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The Analysis of Adsorption Phenomenon for Nano Silica with Some Radionuclides Released in The Primary Coolant of PWR

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NANO silica particles were tested to remove some radionuclides (R.Ns) from primary coolant water through different experiments. A simulation of the R.Ns such as Strontium (Sr), Nickel (Ni) and Cobalt (Co) was conducted by using the same chemical elements. From experiments, the adsorption capacity values at elements of concentration 400mg/l were 19128, 18270 and 19728mg/g, respectively. The analysis of the adsorption phenomena was described through different kinetic factors, adsorption isotherms, and thermodynamic parameters. From the data of experiments, The amount of elements adsorbed by nano particles ($q_{e\,cal}$) was the same for three elements and equal 20000 mg/g in the pseudo second order model. By the intraparticle diffusion model, the $q_{e\,cal}$ values were equal 19024, 18006 and 19131mg/g, respectively. It meant a very strong chemical adsorption process. In Freundlich isotherm, the calculated correlation factors of three elements were 0.979, 0.992 and 0.990, respectively. These results confirmed the heterogeneity of nano-silica surface and the adsorption was multilayer and cooperative process. From D-K-R isotherm, the calculated energies were 316.23, 316.23 and 353.55 kJ mol-1, respectively. From the thermodynamic results, the reaction for the three elements was spontaneous. This work confirmed that the nano silica could be good adsorbent material for removing R.Ns.

Keywords: Thermodynamic, Sorption; Nano silica, Sr; Ni, Co, Kinetic .

Introduction

Pressurized water reactor (PWR) is divided into two circuits: a-primary coolant circuit, b-secondary coolant circuit. The primary coolant water (PCW) in primary coolant circuit could polluted by different radionuclides. These R.Ns might be fission product (FP) such as 90Sr, activation product (AP) such as 59Ni and corrosion products (CP) such as 60Co. Released radionuclides (R.Ns) in the PCW can be removed through the chemical volume control system (CVCS) by using four ion exchange vessels [1-3].

Ion-exchangers are containing resin materials which applied to isolate and treat the target ion from the polluted solutions [4]. Some of the ion exchange resins are organic material like, phenolic resins, cellulose and charcoals. They do not have high capacity of exchange. They are swelled and does not have fixation in both the thermal bath and the radiation bath [5]. Besides, they might be high in cost. they do not eliminate the aim ion in the presence of other ions very well. After all the problems caused by organic resins, researchers were forced to try and apply inorganic substances such as clays [6], hexacyanoferrates [7] and zeolites [8]. Also, the using of them

appeared non stability in the mechanical form and in chemical bath. They are very expensive such as zeolites. Most of them are very sensitive to severe pH ranges [9]. Therefore, this work tried to find an alternative had the same role and did not cause problems. Consequently, nano technology was used as a new field for the removal of the R.Ns from PCW.

Nanotechnology is an engineering material science. Most of the synthesized nano particles are higher strength, lighter weight, and greater chemical reactivity than their larger-scale counterparts [10]. Because of the special size of nano particles, shape and crystal-phase, they are applied in the adsorption of different elements. The porosity, surface charge, chemical composition, and purity are important determinants of the nano particles' intake for the elements [11-13]. Nanoparticles show good diffusion at elevated temperatures due to their high surface area to volume ratio [14-15]. At the nanoscale, different forces are dominated such as particle-particle interactions, weak Van der Waals forces, stronger polar, electrostatic interactions and/or covalent interactions [16-17].

An example of nanoparticles is the nano silica. It is used to improve the durability, continuity of concrete and improve mechanical properties of cement materials [18-19]. Meanwhile, the cement materials are used in solidification and preparation of containers of radioactive waste. Accordingly, in previous work [20], the nano silica particles were tested in the treatment of the contaminated water to take its advantages with the cement material during conditioning of the waste. The results exposed that nano silica particles give a high removal rate for some elements from contaminated water [20]. Therefore, it was proposed as an alternative treatment material than organic resin beds in CVCS.

The aim of this work was analyzing the sorption process of the nano silica with these elements. The analysis was conducted by studying kinetic factors, adsorption isotherms and thermodynamic parameters.

Methodologies

Different parameters were deeply studied to understand the behavior of nano-silica in the presence of the elements such as; sorption; kinetic factors, adsorption isotherms and thermodynamic parameters.

Sorption

It is a physical and thermo-chemical process by which one substance becomes attached to another by either absorption or adsorption. The Absorption process is the combination of a substance in one state into another of a different state. In absorption process substance penetrates the surface. It occurs at uniform rate. It is unaffected by temperature; it is an endothermic process [21]. In the other hand, adsorption is physical cohesion of binding ions and molecules on surface of another phase [22]. It is surface phenomenon. It is an exothermic process [21].

Physical Adsorption or Physisorption

This phenomenon depends on the weak Van der Waal forces. The increasing in temperature increases physisorption. Porous substances are better adsorbents as an increased surface area, which raise adsorption. It does not need any energy for activation [23].

Chemical Adsorption or Chemisorption

It is an exothermic process, which promote temperature. It takes place slowly at low temperature in a higher rate and an increase in pressure. Both physisorption and chemisorption cases are directly proportional to surface area [23].

