervals as necessary and the concentration of uranium was determined using a Unicam AAS spectrometer, model 969. All experiments were performed in triplicate and the uncertainty of the values was generally

below 10% and is basically attributed to the error associated with analytical method used (e.g. spectrophotometry using arsenazo-III). For studying the effect of the initial metal ion concentration, a specific amount of the LMP resin (1 g) was added to aqueous $(\text{UO}_2(\text{CO}_3)_3)^{4-}$ solutions (25 mL) of known U (VI) concentration ($8.4 \times 10^{-4} \text{ M} - 1.47 \times 10^{-3} \text{ M}$). The amount of the adsorbed U (VI) on the resin (q_e , mg.g^{-1}) and the % removal efficiency ($\%q_e$) were calculated using following equations (1):

$$q = (C_o - C_e) \frac{V}{m} \dots\dots\dots(1)$$

$$U\% = \frac{(C_o - C_e)}{C_o} \times 100 \dots\dots\dots(2)$$

Where C_o and C_e are the initial and equilibrium concentrations of uranium in the solution (mol L^{-1}), V is the volume of solution (L), m is the weight of the resin (g). All experiments were performed at pH 9.5 in duplicate and the average values were taken.

3. Results and discussion

3.1. Sorption performance

The affinity of LMP resins towards U (VI) was tested by adsorption of uranium upon LMP in a batch reactor at 28 °C. As shown in Fig. 1, the uptake percent increases with time until it reaches a plateau. The adsorbability of the Lewatit resin towards the uranium anions decreases with the temperature (see Fig. 1). The ion exchange of metal ions involves the formation of different mixed species in the resin phase depending on the pH values. The latter plays an important role on sorption extent because of its influence on the degree of ionization and the surface properties of the applied sorbents. The speciation of uranium anion in aqueous solution could be described by the following reaction:

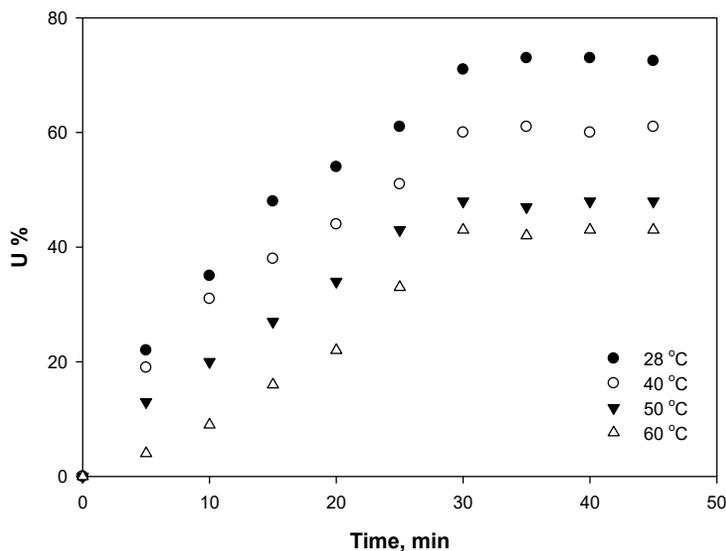
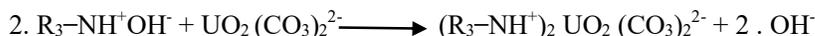


Fig. 1: Uptake percent of uranium from a synthetic solution on LMP resin. Amount of resin 1.0 g, shaking speed 300 rpm.

The variation in the removal extent of U (VI) with pH using LMP was studied by batch experiments and shown in Fig. 2. As it was expected, the solution pH greatly affects the sorption of U (VI) in accordance with the proposed specification according to the above equation. As the pH

increases the amount adsorbed increases before it decreases again at $\text{pH} > 9.5$. The last observation can be attributed to the hydrolysis of the U (VI) anions, a process which decreases the adsorbance of the uranium anions.

