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Sorption Behaviour of Cobalt and Zinc Radionuclides onto Zirconium (IV) selenomolybdate Gel Matrix.

M. A. EL-AMIR^a, H. EL-SAID^a, H. E. RAMADAN^a, A. S. AMIN^{b,*} and A. F. EL-DAOUSHY^a.

^aRadioactive Isotopes and Generators Dept., Hot Labs. Center, Atomic Energy Authority, P.No. 13759, Cairo, Egypt.

^bChemistry Dept., Faculty of science, Benha University, Benha, Egypt.

ABSTRACT

Sorption experiments were carried out to investigate the sorption behaviour of ⁶⁰Co(II) and ⁶⁵Zn(II) radionuclides from aqueous solutions onto zirconium(IV) selenomolybdate gel matrix. The effects of pH, initial concentration of Co(II) and Zn(II), sorbent dose, contact time and temperature on the sorption process were investigated. The data showed that the sorption kinetics and isotherms were fitted well to the pseudo-second-order and the Freundlich models; respectively. Thermodynamic studies were carried out and it was found that the process was spontaneous endothermic in nature. According to the data obtained, the prepared material can be used as a promising sorbent for removal of ⁶⁰Co(II) and ⁶⁵Zn(II) radionuclides from aqueous solutions.

Keywords: Sorption; Co(II); Zn(II); Solid phase extraction; Sorption kinetics; Thermodynamic parameters.

**Corresponding author*

INTRODUCTION

Recently, scientists in different fields of science are concerned with facing environmental pollution to rescue human health. Heavy metals are considered as a major cause of environmental pollution as they are a main source of air, water and soil pollution and also found as a main component of waste released from industry and medicine sector as well as from research and nuclear facilities [1-3]. The radioactive pollution is a critical problem that attracts the attention of many scientists over the world due to the increased demand on nuclear technology [4]. Cobalt-60 ($T_{1/2}=5.27$ years) and Zinc-65 ($T_{1/2}=245$ days) are long-lived synthetic radioactive isotopes that are produced by neutron activation [5-8]. They are of a particular interest due to their relatively large abundance in the reactor and their ability to interact in the biological systems. They can be released to the environment through leaks or spills at nuclear power plants. People may ingest them with food and water that has been contaminated and that may result in an increased risk of cancers, so that their removal from aqueous solutions is mostly needed [9, 10].

Ion exchangers are widely used for the removal of such toxic heavy metals from both industrial and nuclear waste solutions. For nuclear waste management, inorganic ion exchangers are used mainly to concentrate the radioactivity into small volumes to ease its management process and also to facilitate the recovery of some valuable radioactive nuclides for their reuse either in research or in different applications and to lower the reactivity of the treated waste [11, 12]. Synthetic inorganic ion exchangers are distinct from organic ones with their selective sorption properties, rapid rate of uptake, high thermal, chemical and radiation stability [13-15].

Heteropolyacid salts are considered a distinct type of inorganic ion exchangers because they have exchangeable protons and thus widely used as sorbents due to their wide and desirable variations available in their compositions which enhance their selectivity [16, 17]. Their ion exchange capacity is higher compared to single inorganic salts [18] and they are widely used for radiochemical separation of radioisotopes. Heteropolyacid sorbents such as titanium(IV) molybdosilicate [19], tin(IV) Molybdotungstate, zirconium molybdophosphate [20], Stannic silicomolybdate [21] and many others are efficient ion exchange sorbents for the removal of metal ions as Cs(I), Pb(I), Ag(I), Co(II), Zn(II), Eu(III) and Cd(II).

This study aims to evaluate the applicability of the removal of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ radionuclides from aqueous solutions using zirconium(IV) selenomolybdate sorbent.

MATERIALS AND METHODS

Materials

All chemicals used in this study were of analytical grade purity (A. R. grade) and were used without further purification. Distilled water was used for solution preparations and washing. Cobalt chloride ($\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$) was received from winlab Co.-U.K. Zinc sulfate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) and Selenous acid (H_2SeO_3) were received from Sigma-Aldrich Co.-U.S.A. Zirconium oxychloride ($\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$) and hydrochloric acid 37% were received from Merk Co.-Germany. Sodium molybdate ($\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$) was received from Prolabo Co.-Paris.

Instrumentations

Radiometric identifications and measurements were made by using a multichannel analyzer (MCA of "Inspector 2000" model, Canberra Series, made in U.S.A, coupled with a high-purity germanium coaxial detector (HPGe) of "GX2518" model. Samples of constant geometry were counted with low dead time (< 5%). A pH-meter with a microprocessor (Hanna Instruments pH211 model, Portugal) was used for measuring pH values of solutions. An analytical balance (A&D Engineering Inc., AND HR-202 model, USA) having dual range (42 g/0.01 mg, 210 g/0.1 mg) was used for weighing.

Method

Radioactive isotopes

For preliminary radiochemical investigations, $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ radionuclides were produced by thermal neutron irradiation of 0.1 g of cobalt chloride and zinc sulphate powders, respectively. The irradiation process was carried out in the 22 MW water cooled Egyptian Second Research Reactor (ETRR-2) in Inshas, Egypt. Each target was wrapped in a thin aluminum foil, placed in thick aluminum irradiation can and irradiated at a thermal neutron flux of $10^{14} \text{ n.cm}^{-2}.\text{sec}^{-1}$ for 4 hours.