The sorption studies
Sorption capacity
The mass balance of element is given by:

$$m \cdot q = V (C_0 - C) \qquad (1)$$

Where m, q, V, C_0, and C are the mass of nano silica (g), amount of element removed by unit of weight (mg element/g nano silica), volume of element solution (l), initial element concentration of solution (mg/l), and the concentration of element at the time *t* of adsorption (mg/l) [24].

Kinetic factors

In different cases, the adsorption kinetics are affected by various diffusion mechanisms either bulk diffusion or film diffusion. Sometimes the impact diffusion of intraparticle cannot be ignored on the mechanism. Three models were used for studying the kinetic factors based on the pseudo-first order equation, the pseudo-second-order equation and the intraparticle diffusion model [25-26].

The pseudo-first order equation (Langergren and Svenska, 1898) can be expressed as Eq. (2):

$$\text{Log} (q_e - q) = \log q_{e\,cal} - (k_1 / 2.303)\, t \qquad (2)$$

Where q is the amount of element adsorbed (mg. g^{-1}) at any given time t (min), q_e is the amount of element adsorbed (mg.g^{-1}) at equilibrium and k_1 is the pseudo-first order reaction rate constant for adsorption (min^{-1}).

The pseudo-second order equation (Ho andMckay, 1998) is defined as

$$t/q_t = 1/(k_2 q_{2e\ cal}) + (t/q_{e\ cal})\qquad(3)$$

Where q_t is the amount of element adsorbed (mg. g^{-1}) at any given time t (min), q_e is the amount of element adsorbed (mg.g^{-1}) at equilibrium and k_2 is the second order reaction rate constant for adsorption (g $(mg.min)^{-1}$).

The intraparticle diffusion model (I. Smičiklas, et al., 2006) can be calculated in the following equation :

$$q_t = k_D.t\ 0.5 + C_i\qquad(4)$$

Where q_t is the amount of element on the surface of the nano silica at time t (mg.g $^{-1}$), K_D is the intraparticle rate constant (mg (g.min 0.5) $^{-1}$), t is the time (min) and C_i represents the boundary-layer effect.

Adsorption Isotherms
It is important to analyze the equilibrium data to detect the isotherm equation of the adsorption mechanism. The obtained results are important to use in the design purposes [27]. The present work applies the Langmuir, Freundlich and The DKR equations to study the equilibrium relation between elements and its concentration at constant temperature [28-29].

Langmuir Adsorption Isotherm
This model determines the number of nano silica active sites for adsorption.

the equation is described as follow [30]:

$$C_e/q_e = (1/q_m)\ C_e + (1/(q_m * k))\qquad(5)$$

Where C_e is the equilibrium concentration (mg /l); q_e is the adsorption capacity on nano silica (mg g^{-1}); q_m refers to the maximum adsorption capacity at monolayer coverage (mg.g^{-1}); k is the Langmuir adsorption constant (l .mg^{-1}).

Freundlich Adsorption Isotherm
This isotherm gives information about the degree of surface heterogeneity [31].

The equation is:

$$Ln\ q_e = ln\ K_f + (1/n)\ ln\ C_e\qquad(6)$$

Where 1/n is a heterogeneous factor. When 1/n<1 it means that the adsorption process is normal process. When 1/n>1 it means the adsorption is cooperative process [32]. K_f is the Freundlich adsorption constant (mg g^{-1}). Each of them is determined by the slope and intercept of the linear plots.

The Dubinin– Kaganer– Radushkevich equation (DKR)
The DKR equation is used for estimating the adsorption energy

It has the form :

$$Ln\ q_e = Ln\ q_m - \beta\ \varepsilon2\qquad(7)$$

Where β (mol2/J2) is the constant of the adsorption energy related to mean adsorption energy, and ε is the Polanyi potential, which is equal t:

$$\varepsilon = R\ T\ ln\ (1 + 1/Ce)\qquad(8)$$

Where R is the gas constant (8.314 J/mol.K) and T is the temperature (K).

Furthermore, E is the value of mean energy of adsorption (kJ/mol), it is expressed as following:

$$E = 1/(2\beta)0.5\qquad(9)$$

Thermodynamic parameters
The main Thermodynamic parameter used in this work for the sake of the design is gibbs free energy ($\Delta G°$). It is given by the following equatio:

$$\Delta G° = \Delta H° - T\ \Delta S°\qquad(10)$$

$\Delta G°$ It determines the spontaneity of adsorption process (kJ/mol) [33], and ($\Delta H°$) calculates the heat direction of adsorption reaction; in other words, endothermic or exothermic [34]. The change of entropy ($\Delta S°$) is the measure of the randomness of a system; low entropy is highly ordered [35].

The thermodynamic parameters can be calculated from the temperature dependent isotherm by the equatio :

$$K_d = (\text{amount of element in solution}/\text{amount of element in nano silica})*(V/m)\qquad(11)$$

Where V is the volume of the solution (ml) and m is the weight of adsorbent (g).

$$Ln\ K_d = -(\Delta H°/RT) + (\Delta S°/R)\qquad(12)$$

Where K_d is the distribution coefficient, ml/g; R is the universal gas constant equal 8.314 J/mol.K and T is the absolute temperature (K). the $\Delta H°$ and $\Delta S°$ are calculated from the slope and intercept of ln K_d versus 1/T.