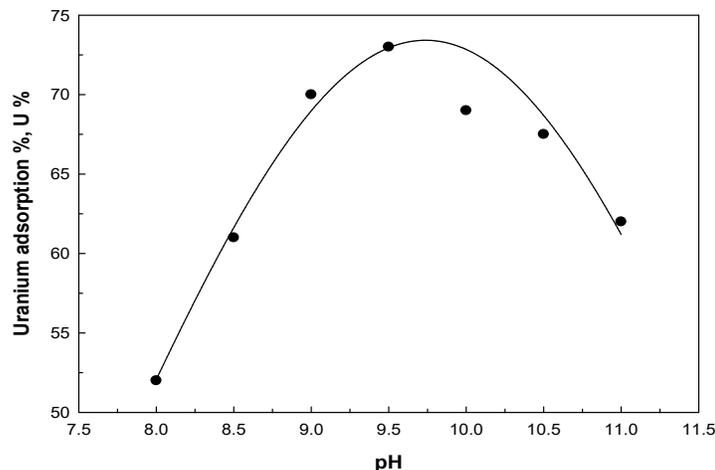


Fig. 2: Effect of pH on the adsorption of U on LMP resin. Amount of resin 1.0 g, shaking speed 300 rpm at 28°C.

The pH has a dramatic effect on the adsorption extent of U (VI) on LMP. The pH influences the degree of ionization of the reactive acidic group of the resin. Fig .3 indicating the effect of U carbonate loaded on LMP with time at different pH values designating high performance at pH 9.5 result to 72 % comparing to 61.5 and 68 % for pH 8 and 11 respectively.

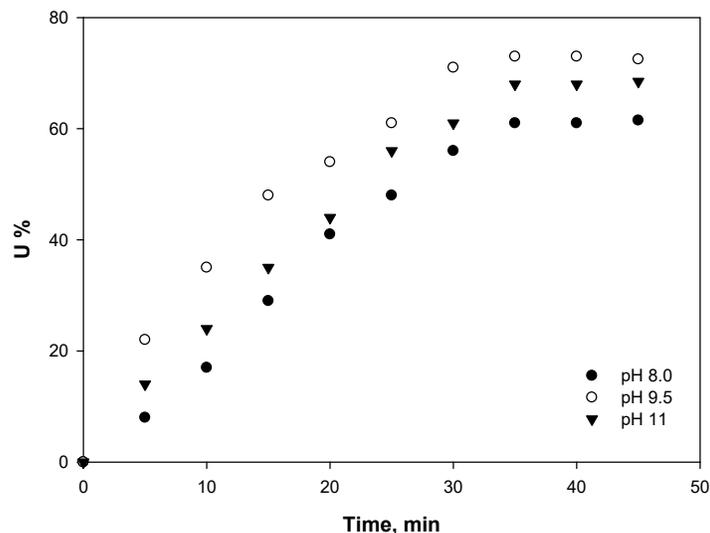


Fig. 3: Effect of pH on the adsorption of U on LMP resin with time. Amount of resin 1.0 g, shaking speed 300 rpm at 28°C.

Since maximum sorption occurs at pH 9.5, this value possessed as the optimum value for all sorption studies at the running experimental conditions. This pH credence was basically attributed to the electrostatic attraction between U (VI) species, which in the weak acidic pH range are mainly

positively charged U (VI) species (e.g. UO_2^{2+} , $\text{UO}_2 \text{OH}^+$, $(\text{UO}_2 (\text{CO}_3)_3)^{4-}$ and the negatively polarized carbonyl oxygen atoms on the fiber surface (Hadjittofi and Pashalidis, 2015). This interaction, which is schematically presented in Fig. 2, was favored with increasing pH, because the concentration of the competitive proton ions gradually decreased (Ilia *et al.*, 2017). In addition, increasing pH may result, despite the acidic conditions, in partial deprotonation of the amino moieties ($\text{pK}_a=10^{-11}$) and could also affect the U (VI) adsorption process. However, because the amino groups are protonated in the acidic pH range, their effect regarding U (VI) adsorption in this pH range was expected to be negligible. For pH values beyond 8 the value of the relative adsorption starts decreasing due to the formation of U (VI)-carbonate species, which stabilize U (VI) in solution and compete the adsorption process (Pashalidis *et al.*, 1993). It is noteworthy that for $\text{pH} < 4$ the relative adsorption decreases almost linearly with pH increment assuming that the adsorbent could be reused after acidic aqueous regeneration.