Preparation of zirconium(IV) selenomolybdate gel matrix

5.062 g $\text{ZrOCl}_2.8\text{H}_2\text{O}$ was dissolved in a small portion of distilled water and then completed to 62.5 mL, after that it was heated just to 60 °C, and left to cool to room temperature ~ 25 °C. Then, 3.025 g Na_2MoO_4 was dissolved in a small portion of distilled water and then completed to 50 mL to form Na_2MoO_4 solution. The pH value of Na_2MoO_4 solution was adjusted to about 4.5 with 2 M HNO_3 . After that, 1.288 g H_2SeO_3 was dissolved in a small portion of distilled water and then completed to 50 mL. While stirring, Selenic acid solution was added to the stirred sodium molybdate solution and the produced mixture was added to zirconium oxychloride solution to form zirconium(IV) selenomolybdate (ZSM) gel mixing solution. The pH of ZSM gel mixing solution was adjusted to 4.5 with 2 M Na_2CO_3 solution, and stirred for about 10 min. The gelatinous precipitate so formed was allowed to stand for 30 minutes in the mother liquor for digestion. The resulting gel mixing solution was centrifuged and dried in an oven at 50 °C for about 24 hours. The dried gel was immersed in water to be cracked into small granules and to remove the superfine particles. Finally, the ZSM gel dried again at 50 °C.

Batch distribution studies

The prepared material was studied using the batch contact method. The distribution coefficients (K_d) for $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ ions in aqueous HCl and HNO_3 acids solutions onto zirconium(IV) selenomolybdate gel matrix samples were determined by the static batch equilibration technique. Also, the batch experiments were to demonstrate the effect of contact time, reaction temperature, initial concentration of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ and sorbent dose on the uptake of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ radionuclides. For this purposes, 10 mL of aqueous solutions of cobalt chloride (tagged with Co-60) or zinc sulfate (tagged with Zn-65) with 0.1 g of the Zirconium(IV) selenomolybdate gel material were shaken at $25^\circ\text{C} \pm 1^\circ\text{C}$ for 24 hours. Thereafter, the supernatants were withdrawn and 2 mL of the supernatant solution was pipetted for radiometric assay. The distribution coefficients (K_d) were determined using the following equation:

$$K_d = \frac{A_i - A_f}{A_f} \times \frac{V}{m} \text{ (ml/g)} \quad (1)$$

where; A_i and A_f are the counting rates of the aqueous phase before and after equilibration with the gel matrix, respectively, V is the volume of the aqueous phase (10 mL) and m is the weight of the matrix (0.1 g). The percentage uptake, % U, on the solid could be calculated from equation (2) as:

$$\% \text{ uptake} = \frac{A_i - A_f}{A_i} \times 100 \quad (2)$$

Where; A_i is the initial activity expressed in counts/sec and A_f is the residual activity.

Sorption kinetics

Sorption kinetics of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ was conducted by contacting, in a glass bottles, the sorbate solution ($^{60}\text{Co(II)}$ or $^{65}\text{Zn(II)}$; 10 mL of 10^{-4} M for each) with 0.1 g of zirconium(IV) selenomolybdate gel matrix. The bottles were kept in a thermostated water bath shaker at $25^\circ\text{C} \pm 1^\circ\text{C}$. At appropriate time intervals; the sorption of each ion on the gel material was followed with time until equilibrium is attained.

Sorption isotherms

Sorption isotherm experiments were conducted batch wise, by contacting different concentrations of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ solutions. The concentrations were ranged from 10^{-5} to 10^{-3} M for either $^{60}\text{Co(II)}$ or $^{65}\text{Zn(II)}$. A 10 mL of each solution was added to 0.1 g of the zirconium(IV) selenomolybdate gel matrix and the mixture

was shaken in a thermostated water bath shaker at 25 ± 1 °C. Initial and equilibrium concentrations of metal ions in the aqueous phase were determined and the amount of metal ions adsorbed per gram of the gel material (q) was calculated using equation (3) as follows:

$$q = (C_0 - C_e) \frac{V}{m} \quad (3)$$

Where; m is the weight of the gel material (g) and V is the volume of the solution (L).

RESULTS AND DISCUSSION

The prepared zirconium(IV) selenomolybdate gel matrix was obtained in the form of glassy white powder which has high mechanical resistance as well as high chemical stability in salts of NH_4^+ and sodium chloride solutions and is also stable in low mineral acids concentrations.

Sorption Studies

Distribution coefficient studies (K_d)

Batch equilibration method was used to investigate the pH dependence of the distribution coefficients of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ in HCl solution onto zirconium(IV) selenomolybdate gel matrix. The results are shown in Fig. 1. It is clear that the sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ onto the sorbent follows more or less a cation exchange mechanism. It is observed that the corresponding K_d values decrease with increasing $[\text{H}^+]$ in the equilibrating solutions due to the competition between Co(II) and Zn(II) to exchange with H^+ on the surface of zirconium(IV) selenomolybdate gel matrix. At low acid concentrations, high K_d values of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ are obtained due to the predominance of cationic species $[\text{Co(II)(H}_2\text{O)}]^{2+}$ for cobalt and Zn^{2+} , $[\text{Zn(OH)}]^+$ and $[\text{ZnCl}]^+$ for zinc. The decrease of the corresponding K_d values with increasing the acid concentration may be due to the competition between cationic species of cobalt and $[\text{H}^+]$ and due to the predominance of the anionic species of zinc. Similar behaviour of Co(II) and Zn(II) is obtained in HNO_3 acid solutions as shown in Fig. 2.

