

Removal of strontium from aqueous solutions by adsorption onto orange peel: isotherms, kinetics, and thermodynamic studies

M. abdelkreem^{1*} and Dalal Z. Husein²

¹Higher Technological Institute, 10th of Ramadan City, Egypt

²Chemistry Administration, Cairo, Egypt

Abstract

The removal of Sr (II) from aqueous solution using orange peel (OP) and chemically modified ones with NaOH (NaOP) and KCl (KOP) was studied at varying pH, solid/liquid ratio, contact time, temperature range of (20-60°C). Adsorption equilibrium was established in about 1h and the equilibrium data was analyzed using Langmuir, Freundlich, Temkin and Dubinin-Radushkevich adsorption isotherms. Langmuir model provided the best correlation for the adsorption of Sr(II) by the three adsorbents (OP, NaOP and KOP), and the mono-layer adsorption capacity for Sr(II) removal are 12.64, 54.94 and 52.36 for OP, NaOP and KOP mg/g, respectively. The adsorption kinetics followed the pseudo-second order kinetics model and thermodynamic studies showed the spontaneous and exothermic nature of the adsorption of Sr(II) by OP, NaOP and KOP. The present study emphasized that the chemically treated orange peel exhibited a high potential for the removal of strontium (II) from aqueous solution.

Keywords: Strontium, adsorption, isotherm, orange peel

Introduction

Contamination of industrial wastewater by heavy metals is an important environmental problem. Every day many industries release various concentrations of strontium. The primary use of strontium is in the manufacture of X-ray absorbing glass for cathode ray tubes. Also, strontium is used for removing lead from solutions of zinc sulphate in the electrolytic zinc process, and for the production of strontium metal, oxide superconductors and electroceramics. Strontium has a variety of research and commercial uses.

*Corresponding author: Dalal Z. Husein E-mail: mahaabdelkreem@gmail.com

It has been used in certain optical materials, and it produces the red flame color of pyrotechnic devices such as signal flares and fireworks. Strontium has also been used as eliminator for oxygen in electron tubes and to produce glass for color television tubes. Beyond the four stable isotopes which are present in soil naturally, strontium-90 is also present in the surface soil around the world as a result of fallout from past atmospheric nuclear weapons tests.

Strontium prefers to adhere to soil particles, and the amount in sandy soil is about 15 times higher than in interstitial water (water in the pore space between soil particles); concentration ratios are typically higher in clay. Strontium ion is slightly toxic and its toxicity is closely associated with the anion of the compound concerned. The removal of strontium ions from aqueous solutions has been traditionally carried out by chemical precipitation, ion exchange, membrane processes, which are expensive and inefficient, especially for low-strength wastewaters (Chegrouche et al., 2009).

In the last few years, adsorption has been shown to be an economically and feasible alternative method for heavy metals removal from wastewaters and water supplies (Ahmadpoura et al., 2010). Many studies have described the adsorption of Sr(II) ions from aqueous solutions onto various organic and inorganic adsorbents (Chegrouche et al., 2009; Maresova, 2011) and so many people tried hard to find efficient and low cost materials. In fact, most agricultural wastes are considered to be low value products but orange peel is one of the valuable agricultural wastes.

However, using untreated agricultural by-products as adsorbents can also bring severe problems, such as high chemical oxygen demand (COD) and biological chemical demand (BOD) as well as total organic carbon (TOC), due to the release of soluble organic compounds contained in the plant materials, such as lignin, tannin, pectin and cellulose, into the solutions (Feng et al., 2009).

The increase of the COD, BOD and TOC can cause decreasing of oxygen content in water and then threaten the aquatic life. To solve such problems, chemical treatment on solid adsorbents was used as a technique for improving their chemical and physical properties and increasing their adsorption capacity (Feng et al., 2010 - Liang, 2009).