Experimental Work

Preparation of nano-silica

It has been prepared from rice straw ash (RSA) as described in a previous work [36].

Experiment for studying the contact time and calculating the kinetic factors

The chemical compounds such as strontium chloride ($SrCl_2.6H_2O$), nickel chloride ($NiCl_2.6H_2O$) and cobalt chloride ($CoCl_2.6H_2O$) were used. Sr, Ni and Co stock solutions of concentration 400 mg/l were prepared. 20 ml of each stock was mixed and added to 0.01 gm of nano silica. Because of the time range from 5 to 120 min, the previous step was repeated to prepare 6 flasks for more accuracy. The value of pH was 6. All flasks were put in the shaker model (SK-600, Lab Companion) at 150 r.p.m. The samples of volume 15 ml were pulled and put in test tubes. The tubes were put in the centrifuge model (Heraeus Labofuge 200) at 5000 r.p.m for 10 min. After separation, the liquid phase samples were withdrawn by a pipette. All of them were analyzed in the ICP model (720 ICP-OES, Agilent Technologies). The contact time was studied.

Experiment for calculating the adsorption isotherm parameters

Stock solutions containing Sr, Ni, and Co of concentration 100, 200, 300 and 400 mg/l were prepared. A 0.01 g of nano silica was added to 20 ml of each stock solution in a beaker. The previous step was repeated in 5 beakers for accuracy. The beakers were shacked with 150 rpm using the same shaker. The temperature of the solution was at 25°C. The pH of the solution was 6. Batch experiments were performed at time intervals (5, 10, 20, 30, 60, and 120 min). Samples were taken of volume 15 ml and put in test tubes. The test tubes were put in the same centrifuge at 5000 r.p.m for 10 min. ICP was used for sample analysis. The various kinetic parameters and adsorption isotherm factors were calculated from the results of these experiments.

Experiment for calculating thermodynamic parameters

Batch experiments were prepared by mixing 50 ml of each stock and 1 gm of nano-silica in different conical flasks. The flasks were put on the heater shaker bath model (GYROMAX 929 Orbital Water Bath Shaker) at 25, 40 and 60°C. The samples were analyzed in ICP. The results from these samples were utilized to calculate the thermodynamic parameters.

Results and Discussion

In the presence of tiny diameter of nano particles (17-33 nm) as obtained from previous work [37], with respect to the particle diameter of the element, the sorption behavior is considered adsorption and not absorption. In the case of adsorption, the nano particle is the adsorbent and the elements are adsorbate.
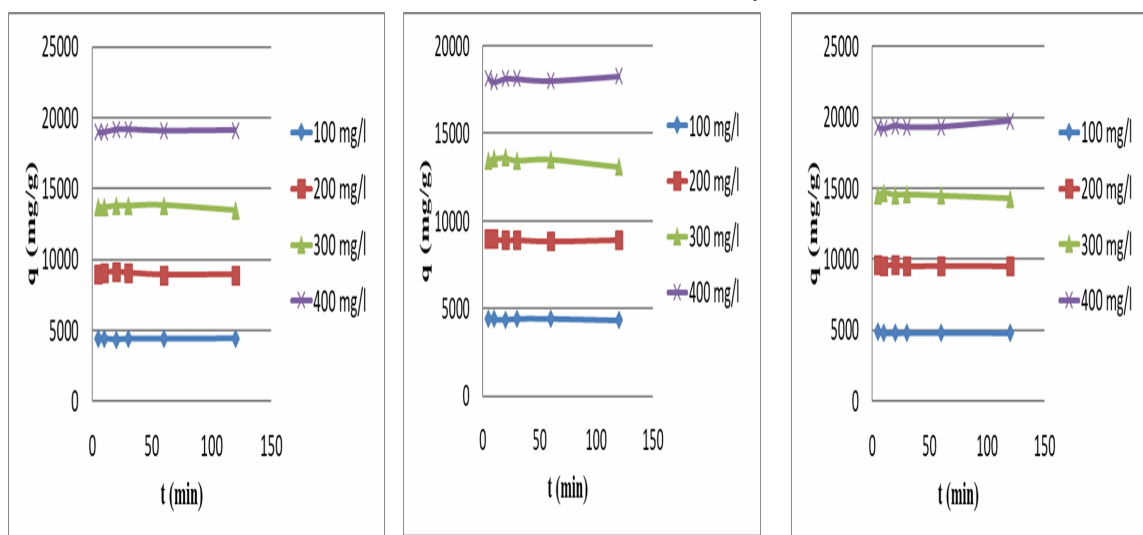
Kinetic factor results

Fig.1. The relation between the amount of element removed by weight of nano silica (q) and time (t) for (a)Sr, (b) Ni and (c)Co.