3.2. Effect of concentration

To inspect the influence of initial uranium concentration upon the adsorption efficiency onto LMP resin, a series of experiments were performed by contacting a fixed weight (0.1 g) of the studied resin with 50 ml from 300 mg/L uranium concentration at pH 9.5 for 60 minutes and at room temperature. The studied initial uranium concentrations ranged from 200 mg/L up to 350 mg/L prepared from dilution of um Bogma leaching liquor. From the obtained results, Figure 4 were plotted and from the obtained data, it can be clarified that uranium adsorption efficiency increases with increasing its initial concentration. In contrast, the adsorption capacity increased with increasing the initial uranium concentration until 300 mg/L after which it become constant. Therefore, the experimental adsorption capacity of the adsorbent was about 120 mg uranium/g resin.

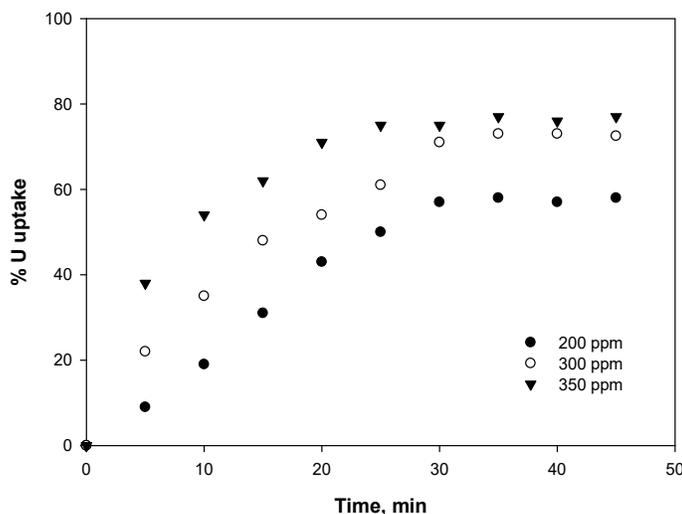


Fig. 4: Effect of initial uranium concentrations on uranium adsorption efficiency and uranium uptake onto the LMP resin (resin weight = 1 g, volume = 50 ml, pH=9.5, 60 min, 28 °C)

3.3. Effect of Resin Amount

The amount of the adsorbent used in the uranium adsorption process is very critical for the economic point of view. Figure 5 represent a series of adsorption experiments was achieved using different adsorbent doses ranging from 1:5 up to 1:20 resin/L. The experiments were achieved under constant initial uranium concentration of 300 mg/L, 60 minutes shaking time and pH 9.5. From the compiled results, it was clarified that the adsorption efficiency increases significantly with increasing adsorbent amount (adsorbent dose). This observation is possibly, where increase in adsorbent dose increases the active sites and, consequently the percentage adsorption increases. By further increasing of the LMP resin amount the active sites become more plentiful than the available uranium ions in the solution. Consequently, the adsorptive capacity of adsorbent available was not fully utilized at a higher adsorbent amount. Based on the latter, 1:5, resin/L is preferred as the usable adsorbent amount.

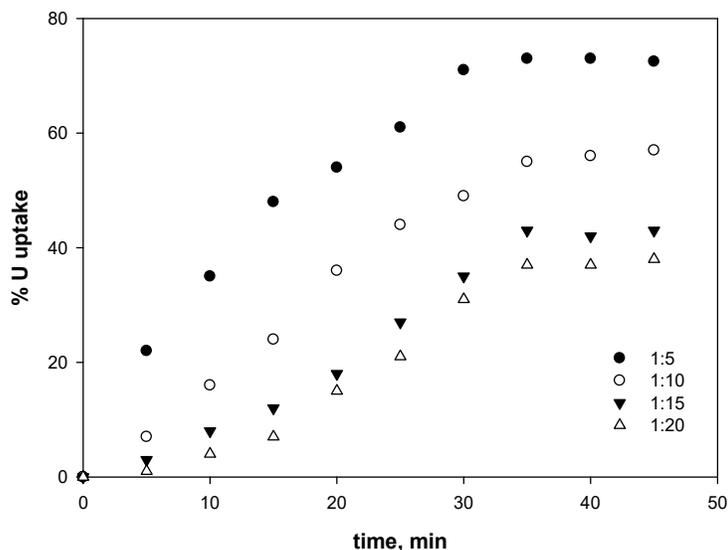


Fig. 5: Effect of adsorbent dose upon uranium adsorption efficiency onto LMP resin

3.4. Sorption kinetics and mechanism

The data obtained from batch experiments which were performed at different temperature ranges (28–60) °C and evaluated by using the simple Lagergren equation (Ho, 2004) in order to determine the rate of the sorptive interactions assuming pseudo first order kinetics:

$$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303}$$

Where q_t and q_e are the amounts of uranium adsorbed (mg/g) at time, t (min) and equilibrium time (30 min), respectively and K_1 is the pseudo first order Lagergren adsorption rate constant (min^{-1}).