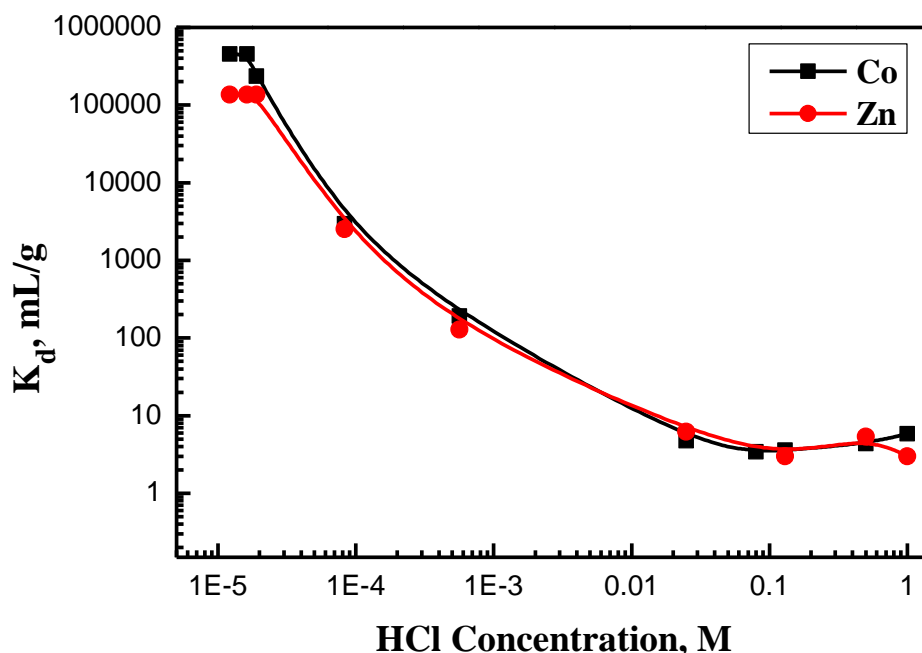


Fig. 1: Distribution coefficients of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ in HCl solution onto zirconium(IV) selenomolybdate gel matrix as a function of concentration of the equilibrating media.

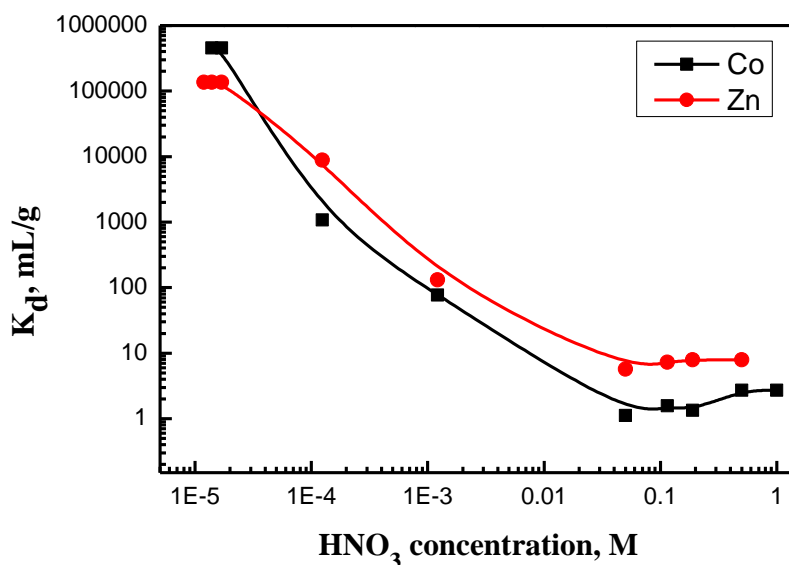


Fig. 2: Distribution coefficients of ⁶⁰Co(II) and ⁶⁵Zn(II) in HNO₃ solution onto zirconium(IV) selenomolybdate gel matrix as a function of concentration of the equilibrating media.

Effect of contact time

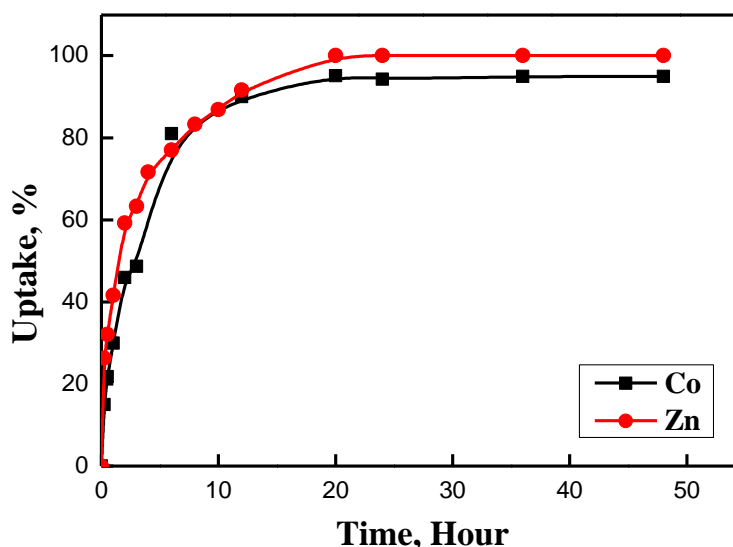


Fig. 3: Effect of contact time on the uptake of ⁶⁰Co(II) and ⁶⁵Zn(II) radionuclides onto zirconium(IV) selenomolybdate gel matrix

The effect of contact time on the percentage uptake of ⁶⁰Co(II) and ⁶⁵Zn(II) radionuclides using the prepared zirconium(IV) selenomolybdate gel matrix was investigated as shown in Fig. 3. From this figure, the uptake increases with time and attains equilibrium in about 20 hours with uptake percent of about 95% and 99% for ⁶⁰Co(II) and ⁶⁵Zn(II) radionuclides; respectively. A further increase in contact time has a slight effect on the uptake of cobalt and zinc up to 48 hours, where it did not represent any remarkable effect. Based on these results, 20 hours was taken as the equilibrium time in sorption experiments. Basically, the removal of sorbate was rapid, but it gradually decreased with time until it reached the equilibrium. The removal of cobalt and zinc ions showed a fast rate of sorption during the first hours of the sorbate-sorbent contact and the rate of percent uptake became almost insignificant due to a quick exhaustion of the sorption active sites. In other words, the rate of percent ion removal was higher in the beginning due to a larger surface area of the adsorbent being available for the sorption of the ions.