Note: the three chemical elements existed together in the form of a mixture in this experiment. The individual behavior for each element was illustrated in separate figures

Data of experiment (2) were applied in equation (1) to get the Fig.1. From Fig.1, the amount of the element removed by unit of weight of nano silica (q) was directly proportional to the concentration of (Sr, Ni, and Co) from 100 to 400 mg/l. The adsorption reaction was fast. The equilibrium was reached after 10 min approximately for the three elements. In the range from 100 to 400 mg/l, the adsorption capacity values at the elements of concentration 400 mg/l were the highest. These values were 19128, 18270 and 19728 mg/g, respectively.
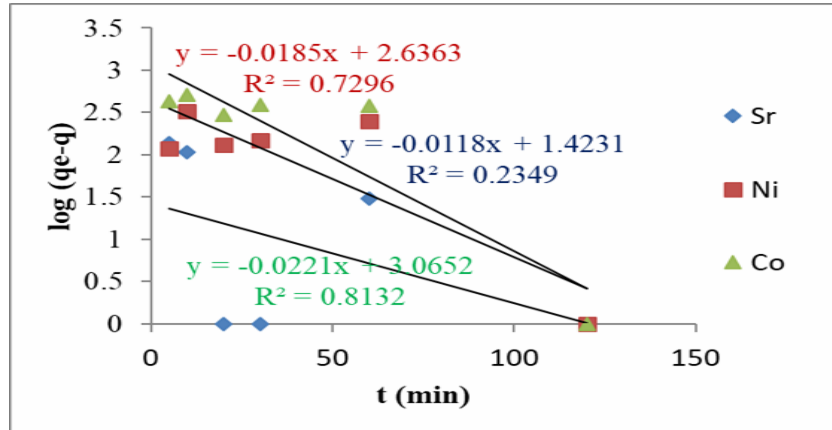

Fig. 2 (a). The relation between the amount of element adsorbed (q), the amount of element adsorbed at equilibrium (q$_e$) and time (t) at the pseudo-first order.
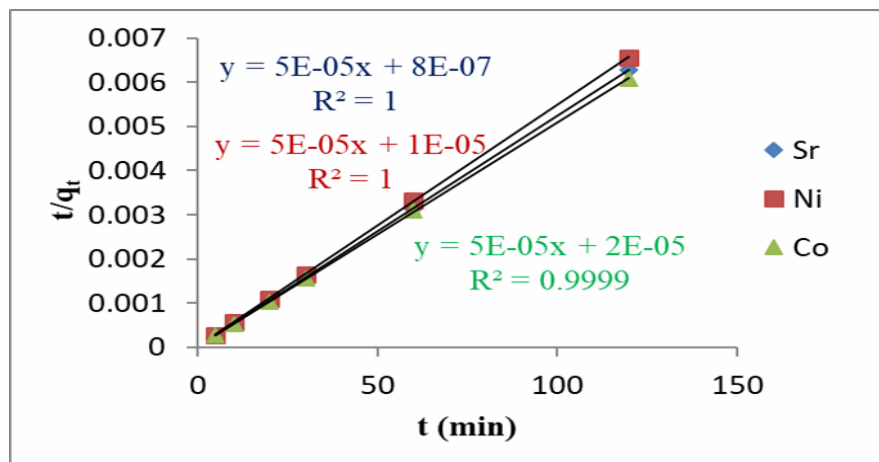

Fig.2 (b). The relation between the amount of element adsorbed (q$_t$) and any time(t) at the pseudo -second order.
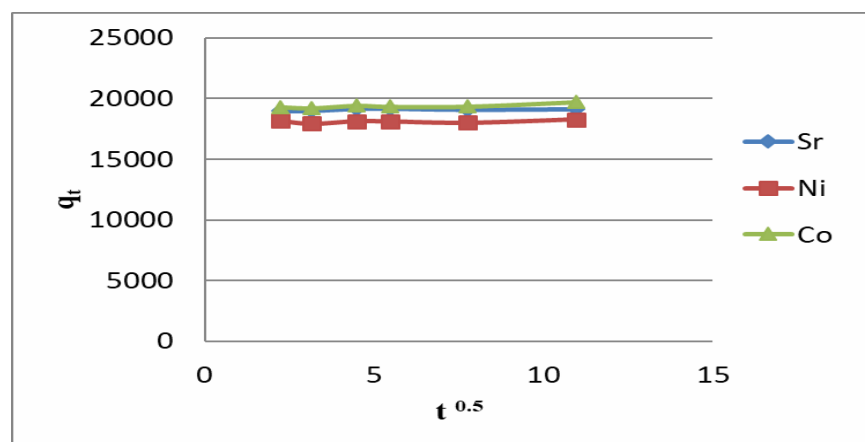

Fig. 2 (c). The relation between the amount of element on the surface of the nano silica (q$_t$) and the time (t) at the intraparticle diffusion model.

The application of pseudo-first order equation, pseudo-second order and intraparticle diffusion was demonstrated by Fig.2 a, b and c, respectively. These models were explained different forms of the amount of the elements adsorbed with time.

By The equation (2) and the Fig.2 (a), $q_{e\,cal}$ could be calculated at the pseudo- first order model. The values of $q_{e\,cal}$ of Sr, Ni, and Co from Fig. 2 (a) were 4.150, 13.961and 21.439, respectively. These values were not in the range of the experimental data, which indicated that the adsorption process for the elements didn't compatible with the pseudo-first order model.