Orange peel (OP) is a material composed of several constituents such as pectin (galacturonic acid), hemicelluloses, cellulose and lignin which bear various polar functional groups, including carboxylic and phenolic acid groups that can be involved in metal ions complexation (Feng et al., 2010). As a low cost adsorbent, OP is an attractive and inexpensive alternative for the adsorption removal of dissolved heavy metals. The present investigation, focused on the removal of strontium ion from aqueous solutions using raw orange peel and that chemically modified with sodium hydroxide and potassium chloride. It investigated various parameters including pH, temperature, contact time and concentration of Sr (II) ions on the adsorption efficiency.

Materials and methods

Chemicals:

All chemicals used in the present study were of analytical purity (Aldrich). 0.1 N HCl and 0.1 N NaOH were used for adjustment of pH value.

Preparation of Sr(II) solution:

An accurately weighed quantity of the $\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$ (purchased from Merck company) was dissolved in deionized water in order to prepare a stock solution (1000 mg/L). Experimental solutions of the desired concentrations were obtained by successive dilutions (25, 50, 75, 125, 150, 175, 200 and 300 mg/L).

Adsorption experiments:

The sorption mixture consisted of 0.1 g of adsorbent and 20 ml of strontium solution (100 mg/L) for 6h at 20°C. After equilibrium, the sorption mixture passed through a filter paper whatman 40 and was analyzed for metal ion content using an atomic absorption (Varian, spectra-110-220/880 Australia Pty. Ltd.) equipped with a Zeeman atomizer. The amount of strontium adsorption at equilibrium q_e (mg/g) was calculated using the following equation:

$$q_e = (C_o - C_e)V / m \quad (1)$$

where C_o and C_e represent the initial and equilibrium metal ion concentrations (mg/L), respectively; V represents the volume of the metal ion solution (mL) and m is the amount of adsorbent (mg).

The adsorbent dosage was changed in the range of 0.04-0.2 g/20 mL Sr(II) solution of 100 mg/L. The strontium concentrations varied from 25 to 300 mg/L.

To study the effect of pH on sorption, the pH of the strontium solution was adjusted to values in the range 1.8 - 7.3 by the addition of 0.1 M HCl or 0.1 M NaOH prior to experiment. All pH measurements were performed using BOECO, BT 600, model pH meter.

Time dependent experiments were carried out by leaving the sorption mixture at various predetermined intervals and analyzing the strontium content at the end of contact time. Each time, a different sample was used to ensure that the solid/liquid (S/L) ratio did not change after sampling. The amount of adsorption at time t , q_t (mg/g), was calculated by the following equation:

$$q_t = (C_o - C_t)V/m \quad (2)$$

The thermodynamic experiments were investigated by carrying out batch study at the optimal conditions and at different temperatures. The temperatures chosen for study were 20°C, 30°C, 40°C, and 60°C. The temperature of the strontium solution was adjusted using a thermostatic water bath (Mettmert WB29 Model).

Adsorbents preparation

Raw orange peel

Orange peel was washed with distilled water to remove dirt and dried in sun light for 4 days. The raw orange peel was excessively dried in an oven at 60°C for 24 h and then ground to a fine powder of particle size less than 355 μm here after, abbreviated as OP.

Treatment with alkali after washing with ethanol

About 15 g raw orange peel was mixed with 100 ml ethanol and 100 ml 1 N NaOH and left for 24 h. The alkali/peel slurry after repeated decantation was filtered and then washed with deionized water until pH was neutral. The filter residue was then dried in an

oven for 24 h at 60°C. Drying at 60°C was chosen because high drying temperature might cause decreasing of number of cellulose based OH- group (Gode et al., 2008). Finally, about 8 g have been remained, and then abbreviated as NaOP. The alkali modified orange peel is crushed then milled and sieved to obtain an average particle size lower than 355 µm.

Treatment with KCl after saponification and washed with ethanol

About 15 g of raw orange peel is soaked in 100 ml ethanol, 100 ml 1N NaOH and 100 ml 1N KCl for 24h. The produced slurry is filtered and then washed with deionized water after repeated decantation until pH value of solution becomes neutral. The modified slurry was dried in an oven at 60°C for 24h, then crushed and milled and finally sieved to particles size lower than 355µm, hereafter, the product is abbreviated as KOP.