Effect of initial concentration

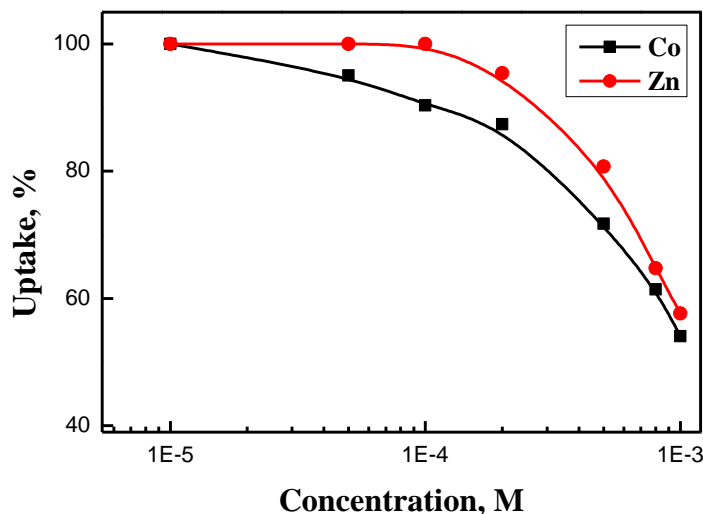


Fig. 4: Effect of initial concentration on the uptake of ⁶⁰Co(II) and ⁶⁵Zn(II) radionuclides onto zirconium(IV) selenomolybdate gel matrix

The effect of initial metal ions concentrations (10^{-5} - 10^{-3} M for each ion) on their uptake percent using the prepared zirconium(IV) selenomolybdate gel matrix is shown in **Fig. 4**. This figure clarify that, the uptake percent decreases with increasing the initial concentrations of ⁶⁰Co(II) and ⁶⁵Zn(II). This could be attributed to the availability of sufficient sorption sites on the synthesized material required for the sorption of metals ions at lower initial metal concentrations. However, at higher metal ion concentrations, the available sorption sites are relatively low compared with metal ion concentrations.

Effect of sorbent dose

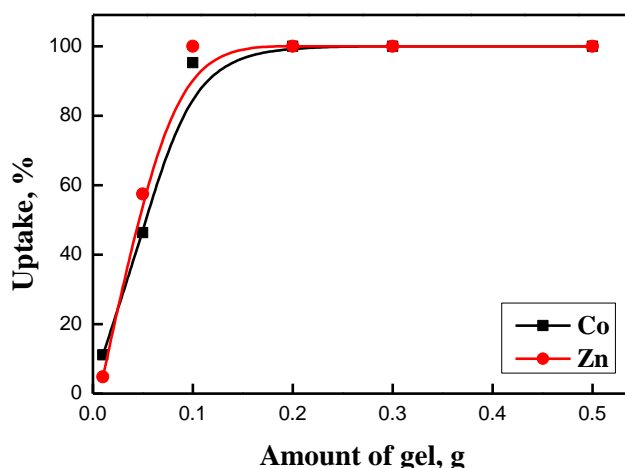


Fig. 5: Effect of sorbent dose onto the uptake of ⁶⁰Co(II) and ⁶⁵Zn(II) radionuclides on zirconium(IV) selenomolybdate gel matrix

The effect of the sorbent dose was studied at 25 ± 1 °C by varying the sorbent amounts from 0.01 to 0.5 g. For all these runs, initial concentration of ⁶⁰Co(II) and ⁶⁵Zn(II) radionuclides were fixed at 10^{-4} M for each. **Fig. 5** shows that, the uptake percent of ⁶⁰Co(II) and ⁶⁵Zn(II) increased rapidly with increasing the amount of zirconium(IV) selenomolybdate gel matrix from 0.01 to 0.1 g. At doses higher than 0.1 g, the uptake slightly increased till equilibrium achieved and seems to be constant. The increase in the rate as well as the percent of

uptake of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ with increasing sorbent dose can be attributed to the availability of more sorption sites.

Sorption kinetics

To investigate the potential rate-determining steps involved in the sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ onto zirconium (IV) selenomolybdate gel matrix, both pseudo-first-order and pseudo-second-order kinetic models are used to fit the experimental data [22].

The pseudo-first-order rate expression of Lagergren model [23, 24] is one of the most widely used rate equations to describe the sorption of a sorbate from the liquid phase and generally expressed as follows:

$$\ln(q_e - q_t) = \ln q_{e1} - k_1 t \tag{4}$$

where, q_e and q_t are the amounts of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ ions sorbed on zirconium(IV) selenomolybdate sorbent at equilibrium and time t (mg.g^{-1}), respectively, k_1 is the pseudo-first-order rate constant (min^{-1}). The plots of $\ln(q_e - q_t)$ verses t give straight line as shown in Fig. 6.