Figure 2 (b) illustrated that the pseudo-second order matches with this process. With The equation (3) and the Fig.2 (b), $q_{e\,cal}$ could be estimated. The $q_{e\,cal}$ value equal 20000 mg/g for the three elements. From these results, the adsorption process was chemical and occurs by film diffusion.

Through The equation (4) and the Fig.2 (c), $q_{e\,cal}$ could be evaluated at the intraparticle diffusion model. The $q_{e\,cal}$ values of Sr, Ni and Co were equal 19024, 18006 and 19131mg/g respectively. These results indicated the compatibility of intraparticle diffusion mechanism with the adsorption process. Therefore, Fig.2 (b) and (c) concluded that the pseudo–second order and intraparticle diffusion models were applied to the current adsorption. The results of kinetics analyses indicated the chemisorption process [38-39].

In general, the mechanism depends on the film and/or particle diffusion-controlled [40]. Before adsorption takes place, the sorbate should pass through the bulk of the solution, then the adsorbent film finally into the (micro and macro) pores of the adsorbent. It wasn't in agreement with the scale of nano-silica and one of the different elements (Ψ) which had been used in this work. An assumption was considered based on the agglomeration of nano silica. This might be responsible for the apparent intraparticle diffusion as shown in Fig.3. The nano-silica was enclosed around the element particles by the effect of agglomeration and prevents its mobility [41]. Therefore, the energy of the adsorption process was increased. The diameter of the element particle was also responsible for this phenomenon. Accordingly, Sr showed the highest adsorption rate. The elementary particles of fewer diameters such as Ni and Co ions had an escaping possibility from the agglomeration phenomenon. Additionally, intraparticle diffusion was not the rate-controlling step because its line not passed through the origin and R2 was very low.

Experimental data were applied in equations (1 up to 4) for calculating the parameters of the models. Table 1 listed the calculated values of various parameters of the different models: the pseudo-first order, the pseudo-second order, and the intraparticle rate constant (K_D) (mg (g.min 0.5)$^{-1}$), respectively.
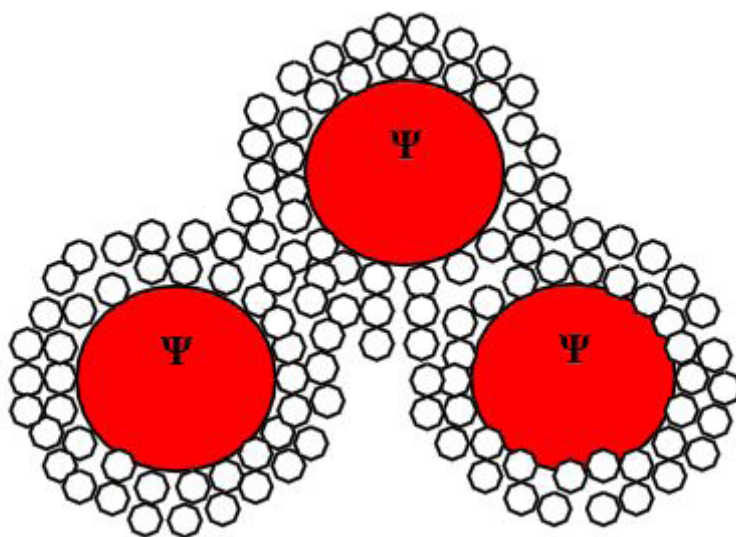

Fig .3. the agglomeration of nano silica around the elements .

TABLE 1. values of parameters calculated using the pseudo-first order, the pseudo-second order and intraparticle diffusion models.

E	Equation	pseudo-first-order kinetic model			
		K_1[min-1]	$q_{e\,cal}$ [mg/g]	$q_{e\,exp}$[mg/g]	R2
Sr	y= -0.0118x+1.4231	0.027	4.150	19128	0.235
Ni	y= -0.0185x+2.6363	0.043	13.961	18270	0.730
Co	y= -0.0221x+3.0652	0.051	21.439	19728	0.813
		pseudo-second-order kinetic model			
		K_2[min-1]	$q_{e\,cal}$ [mg/g]	$q_{e\,exp}$[mg/g]	R2
Sr	y= 5E-05x+8E-07	0.003	20000	19128	1
Ni	y= 5E-05x+1E-05	0.00025	20000	18270	1
Co	y= 5E-05x+2E-05	0.0001	20000	19728	0.999
		Intraparticle diffusion model			
		K_d[mg.g-1min-1/2]	$q_{e\,cal}$ [mg/g]	$q_{e\,exp}$[mg/g]	R2
Sr	Y=12.346x+19024	12.346	19024	19128	0.2888
Ni	Y=17.536x+18006	17.536	18006	18270	0.2437
Co	Y=46.363x+19131	46.363	19131	19728	0.708

Results of Adsorption isotherm parameters:

Figure 4.a), b) and c) represented Langmuir, Freundlich and (DKR) adsorption isotherms, respectively. From experimental data, the equations (5 up to 6) were used for calculating the parameters of the isotherms. The results reflected that the three elements had the same adsorption behavior. as shown in Fig.4 (b) and (c), the process followed the Freundlich and the Dubinin isotherms according to their high correlation coefficient R2. Depending on Freundlich isotherm, the nano-silica had heterogenous surface and the adsorption occurred in multilayers. A cooperative adsorption process was observed because of the higher values of the heterogeneity factor i.e (1/n > 1).