Adsorbents characterization

The FTIR analysis of the three adsorbents (OP, NaOP and KOP) were taken with a Fourier-transform infrared spectrophotometer (JASCO FT/IR-410, Japan). Pressed pellets were prepared by grinding the powder samples with spectroscopic grade KBr for FTIR spectra test. The spectra were recorded from 4000 to 400cm⁻¹.

Results and Discussion

Characterization of the adsorbents

The FTIR analysis were carried out as a qualitative analysis to determine the main functional groups present in the orange peel adsorbents; OP, NaOP and KOP. The FTIR spectra details of the three concerned adsorbents are given in **Table 1**. The broad band of 3397-3321 cm⁻¹ is O-H stretching vibrations of cellulose, pectin, absorbed water, hemicellulose and lignin. The band 2924-2922 cm⁻¹ assigned to symmetric or asymmetric C-H stretching vibration of aliphatic acids while the peaks at 1095-1061 cm⁻¹ indicated vibration of C-O-C and O-H of polysaccharides.

Table 1. Comparison of infrared bands in 4000 - 400 cm⁻¹ spectral region.

Functional group of adsorbent	Wavenumber/cm ⁻¹		
	OP	NaOP	KOP
O-H stretching vibration	3321	3321	3397
Symmetric and asymmetric C-H stretching vibration	2924	2924	2922
Non-ionic carboxyl groups (-COOH, -COOCH ₃)	1736	-	-
Asymmetric vibrations of C=O	-	1623	1613
Symmetric vibrations of C=O	-	1423	1420
Stretching vibration of C-O-C	1084	1095	1061

The band at 1736 cm⁻¹ in the OP spectrum indicated non ionic carboxylic groups (-COOH, -COOCH₃). Disappearing of such peak at NaOP and KOP spectra indicated that the methyl ester is hydrolyzed with alkali, NaOH, and ester group is converted to carboxylate ions. The spectra of both NaOP and KOP show two new peaks, the first one at 1624-1613 cm⁻¹ may be assigned to asymmetric vibrations of C=O while the second of 1423-1420 cm⁻¹ may be attributed to symmetric vibration of C=O.

Effect of pH on Sr (II) removal

The experiment was carried out at different pH of values showed that there was a change in the removal percentage of strontium ions over the entire pH range shown in **Figure 1**.

It can be observed that both NaOP and KOP showed higher adsorption ability for Sr(II) than OP but NaOP shows a little better adsorption ability for Sr(II) than KOP. As shown in Fig.1 at low pH value of 1.8, the adsorption performance was 68.20% and 34.15% for NaOP and KOP, respectively, and for OP, the value was only 18.05. When solution pH raised from 1.8 to 7.3, the adsorption ability increased sharply first and increased less until pH reached 6.6 and then decreased.

The maximum strontium ion uptake was recorded at the pH 6.6, and the adsorption efficiency reached about 98.37% for NaOP and 98.13% for KOP. The slight increase in adsorption efficiency of NaOP may be due to the more availability of free active sites on the surface of NaOP. At low pH, the concentration of proton is high, so strontium ions binding sites become positively charged and then metal cations and protons compete for