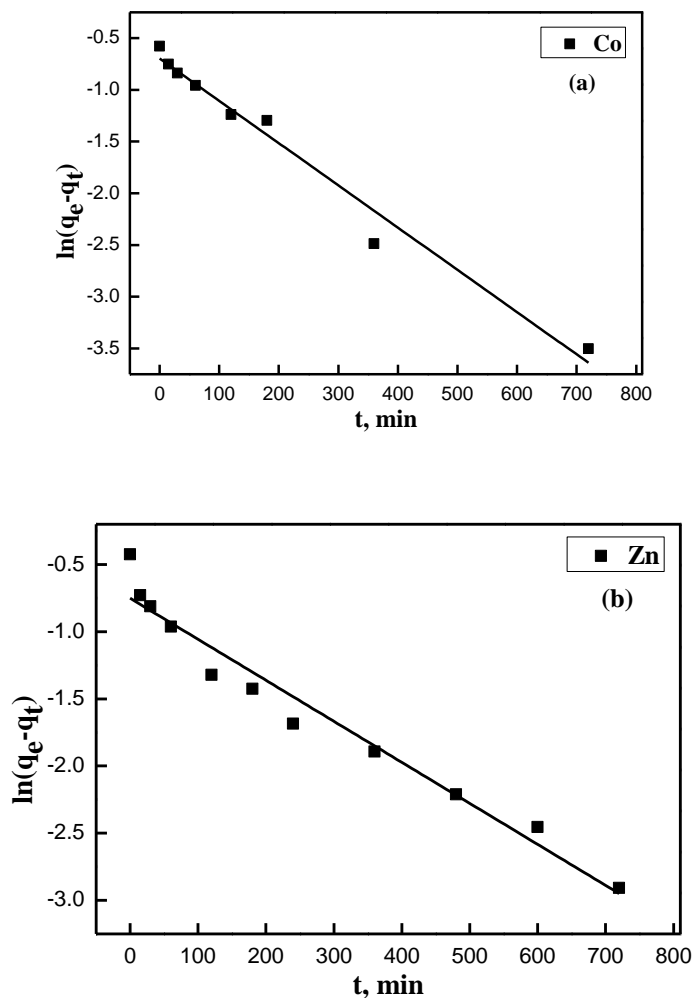


Fig. 6: Pseudo - first - order plots for sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ onto zirconium(IV) selenomolybdate gel matrix

The pseudo-second-order equation is expressed as follow [22]:

$$\frac{t}{q_t} = \left(\frac{1}{k_2 q_e^2} \right) + \left(\frac{1}{q_e} t \right) \tag{5}$$

where, q_e and q_t are the amounts of metal ion sorbed on the zirconium(IV) selenomolybdate sorbent at equilibrium and time t (mg.g^{-1}), respectively, k_2 is the pseudo-second-order rate constant ($\text{g.mg}^{-1} \text{min}^{-1}$). The plots of (t/q_t) versus t are shown in Fig. 7.

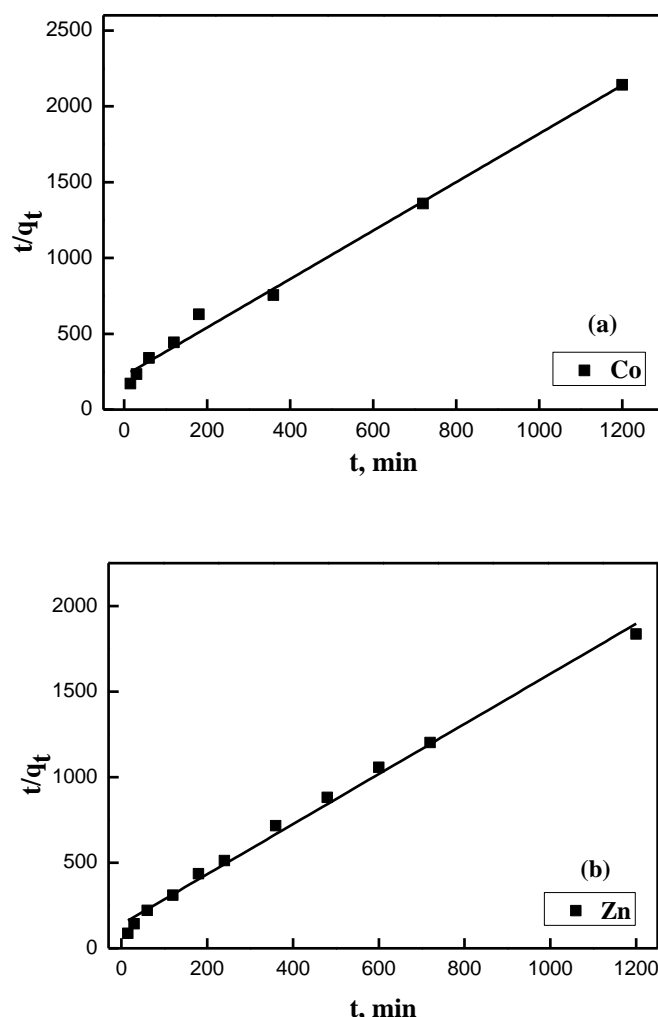


Fig. 7: Pseudo - second - order plots for sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ onto zirconium(IV) selenomolybdate gel matrix

The rate constants k_1 and k_2 of the pseudo-first order and the pseudo-second order models are obtained from the plots of represented in Figs. 6 and 7. The rate constants, the correlation coefficients and the calculated q_e for the two kinetic models of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ are shown in Table (1).