The k_1 values could be obtained by plotting $\log(q_e - q_t)$ versus t for uranium adsorption at different temperatures as shown in Figure 6.

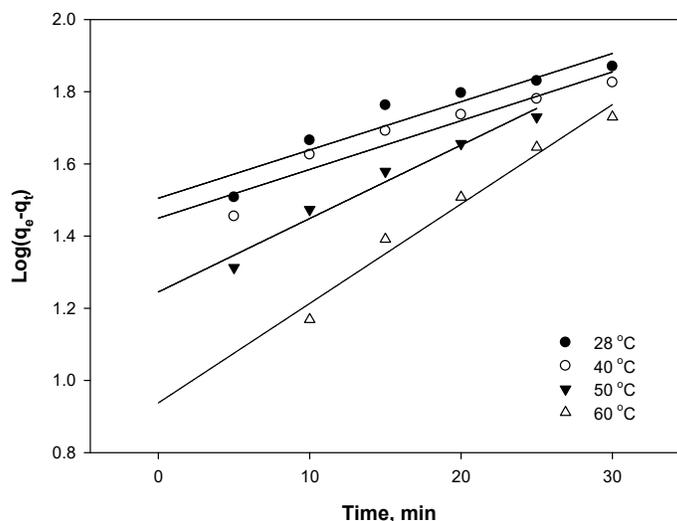


Fig. 6: Lagergren plots for the adsorption of uranium

The values of the first order rate constant (k_1) and correlation coefficient (r^2) obtained from these plots are listed in Table 2. The values of k_1 indicated that the rate of the process increases with temperature. The first order mechanism suffered from inadequacies when applied to uranium sorption on the LMP

resin. One of the major discrepancies was observed when q_e values obtained from the pseudo first order plots were compared with the experimental q_e values as presented in Table (2). The experimental q_e values are varied from the corresponding theoretical values, hence, the interaction of uranium with the LMP resin does not follow the first order kinetics.

Table 2: Data of kinetic parameters for uranium adsorption onto LMP resin

Temp. °C	Lagergren pseudo first order				Pseudo second-order			
	K_1 (min^{-1})	q_{ecal} (mg/ g)	q_{exp} (mg/ g)	R^2	K_2 (min^{-1})	q_{ecal} (mg/ g)	q_{exp} (mg/ g)	R^2
28	0.031	31.97	106.0	0.9413	8.413×10^{-4}	101.01	106.0	0.998
40	0.031	28.16	115.2	0.9517	3.81×10^{-4}	111.11	115.2	0.9923
50	0.047	17.58	120.2	0.9848	2.663×10^{-4}	119.05	120.2	0.9942
60	0.064	8.66	128.0	0.9856	1.296×10^{-4}	126.58	128.0	0.9838

In order to ensure the description of the kinetics, second order kinetic equation was applied. The pseudo second order kinetics can be represented by the following linear equation (Ho and McKay 1999):

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \left(\frac{1}{q_e} \right) t$$

Where k_2 is the second order rate constant ($\text{g. mg}^{-1} \text{min}^{-1}$). The kinetic plots of t/q_t versus t for uranium are shown in Figure 7.