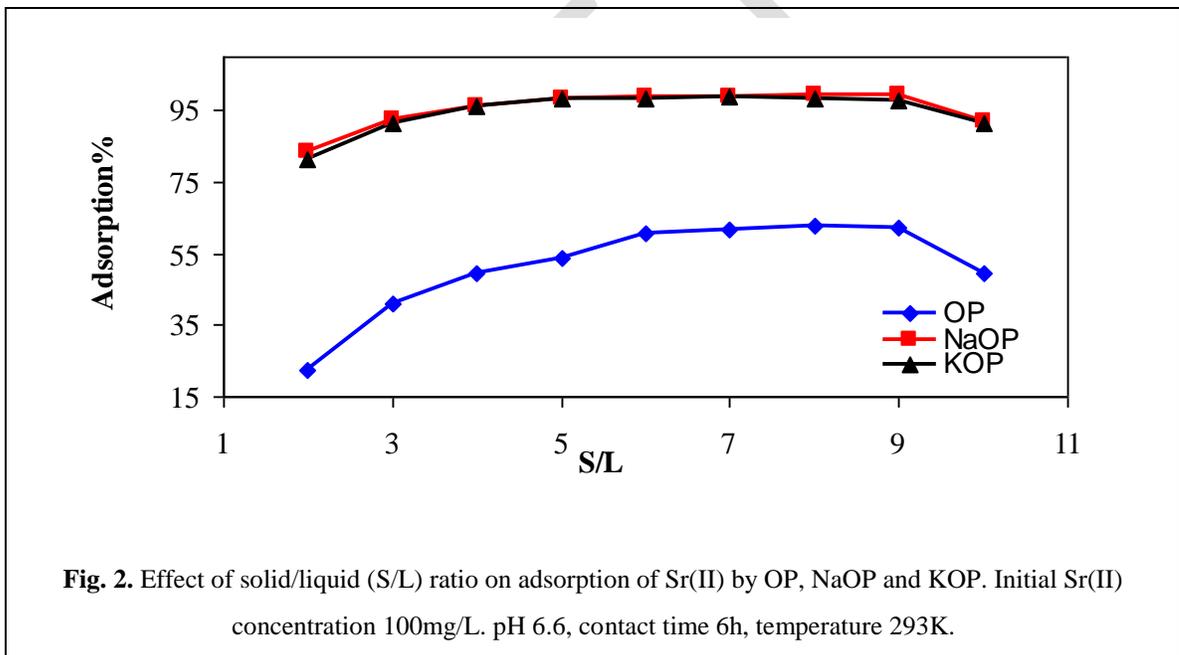
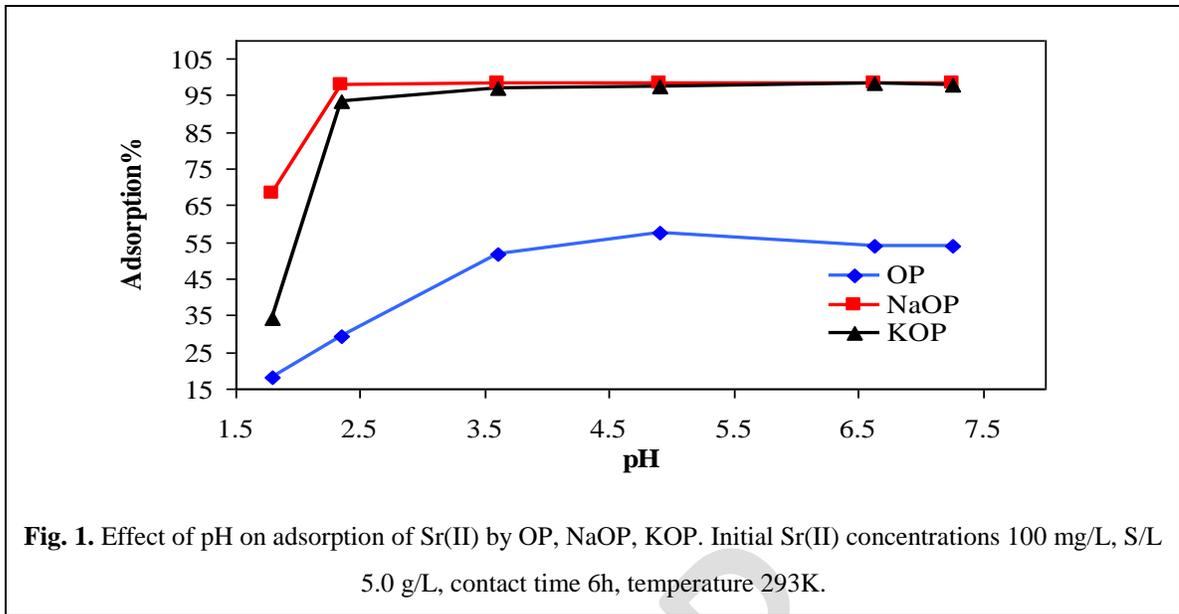
binding sites of orange peel adsorbent which results in lower uptake of strontium ions. As pH increases in the range from 1.8 to 6.6, the concentration of proton exist in the solution will be decreased and hence will not give the chance to compete with strontium ions on the adsorption sites of the adsorbent surface, thus facilitating greater strontium ions uptake.