The type of adsorption process could be determined from the value of apparent adsorption energy E. If the value of E was lower than 8 kJ/mol, the process was physical adsorption. If the value of E was higher than16 kJ / mol, the process of chemical adsorption was very strong [36-38]. The adsorption energy values of the process calculated from (DKR) equations were 316.23, 316.23 and 353.55KJ mol-1, respectively. These results confirmed the virtual chemical adsorption. Additionally, surface charge and electrostatic forces and speciation of element [42-44] could

play some roles in the adsorption process, which prove the high values of energy.

Equations (5 up to 9) were applied for evaluating the parameters by using the experimental data. Table 2 listed the calculated parameters of the Langmuir, Freundlich, and Dubinin–Kaganer–Radushkevich (DKR) isotherms.

Determination of thermodynamic parameters:
The amount of each R.N adsorbed on nano silica at different temperatures was determined as shown in Fig.5 (a). From experimental data, K_d was calculated by equation (11). From the Fig.5 (b), the thermodynamic parameters: $\Delta H°$, and $\Delta S°$ were specified by the slope and intercept of the line using the equation (12).

From equation (10), $\Delta G°$ was calculated and showed (–ve) sign in case of the three elements which reflect spontaneous reaction. However, in the case of Sr, the reaction of adsorption was endothermic evaluated from the positive sign of enthalpy. The slightly increase in K_d with the temperature confirmed the endothermic reaction. In the case of Ni and Co the adsorption reaction was exothermic ($\Delta H°$=-ve); (K_d) values for Ni and Co were slightly decrease with the temperature. Table 3 listed the calculated values of thermodynamic parameters. Low values of $\Delta S°$ mean highly order.
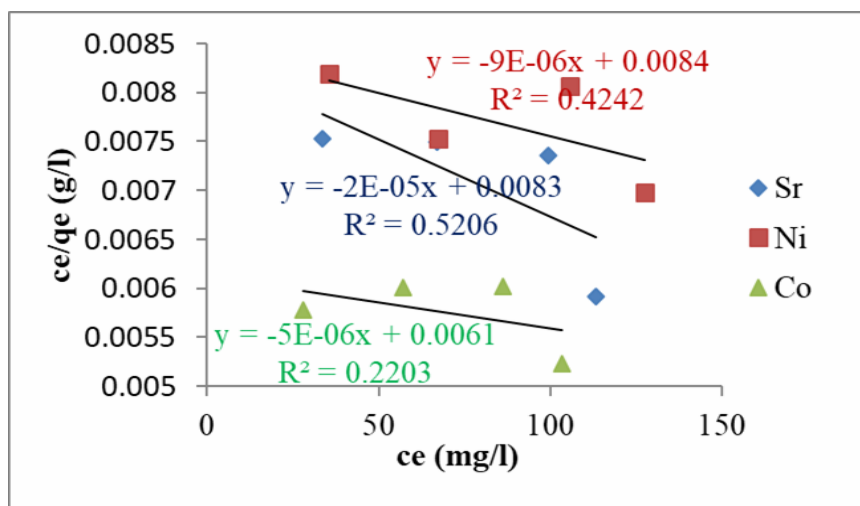
Fig. 4 (a).The relation between equilibrium concentration (C$_e$) and the adsorption capacity on nano silica (q$_e$) in Langmuir adsorption isotherm.
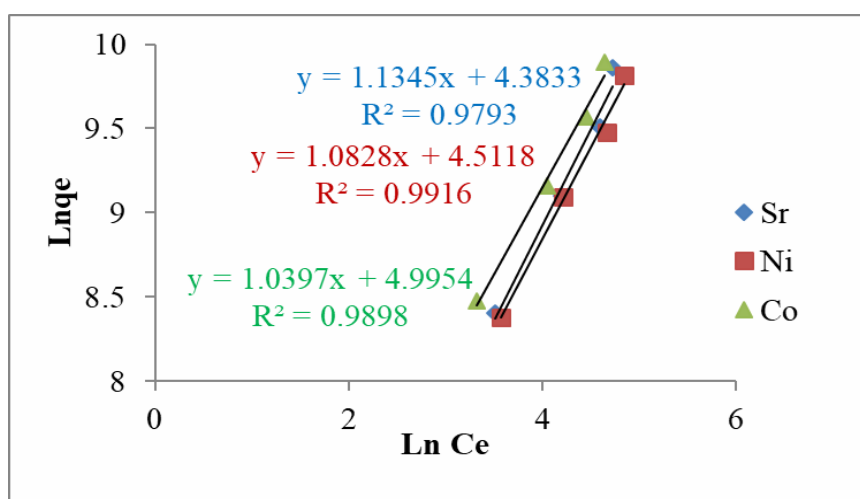

Fig.4 (b). The relation between the adsorption capacity on nano silica (Lnq$_e$) and the equilibrium concentration (LnC$_e$) in Freundlich adsorption isotherm.