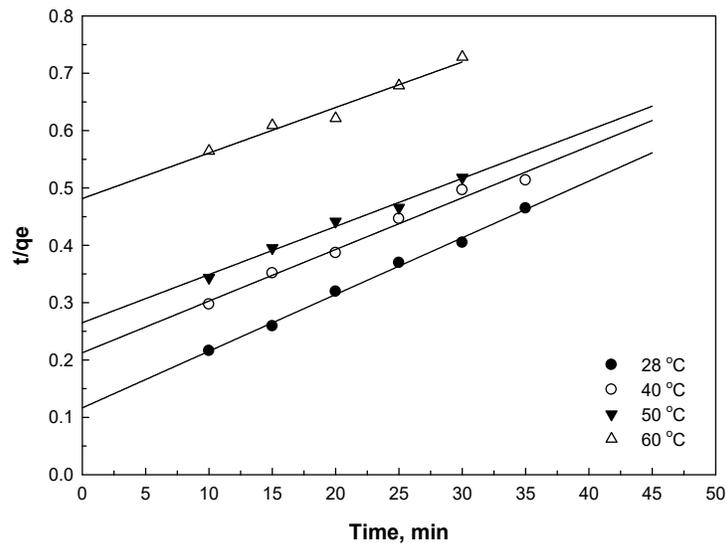


Fig. 7: Pseudo second-order plots for the adsorption of uranium

The plots show straight lines with good linearity temperatures. The calculated correlation coefficients are closer to unity for the pseudo second order kinetic model. The calculated equilibrium adsorption capacity (q_e) is consistent with the experimental data. The k_2 values showed the applicability of the above equation for the resin. Therefore, the sorption reaction can be approximated more favorably by the pseudo second order sorption as the predominant mechanism.

The obtained data at different temperatures indicated that increasing the temperature decrease the adsorption rate process. The activation energy can be determined using Arrhenius equation

$$k = Ae^{-\frac{E_a}{RT}}$$

Where A is the pre-exponential factor or simply the prefactor and R is the gas constant. The unit of the pre-exponential factor was identical to that of the rate constant and varies depending on the order of the reaction. Fig. 8 is the Arrhenius plot for the adsorption of U on LMP. The activation energy can be determined from Fig. 5 to be 27.1 kJ/mol.

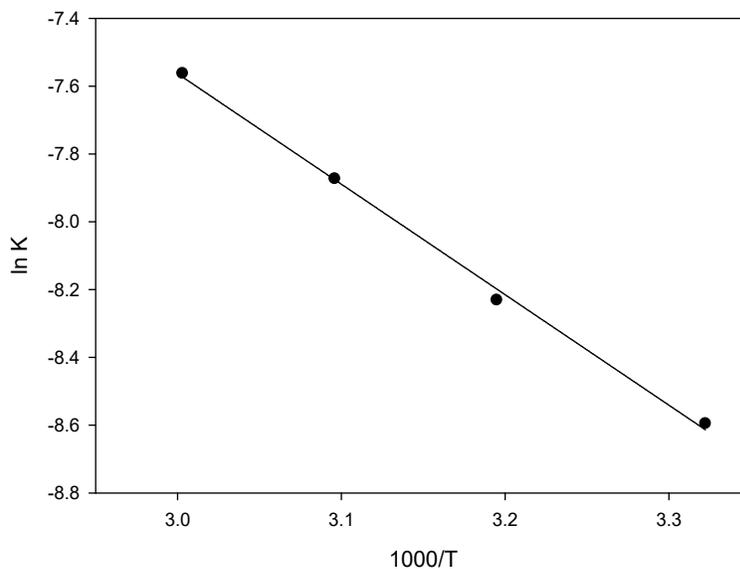


Fig. 8: Plot of $\ln K_d$ versus $1/T$ of uranium ions onto LMP resin

The results obtained concerning the activation energy indicate diffusion controlled process (Saleh, 2006). As in other heterogeneous reactions between solids and fluids (i.e. between the U (VI) and the LMP anion-exchange resin, our present study), the reaction could be explained through a number of sequential processes that determine the rate of reaction namely; (a) diffusion of ions through the liquid film surrounding the particle, (b) diffusion of ions through the polymeric matrix of the resin (c) chemical reaction with the functional groups attached to the matrix. One of the steps usually offers much greater resistance than the others so it can be considered as the rate limiting step of the process. There are only few cases in which the rate of ion-exchange reactions was controlled by chemical reaction. When a kinetic study is in its initial stage, it is generally assumed that the chemical reaction is infinitely fast. Helfferich (1962) gave 11 examples in which reactions have an influence on the rate of exchange; they were related with some kind of parallel ionic reaction that changes the identity of the ions involved. In many cases, ion-exchange kinetics is limited by the step of diffusion inside the resin particle. When convection in the solution is weak and/or the degree of polymer cross-link is low, it is likely that the main resistance to diffusion can be found in the liquid phase. When the degree of cross-linking is high, the resins are more compact, so the mass transfer inside the particles is more difficult. Homogeneous Particle Diffusion Model (HPDM) is the kinetic model which is widely used to describe the metal adsorption by ion exchange resin. In this model, the extraction mechanism involves counter diffusion of M^{2+} ions from the aqueous solution and H^+ ions from the resin phase through a number of possible resistances. The M^{2+} species originally in the solution phase must diffuse across the liquid film surrounding the ion exchange resin particle, transfer across the solution particle interface, diffuse into the bulk of the ion exchange resin particle and possibly interact with ion exchange reactive group. The species within the ion exchange reactive group simultaneously experience the same sequence in reverse order.