Table (1): Kinetics parameters for sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ by zirconium(IV) selenomolybdate sorbent

Sorbate	pseudo-first-order			pseudo-second- order		
	k_1	R^2	q_e	k_2	R^2	q_e
Co	0.004	0.974	0.497	0.011	0.991	0.626
Zn	0.003	0.958	0.471	0.0153	0.993	0.683

From Table (1), the correlation coefficients (R^2) of the pseudo-first order model are 0.974 and 0.958 for $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$, respectively. While for the pseudo-second-order model, the correlation coefficients (R^2) are 0.991 for $^{60}\text{Co(II)}$ and 0.993 for $^{65}\text{Zn(II)}$. These results indicated that the sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ on the prepared zirconium(IV) selenomolybdate gel matrix followed the pseudo-second order model rather than the pseudo-first order model. Which means that, the sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ onto zirconium(IV) selenomolybdate gel matrix depends on both; the concentration of sorbent and the metal ions. So, it can be

concluded that chemical interaction takes place during the sorption process i.e., the process is chemisorption

Sorption isotherm

Sorption isotherms are important for the description of how molecules of the sorbate interact with the sorbent surface. Hence, the correlation of equilibrium data using either a theoretical or empirical equation is essential for the sorption interpretation and prediction of the extent of sorption. The equilibrium sorption data were generally interpreted using Langmuir and Freundlich models [25]. Langmuir model [26] is based on the assumption of monolayer formation of sorbate ions on the sorbent surface. The linear form of this equation is expressed as:

$$\frac{C_e}{q_e} = \frac{1}{Q_{max}K_L} + \frac{C_e}{Q_{max}} \quad (6)$$

where q_e (mg.g^{-1}) is the sorbed amount of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ ions at the equilibrium concentration C_e (mol.L^{-1}), Q_{max} is the maximum sorbed amount of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ in mg.g^{-1} and k_L is Langmuir constant (L.mg^{-1}) which is related to the intensity of sorption.

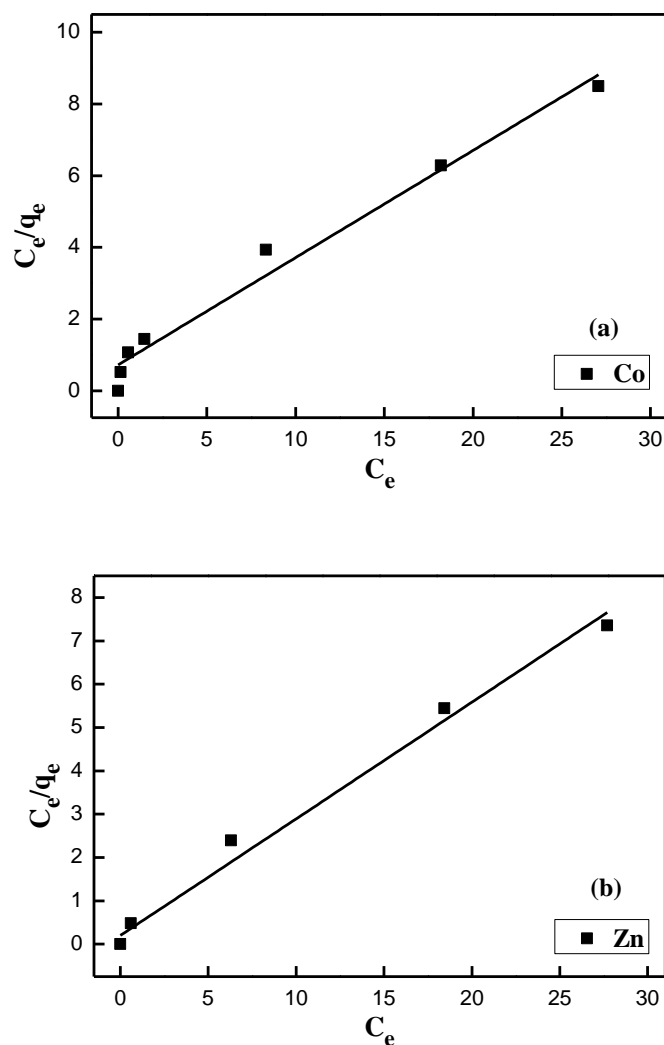


Fig. 8: Langmuir plots for sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ onto zirconium(IV) selenomolybdate gel matrix

Figs. 8 a and b compiles the plots of C_e/q_e as a function of C_e for the sorption of cobalt and zinc. From these figures, linear plots are obtained with R^2 values of 0.974 and 0.987 for $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$; respectively.

The linear form of Freundlich equation is expressed as follow [27]:

$$\log q_e = \log K_F + \frac{1}{n} \log C_e \tag{7}$$

Where, q_e is the sorbed amount of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ (mg.g^{-1}), C_e is the equilibrium concentration of elements in solution (mg.L^{-1}), K_F is Freundlich isotherm constant and n is a Freundlich isotherm exponent constant related to the sorption intensity. **Fig. 9 a and b** displays the plots between $\log q_e$ and $\log C_e$ for the sorption of cobalt and zinc. It was found that the correlation coefficients values are 0.990 and 0.993 for $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$; respectively.