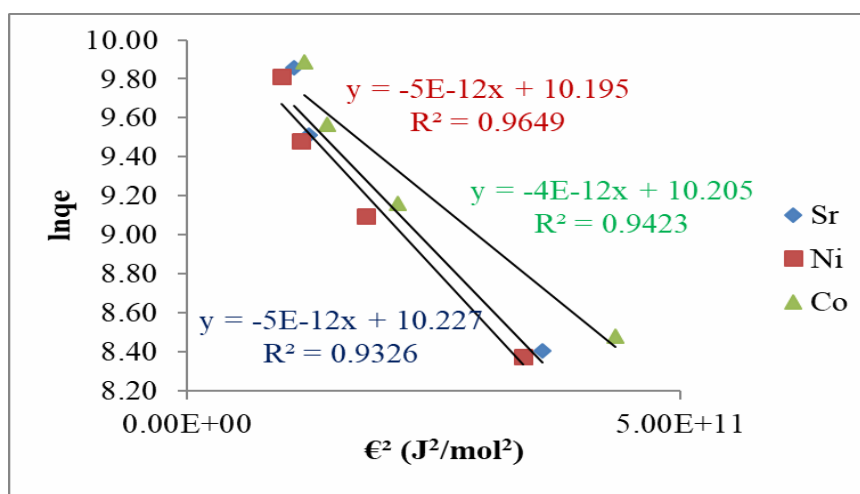
Fig. 4 (c). The relation between the adsorption capacity on nano silica (Lnq$_e$) and Polany potential in Dubinin–Kaganer–Radushkevich adsorption isotherm.

TABLE 2. Calculated parameters of Langmuir, Freundlich, and Dubinin–Kaganer–Radushkevich (DKR) isotherms .

		Langmuir			Freundlich		
Adsorbate	T(K)	q_m(mg/g)	K	R2	K_f (mg g^{-1})	1/n	R2
Sr	298	-5.00E+04	-2.41E-03	0.521	80.10	1.13	0.979
Ni	298	-1.11E+05	-1.07E-03	0.424	91.09	1.08	0.992
Co	298	-2.00E+05	-8.20E-04	0.220	147.73	1.04	0.990

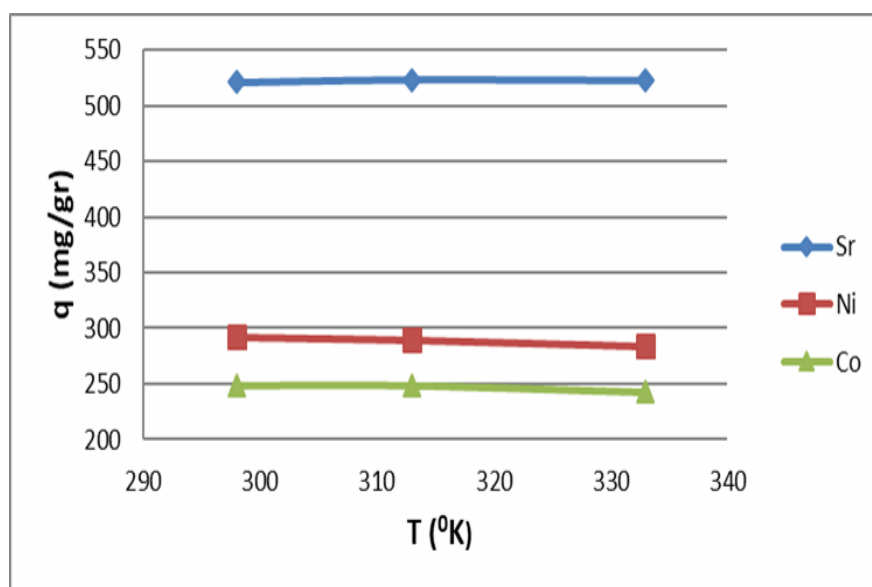|	Dubinin-Redushckevich		
Adsorbate	β (mol²J-²)	q_m (mg g^{-1})	E (KJ mol-1)
Sr	5.00E-12	27639.47	316.23
Ni	5.00E-12	26769.01	316.23
Co	4.00E-12	27038.04	353.55

Fig. 5 (a). The relation between the adsorption capacities of the elements (q) and temperature (T).
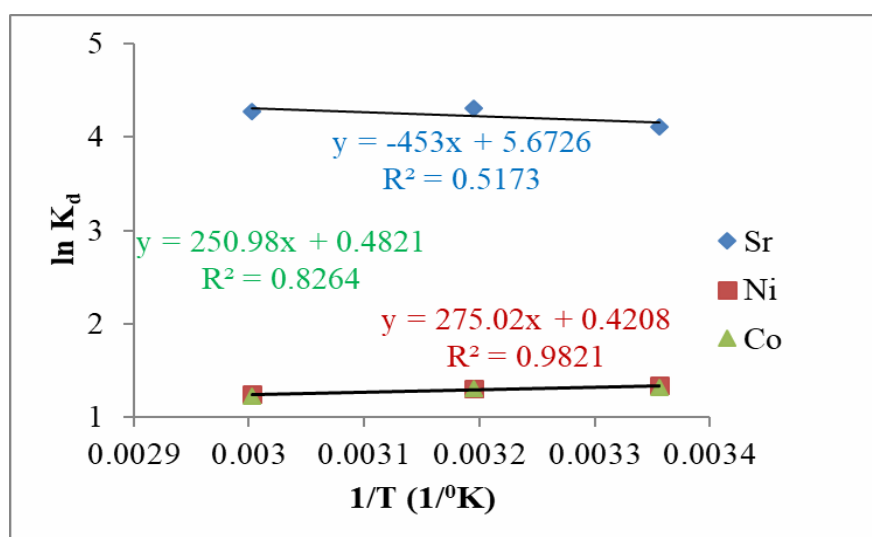

Fig. 5 (b). the relation between the distribution coefficient (K_d) and the temperature (T).