3.5. Data analysis using the homogeneous diffusion model

The transport of solute molecules from liquid phase up to solid phase boundary plays the most significant role, where the following expression can be used to describe the rate of the ion exchange (Gonzalez-Luque & Streat, 1983; Cortina & Miralles 1997; Liberti *et al.*, 1977; Helfferich, 1962):

$$-\ln(1 - X) = K_{FD}t \text{ where } K_{FD} = \frac{3D_{FD}C_0}{rC_e\delta}$$

If matrix phase diffusion controls the rate of exchange, the following analogous expression can be used:

$$-\ln(1 - X^2) = 2K_{MD}t \text{ where } K_{MD} = \frac{\pi^2 D_{MD}}{r^2}$$

Where X is the fractional attainment of equilibrium ($X = q_t/q_e$). A linear plot of $\ln(1 - X^2)$ versus time t with zero intercept would suggest that the kinetics of the sorption process is controlled by diffusion through the liquid film surrounding the solid sorbents. Further investigation for the data obtained from batch experiments leads to subdivision of the adsorption process to two stages. Figures. 9 (a-d) showed the application of the HDM on the experimental data of U sorption on LMP at different temperatures.

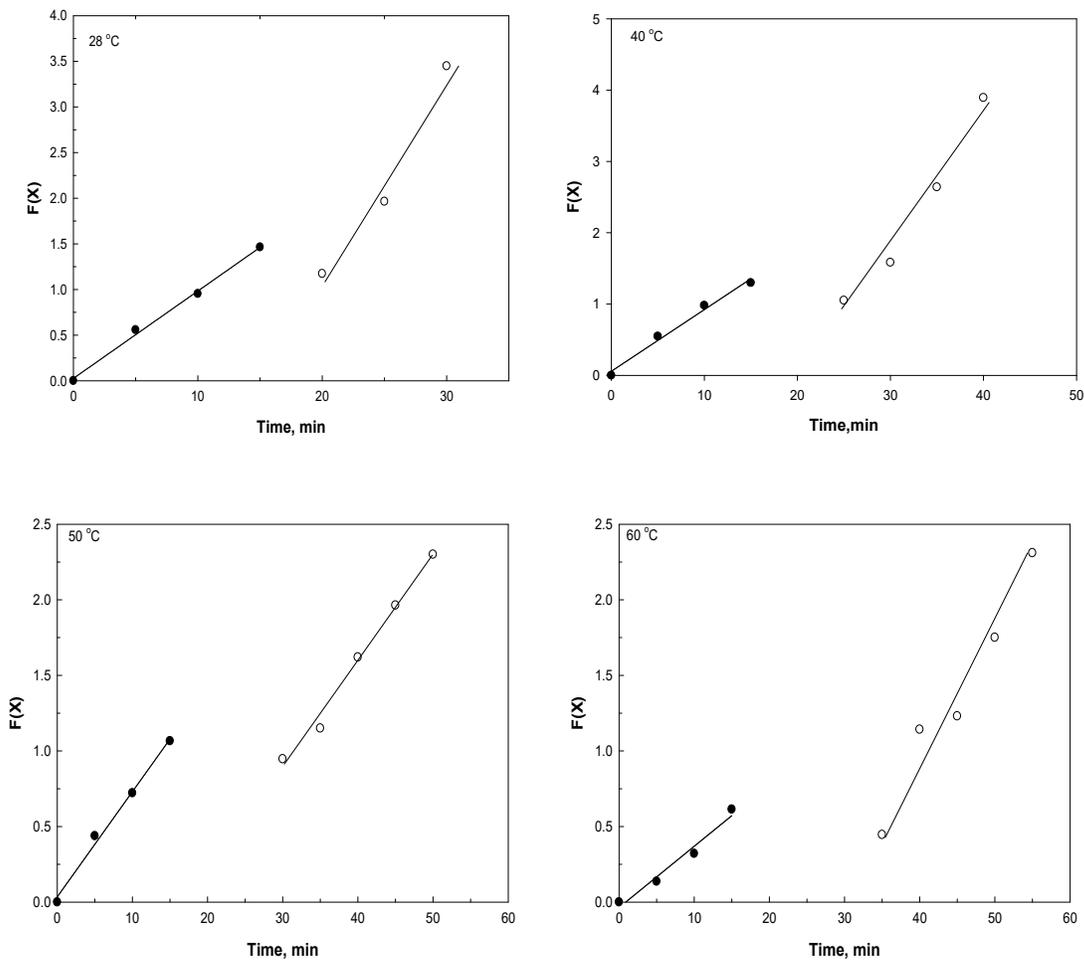


Fig. 9: (a–d) Homogenous diffusion mode plots for sorption of U (IV) ions on LMP resin at different temperatures. FD holds for film diffusion mode given by Eq. (8) and MD holds for matrix diffusion mode given by Eq. (9).

The data show different stages (modes) of the controlling diffusion processes. The two main modes were film diffusion mode (FD) and matrix diffusion mode (MD) are given respectively, by Eqs. (8) and (9) above. The experimental data follow FD mode at the beginning of the sorption process (first stage) followed by MD mode after specific time interval (final stage). These specific time intervals depend on the temperature of the solution. For instance, the inflections between the two modes (FD