After pH 6.6 the removal efficiency starts decreasing as pH increases, which is referred to insoluble strontium hydroxide that starts precipitating from the solution. Therefore, at these pH values, both adsorption and precipitation are the effective mechanisms of the strontium removal from aqueous solution. The strontium cations in aqueous solution convert to different hydrolysis products (Kumar et al., 2009).

Effect of solid to liquid (S/L) ratio

Solid to liquid ratio is another important parameter influencing the adsorption performance. Fig.2. shows the effect of S/L ratio on the Sr(II) adsorption by the three concerned adsorbents, OP, NaOP and KOP. As shown in **Figure 2**, the strontium ions uptake increased as the S/L ratio increased, but it increased less when S/L ratio surpassed 5.0 g/L. This trend is expected because as the dose of adsorbent increases, the number of active sites for binding metal ions on the adsorbent surface increases and thus more strontium is attached to their surface.

Thus it results in the increment of adsorption ability until saturation. However, considering the cost, the optimum ratio 5.0 g/L was chosen in this investigation. As shown in **Figure 2**, the strontium uptake by NaOP is slight better than that recorded for strontium uptake by KOP.



Adsorption isotherm

The study of the adsorption isotherm is fundamental, and plays an important role in the determination of the maximum capacity of adsorption. It also provides a panorama of the course taken by the system under investigation in a concise form, indicating how

efficiently an adsorbent will adsorb and allows an estimate of the economic viability of the adsorbent commercial applications for the specified pollutant (Kumar et al., 2009).

Four isotherms equations have been tested in the present work to analyze the equilibrium data of the three adsorbents (OP, NaOP and KOP), namely, Langmuir (Langmuir, 1918), Freundlich (Freundlich, 1906), Temkin (Temkin & Pyzhev, 1940) and Dubinin-Radushkevich (Dubinin & Radushkevich, 1947). Langmuir isotherm is the most widely used and its equation written as,

$$C_e/q_e = (1/q_L K_L) + (1/q_L) C_e \quad (3)$$

where q_e is the mono-layer adsorption capacity of the adsorbent (mg/g), K_L is the Langmuir adsorption constant (L/mg) and q_L is the mono-layer adsorption capacity of adsorbent (mg/g). Therefore, a plot of C_e/q_e versus C_e gives a straight line of intercept $1/(q_L K_L)$ and slope $1/q_L$.

The Freundlich isotherm can be expressed as the following equation:

$$\text{Log } q_e = \text{log } K_F + (1/n) \text{ log } C_e \quad (4)$$

where both K_F and n are the Freundlich adsorption constants, which can be determined by the linear plot of $\text{log } q_e$ versus $\text{log } C_e$.

The Temkin model equation is given as:

$$q_e = B \ln A + B \ln C_e \quad (5)$$

where A and B are Temkin constants and can be determined by the plot of q_e versus $\ln C_e$.

The Dubinin-Radushkevich (D-R) model was also used to fit with the experimental data, and it can be represented as,

$$\ln q_e = \ln q_m - \beta \varepsilon^2 \quad (6)$$

where β is a coefficient related to the mean free energy of adsorption (mmol^2/J^2), q_m is the maximum adsorption capacity and ε is the Polanyi potential (J/mmol) that can be given as:

$$\varepsilon = RT (1+1/C_e) \quad (7)$$

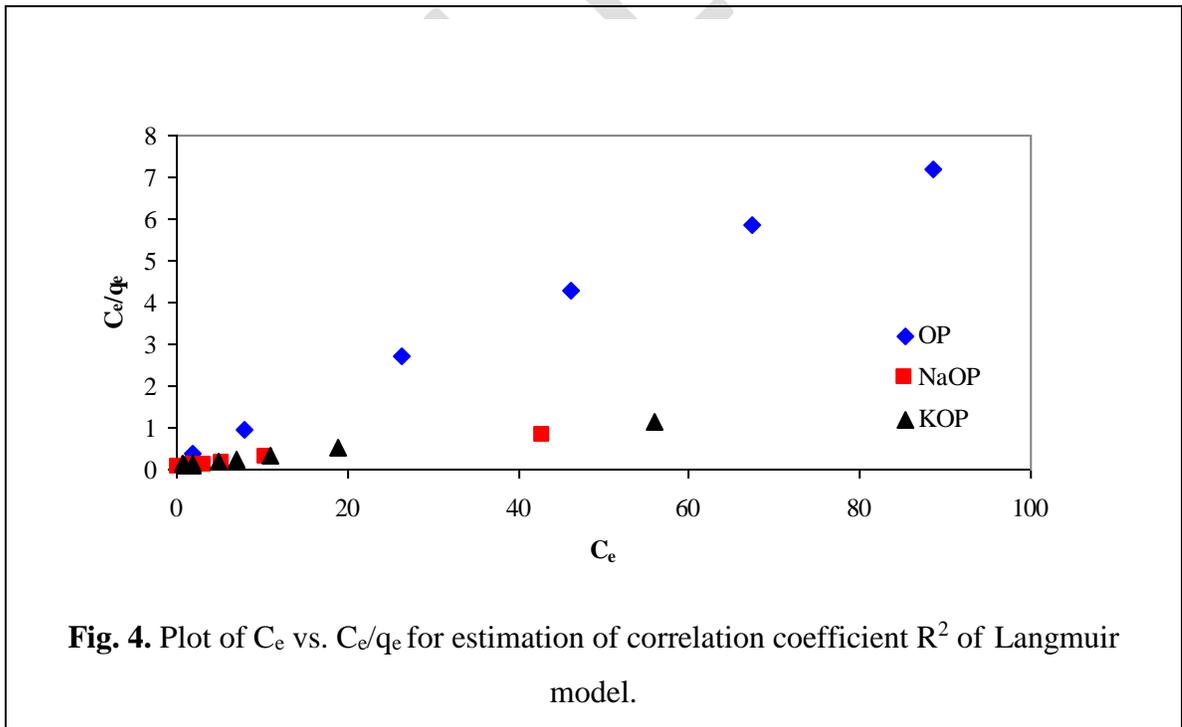
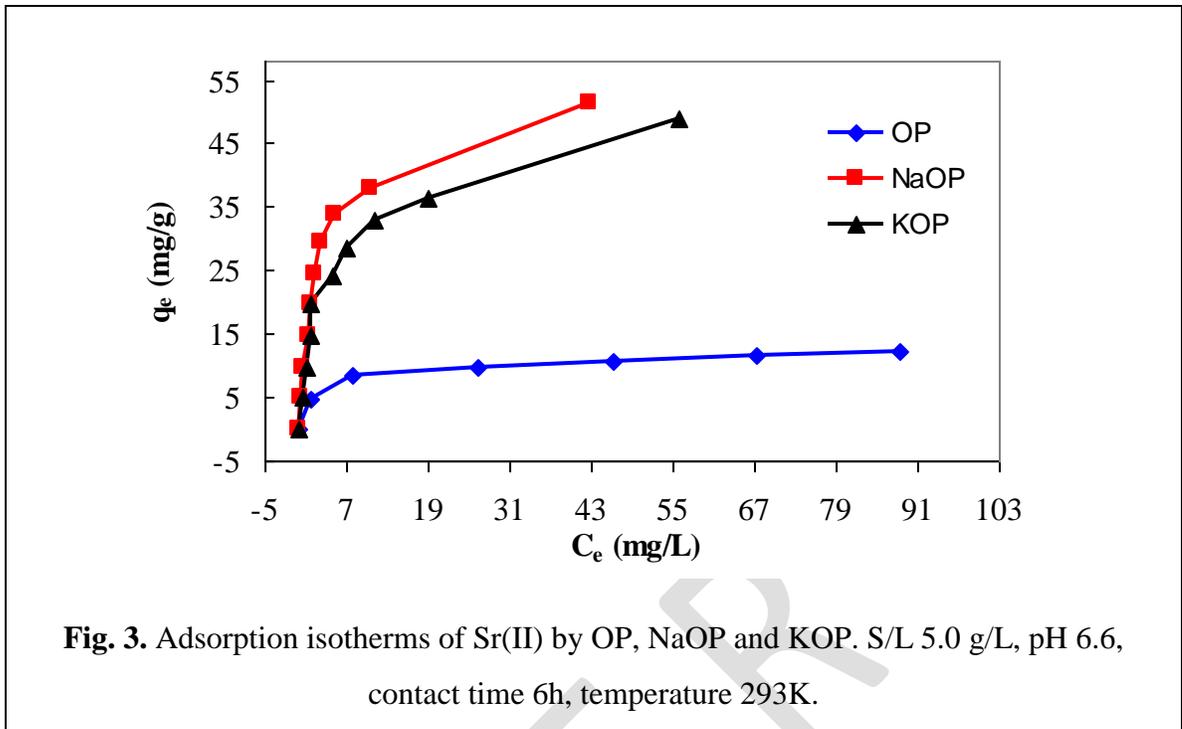
where R is the gas constant and T is the absolute temperature.