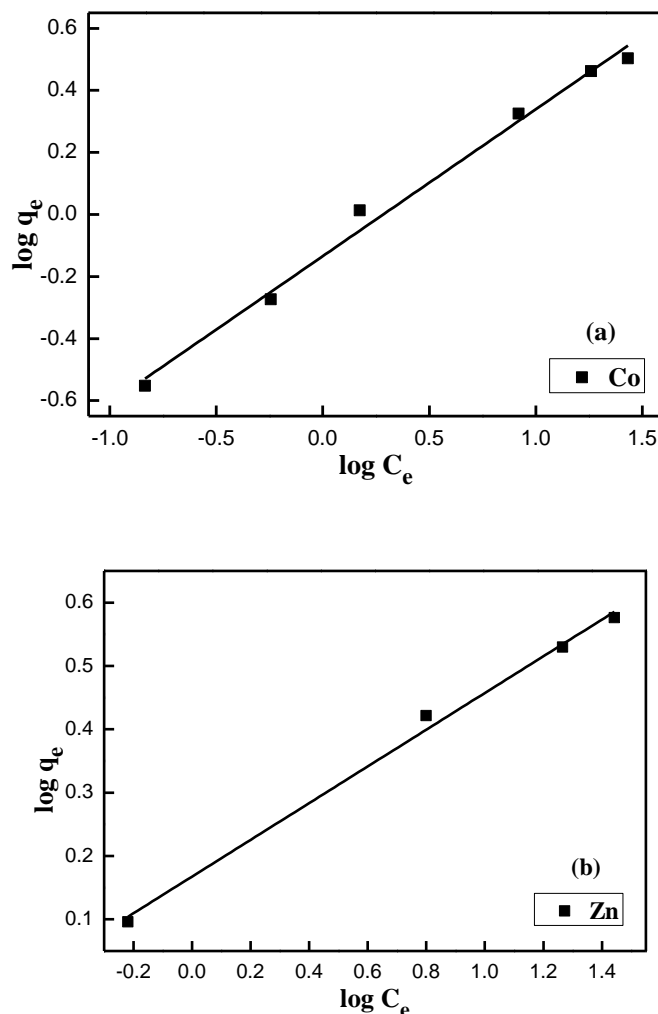


Fig. 9: Freundlich plots for sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ onto zirconium(IV) selenomolybdate gel matrix

Table (2): The correlation constants for Langmiur and Freundlich isotherms for $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ sorption onto zirconium(IV) selenomolybdate sorbent

Sorbate	Langmiur isotherm			Freundlich isotherm		
	$K_L (\text{Lmg}^{-1})$	$q_{\max} (\text{mg/g})$	R^2	$K_F (\text{mg/g})$	$1/n$	R^2
Co	0.412	3.345	0.974	0.734	0.473	0.990
Zn	1.354	3.715	0.987	1.470	0.289	0.993

Comparing the correlation coefficient values (R^2) of Langmiur model with those of Freundlich model as shown in **Table (2)**, it was found that, Freundlich isotherm is more fitted to the experimental date of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ than Langmiur model. So, Freundlich isotherm is more suitable and applicable in the present sorption systems.

Effect of temperature and thermodynamic parameters

The sorption of $^{60}\text{Co}(\text{II})$ and $^{65}\text{Zn}(\text{II})$ onto zirconium(IV) selenomolybdate gel matrix was carried out at three different temperatures 298, 313 and 333 °K. **Fig. 10** compiles the plots of $\ln K_d$ as a function of the reciprocal of absolute temperature for the sorption of cobalt and zinc. It is evident from this figure that the temperature elevation improves the sorption processes $^{60}\text{Co}(\text{II})$ and $^{65}\text{Zn}(\text{II})$ radionuclides which indicates that the present sorption processes are endothermic.

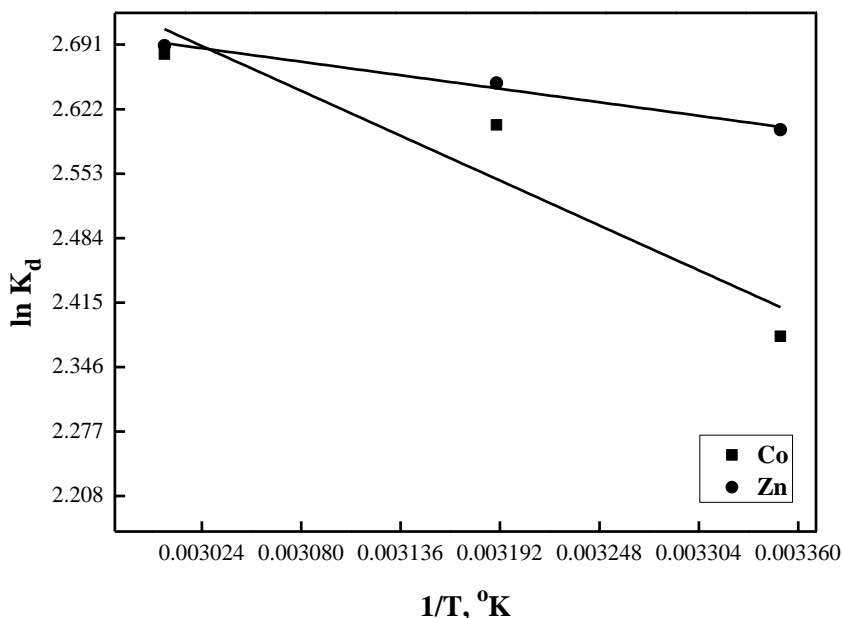


Fig. 10: Effect of reaction temperature on the sorption of $^{60}\text{Co}(\text{II})$ and $^{65}\text{Zn}(\text{II})$ radionuclides onto zirconium(IV) selenomolybdate gel matrix

Based on the data given in **Fig. 10**, thermodynamic parameters such as enthalpy change (ΔH°), entropy change (ΔS°) and Gibbs free energy (ΔG°), can be explained on the basis of by using Vant Hoff equation [28]:

$$\ln K_d = \left(-\frac{\Delta H^\circ}{RT} \right) + \left(\frac{\Delta S^\circ}{R} \right) \quad (8)$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad (9)$$

$$\Delta G^\circ = -RT \ln K_d \quad (10)$$

Where K_d is the distribution coefficient (mL g^{-1}), R ($0.008314 \text{ kJ mol}^{-1} \text{ K}^{-1}$) is the ideal gas constant and T ($^\circ\text{K}$) is the temperature in degree Kelvin.