TABLE 3. Calculated thermodynamic parameters for the adsorption of the elements onto nano-silica in aqueous solutions.

Adsorbate	T (K)	K_D	ΔG^o(J/mol)	ΔH^o (J/mol)	ΔS^o (J/mol.K)
	298	60.58	-10.28		
Sr	313	74.77	-10.99	3.77	0.05
	333	71.63	-11.93		
	298	3.82	-3.33		
Ni	313	3.70	-3.38	-2.29	0.003
	333	3.47	-3.45		
	298	3.71	-3.28		
Co	313	3.70	-3.34	-2.09	0.004
	333	3.40	-3.42		

Conclusions

The nano silica particles were experimented, in previous work, with the three elements and gave remarkable results. The high removal percentages of the elements by nano-silica confirmed that it was a good adsorbed material. In the present work, the analysis of the adsorption mechanism of nano-silica with the elements was explored. Kinetic factors, adsorption isotherms, and thermodynamic parameters were studied.

The nano silica showed a discrepancy between theoretical and experimentally values of kinetic studies and adsorption isotherm models as the results of its unique adsorption process.

From Kinetic study, the nano silica followed the pseudo–second order and intraparticle diffusion models. In other words, the adsorption process could be a chemical reaction and was controlled by film diffusion. Considering the scale of nano particle relative to the elementary particles, the adsorption process was affected by the agglomeration of nano silica.

From adsorption isotherm, the adsorption reaction was fitting the Freundlich isotherm which indicated the heterogeneous surface, multilayers adsorption and cooperative process. In other words, the adsorption process was occurred on more than active sites. It was compatible with the vision of the apparent intraparticle diffusion of nano-silica around R.N. The calculated adsorption energy, from DKR equation, showed very high values. The values were 316.23, 316.23 and 353.55KJ mol^{-1} for Sr, Ni, and Co, respectively. These values confirmed the existence of many processes rather than the virtual chemisorption such as the effect of surface charge and electrostatic forces.

From thermodynamic parameters, the Sr reaction in the presence of nano silica was spontaneous and endothermic. In the case of Ni and Co, the process was spontaneous and exothermic. The change of entropy for the elements was low and the system was ordered. From these results, the nano silica was proofed that it is an efficient material for the treatment of the contaminated water.

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تحليل ظاهرة الامتزاز للنانو سليكا مع بعض النويدات المشعة التى تنطلق فى المبرد الاولى لمفاعل الماء المضغوط

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تم اختبار جزيئات النانو سيليكا لإزالة بعض النويدات المشعة (R.Ns) من مياه المبرد الأساسي من خلال تجارب مختلفة. أجريت محاكاة للـ R.Ns مثل الاسترنشيوم(Sr) ، والنيكل (Ni) والكوبالت (Co) باستخدام نفس العناصر الكيميائية. من التجارب ، كانت قيم قدرة الامتزاز عند تركيز ٤٠٠ مجم / لتر من العناصر هي ١٩١٢٨ و ١٨٢٧٠ و ١٩٧٢٨mg / g ، على التوالي. وقد وصف تحليل ظاهرة الامتزاز من خلال العوامل الحركية المختلفة ، متساوي الحرارة الامتزاز والمعايير الديناميكية الحرارية. من بيانات التجارب ، كانت كمية العناصر التي تمتصها جزيئات النانو (qe cal) هي نفسها بالنسبة للثلاثة عناصر وتساوي ٢٠٠٠٠ ملغم / جم في نموذج الرتبة الثانية المزيفة. بواسطة نموذج الانتشار داخل الجسيمات ، كانت قيم qe cal تساوي ١٩٠٢٤ و ١٨٠٠٦ و ١٩١٣١ ملجم / جم على التوالي. وهذا يعني عملية الامتزاز الكيميائي قوية جدا. في Freundlich isotherm ، كانت عوامل الارتباط المحسوبة للثلاثة عناصر هي ٠,٩٧٩ و ٠,٩٩٢ و ٠,٩٩٠ ، على التوالي. أكدت هذه النتائج عدم تجانس سطح النانو السيليكا وان الامتزاز متعدد الطبقات وانه عملية تعاونية. من D-K-R متساوي الحرارة ، كانت الطاقة المحسوبة ٣١٦,٢٣ ، ٣١٦,٢٣ و ٣٥٣,٥٥ كيلو جول مول ١ ، على التوالي. من النتائج الديناميكية الحرارية ، كان رد فعل العناصر الثلاثة عفوية. أكد هذا العمل أن النانو سيليكا يمكن أن تكون مادة جيدة الامتصاص لإزالة R.Ns.