and MD) occur at 15, 25, 30, and 35 minutes at 28, 40, 50, 60 °C, respectively. As the temperature increases the time interval increases as shown in Figs. 9 (a–d). This is consistent with the fact that the rate of the sorption process decreases with the temperature as discussed in Section 3.2. As the temperature increases the time required for the ions to exchange onto the solid matrix increases and hence reaching to the second stage (mode) subsequently later compared to lower temperatures. The plots at various temperatures as shown in Fig. 9 (a–d) indicate that at the first stage the rate determining step was controlled by film diffusion (FD) while at the final stages were controlled by matrix diffusion (MD).

The kinetic parameters for sorption of Be (II) ions according to HDM were estimated using Eqs. (8) and (9) and Figs. 9 (a–d) and cited in Table 3. The diffusion coefficients in matrix diffusion (DMD) can be estimated by using $r = 2.97 \times 10^{-4}$ m in Eq. (9). It decreases with temperature. The D_{MD} values were found to be equal 1.02×10^{-12} , 1.33×10^{-11} , 2.298×10^{-11} and 3.05×10^{-12} $m^2 s^{-1}$ at 28, 40, 50, 60 °C respectively. These values may be comparable with those found for Cr (III) (4.2×10^{-12} $m^2 s^{-1}$) and Zn (II) (6.2×10^{-12} $m^2 s^{-1}$) (Vitor *et al.*, 2007). On the other hand, the KFD values in Table 3 indicated that the diffusion coefficient in the liquid film, DFD increases with temperature (assuming a constant value of the film thickness d). This is consistent with the fact that the rate of the process reaching to the second stage earlier at higher temperatures.

Table 3: Estimated parameters for sorption of U (VI) ions from plots of the homogenous diffusion model shown in Fig. 6a–d. Kinetic parameters for sorption of U (VI) ions homogenous diffusion model.

Parameters of Fig. 6 (a–d)	Fluid diffusion		Matrix diffusion-		
	T/°C	K_{FD}/S^{-1}	Correlation coefficient/ r^2	K_{MD}/S^{-1}	Correlation coefficient/ r^2
28		9.57×10^{-3}	0.9981	1.12×10^{-4}	0.985
40		8.65×10^{-4}	0.9930	1.46×10^{-3}	0.9856
50		6.96×10^{-4}	0.9963	5.04×10^{-3}	0.9949
60		4.05×10^{-3}	0.9851	3.34×10^{-4}	0.9811