Table (3): Thermodynamic parameters for sorption of $^{60}\text{Co}(\text{II})$ and $^{65}\text{Zn}(\text{II})$ radionuclides onto zirconium(IV) selenomolybdate gel matrix at different temperatures

Sorbate	T, (K°)	ΔG° , (KJ.mol ⁻¹)	ΔH° , (KJ.mol ⁻¹)	ΔS° , (KJ.mol ⁻¹ .K ⁻¹)
Co	298	-13.57	16.41	100.60
	313	-15.61		
	333	-17.09		
Zn	298	-14.86	4.94	66.40
	313	-15.61		
	333	-17.18		

The thermodynamic parameters for the sorption of $^{60}\text{Co}(\text{II})$ and $^{65}\text{Zn}(\text{II})$ ions onto the zirconium(IV) selenomolybdate gel matrix at various temperatures were calculated and summarized in **Table (3)**. The

positive values of ΔH° indicate that the studied sorption processes are endothermic. Furthermore, the negative values of ΔG° demonstrate the spontaneous behavior of the sorption processes [29]. The decrease in the value of ΔG° with the increase of temperature shows that the reaction was more spontaneous at high temperature which indicated that the sorption processes are favored when temperature increases [30]. Finally, the positive values of ΔS° suggested that the increased randomness at the solid-solution interface during the sorption process [31].

CONCLUSION

Sorption of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ radionuclides onto the prepared zirconium(IV) selenomolybdate gel material are studied and the obtained results showed that the sorption process either of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ radionuclides is dependent on the pH value as well as the reaction temperature. The sorption processes of $^{60}\text{Co(II)}$ and $^{65}\text{Zn(II)}$ ions follow the pseudo-second order and the Freundlich models. Thermodynamic studies indicate that the sorption process is spontaneous endothermic in nature and accompanied by entropy gain under the investigated conditions.

REFERENCES

- [1] Brian J, Heavy Metals in Soils-Trace Metals and Metalloids in Soils and their Bio-availability, Springer Netherlands (2013).
- [2] Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregow KN, Toxicity, mechanism and health effects of some heavy metals, PMC, 2014, 7, pp. 60.
- [3] Vaishaly AG, Mathew BB, Krishnamurthy NB, International Journal of Advances in Scientific Research 2015; 1: 60-64.
- [4] International Atomic Energy Agency, Handling and Treatment of Radioactive Aqueous Wastes, Technical Document No. 654, 1992, IAEA, Vienna.
- [5] Cámara-Martos F, Moreno-Rojas R, "Encyclopedia of Food and Health" Elsevier, 2016, pp. 166-171.
- [6] Pyykko P, Mol Phys 2008; 106:1965-1974.
- [7] Haynes WM, Handbook of Chemistry and Physics, 2016, 96th Edition, CRC Press.
- [8] Audi G, Bersillon O, Blachot J, Wapstra AH, Nuclear Physics A 2003; 729: 3-128
- [9] Keegan GM, Learmonth ID, Case C, Critical Reviews in Toxicology 2008; 38: 645-674
- [10] Moyo M, Open Journal of Applied Biosensor 2014; 3: 1-7
- [11] Cobzaru C, Inglezakis V, "Progress in Filtration and Separation - Chapter Ten: Ion Exchange", Academic Press, 2015, pp. 425-498.
- [12] Clearfield A, Nancollas GH, Blessing RH, Ion Exchanger and Solvent Extraction, 1973, Marcel Dekker, New York.
- [13] Dyer A, Ion Exchange, Reference Module in Chemistry, Molecular Sciences and Chemical Engineering, 2015.
- [14] Zagorodni AA, Ion Exchange Materials Properties and Applications, 2007, Elsevier Ltd.
- [15] Bergaya F, Lagaly G, Vayer M, "Cation and Anion Exchange", Developments in Clay Science, 2013, 5, pp. 333-359.
- [16] Inamuddin, Luqman M, Ion Exchange Technology I: Theory and Materials, 2012, Springer.
- [17] Vogel C, Haack J, Desalination 2014; 342: 156-174
- [18] Naushad M, Ion Exchange Letters 2009; 2: 1-14
- [19] Nabi SA, Shalla AH, Khan AM, Ganie SA, Colloids and Surfaces A: Physicochemical and Engineering Aspects 2007; 302: 241-250
- [20] Kai LV, Xiong LP, Luo YM, Colloids and Surfaces A: Physicochemical and Engineering Aspects 2013; 433: 37-46
- [21] Nabi SA, Khan AM, Reactive and Functional Polymers 2006; 66: 495-508
- [22] Ho YS, McKay G, Process Biochem 1999; 34: 451-465.
- [23] Donat R, Akdogan A, Erdem E, Cetisli H, J Colloid and Interface Science 2005; 286: 43-52.
- [24] Lagergren S, Handlingar 1898; 24: 1-39.
- [25] Grabowska EL, Gryglewicz G, Dyes Pigm 2007; 74: 34-40.
- [26] Langmuir I, J Am Chem Soc 1915; 37: 1139 - 1167.
- [27] Freundlich HMF, J Phys Chem 1906; 57: 385-471
- [28] Murray JW, Dillard JG, Geochim Cosmochim Acta 1979; 43: 781-787



- [29] Abd El-Latif MM, Ibrahim AM, El-Kady MF, J Am Sci 2010; 6: 267-283
- [30] Syed M, Muhammad I, Rana G, Sadullah K, Sep Purif Technol 2008; 59: 108-114.
- [31] Abd El-Latif MM, Ibrahim AM, El-Kady MF, Alex Eng J 2009; 48: 137-149.