3.6. Effect of the rate of agitation

Further investigations of the two stages of adsorption were conducted by studying the effect of the rate of agitation. The experiment was carried out at stirring speed ranged between 200 and 400 rpm at 28 °C for 15 minutes. Figs. 7 and 8 showed the application of the HDM equation on the collected experimental data for sorption of U at different shaking speed (rpm). In Figs. 7 (a–d) the FD equation (Eq. (8)) was applied for the sorption process at the early stage. The strategy which has been done with Fig. 6 was applied here too. That is to say, the data in Fig. 7 represent the early stage where as Fig. 8 represent the final stage of the process. Figures. 7 (a) and (b) follow Eq. (9) and relatively good straight lines were obtained with respect to the unsatisfactory straight lines obtained in Fig. 7 (c). The above results imply that FD model can describe the sorption process at lower shaking speed where diffusion of U^{6+} from bulk solution to the sorbent surface is the controlling process. In Fig. 8 the data at the final stage (i.e. after specific time interval similar to those in Fig. (6) applied to the matrix diffusion equation (Eq. (9)) and satisfactory straight lines are obtained. It is evident from Fig. 8 that the second mode (stage 2) (i.e. DM) begins earlier than at lower shaking speed. At higher shaking speed the FD is not controlling and yet the matrix diffusion controls the process faster than at lower shaking speed. The data analysis according to homogeneous diffusion model confirms the concept of the two stages of diffusion. As shown in Figs. 7 and 8, at low rate of agitation the rate determining step is a combination of film and matrix control while at high rate of agitation only matrix diffusion controls the process.

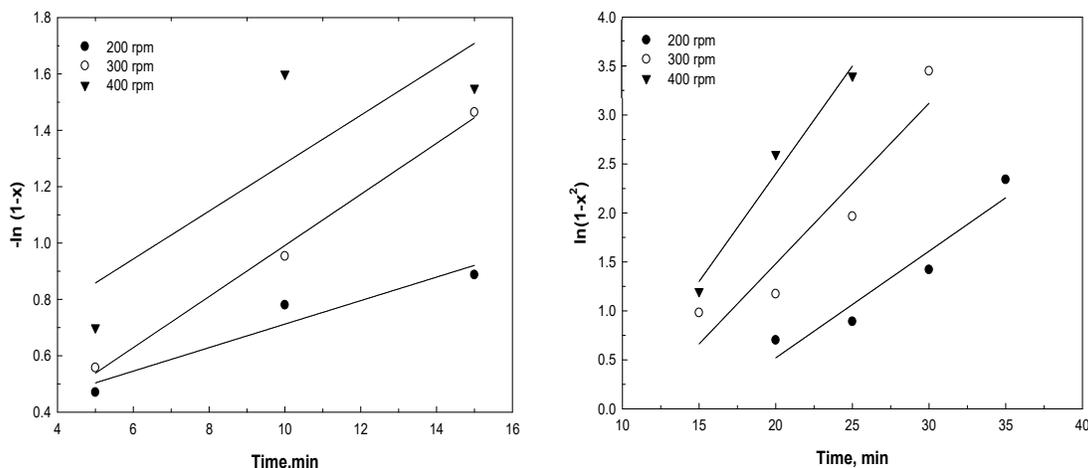


Fig. 10: (a–d) Effect of shaking speed on the liquid film diffusion of the absorption of U (IV) on LMP resin.

4. Summary and conclusions

We have used the equations of the homogenous diffusion model (HDM) and the two-stage concept of the diffusion to fit our experimental data. Results obtained in this work on the kinetics adsorption of Be (II) with Amberlite-IR-120 resins have indicated that: – At the early stage of the process, the sorption is fast and the rate determining step of the metal extraction is the liquid-film diffusion. At the final stage of the process, the sorption is slow and the rate-determining step of the metal extraction is the matrix (resin)-phase diffusion – Both the model and the two-stage concept allow the estimation of the average diffusion coefficient which provides an insight into the diffusion mechanism and a parameter for subsequent design calculations. The kinetic parameters obtained are of the same order of magnitude as those measured by other authors when dealing with heterogeneous chemical adsorption reaction and are higher than those obtained with physical adsorption reaction. This fact gives an indication of the high affinity of U (VI) towards LMP resin. As a final conclusion, the two stages of diffusion mechanisms represent reasonable approaches to the kinetics of the metal extraction reactions on polymeric macroporous ion exchange resin. The present situation calls for more complicated mathematical modeling for better understanding and optimization of the sorption of U (VI) on LMP. The above findings on batch process will be applied using a fixed-bed column and will be reported in the near future.

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