The equilibrium adsorption isotherms were carried out by plotting metal ions adsorbed (q_e) against the equilibrium concentration of strontium ions (C_e) in solution (**Figure 3**). Apparently, the adsorption ability of NaOP and KOP are much higher than that of OP, which indicates the effectiveness of chemical modification and NaOP shows a little better adsorption ability for strontium than KOP.

The correlation coefficients and parameter values for the four isotherms were presented in **Table 2**. Based on the correlation coefficients, (**Figure 4**), the applicability of the isotherms was compared. The experimental results indicated that the adsorption of strontium onto OP, NaOP and KOP followed Langmuir model. Sr(II) adsorption capacity was 12.64, 54.95 and 52.36 for OP, NaOP and KOP, respectively.

Table 2. Values of parameters of each isotherm model used.

Isotherm Model	Adsorbents	Parameter	R ²
Langmuir	OP	$q_L=12.64$ $K_L=0.188$	0.995
	NaOP	$q_L=54.95$ $K_L=0.308$	0.997
	KOP	$q_L=52.36$ $K_L=0.186$	0.992
Freundlich	OP	$K_F=4.610$ $n=4.621$	0.935
	NaOP	$K_F=13.119$ $n=2.182$	0.893
	KOP	$K_F=10.132$ $n=0.994$	0.852
Temkin	OP	$A=14.558$ $B=1.779$	0.973
	NaOP	$A=5.122$ $B=9.599$	0.974
	KOP	$A=3.016$ $B=9.344$	0.988
Dubinin-Radushkevich	OP	$q_m=22.5$ $\beta=1 \times 10^{-7}$	0.926
	NaOP	$q_m=31.27$ $\beta=1 \times 10^{-8}$	0.733
	KOP	$q_m=46.10$ $\beta=6 \times 10^{-8}$	0.9017



To determine if adsorption process is favorable or unfavorable for Langmuir type adsorption process, Langmuir isotherm is then classified using a dimensionless constant separation factor (R_L), which can be written as follows:

$$R_L = 1/(1+K_L C_{\max}) \quad (8)$$

where C_{\max} is the highest initial metal concentration in the solution (mg/L). If the value of $R_L < 1$, it indicates a favorable adsorption and if $R_L > 1$ then, an unfavorable adsorption process. The R_L values for the adsorption of Sr(II) onto OP, NaOP and KOP were in the range $0 < R_L < 1$, indicating that Langmuir adsorption is favorable process.

Kinetics studies

The kinetics of Sr(II) adsorption can be modeled by various equations. The pseudo-first-order Lagergren equation is defined as (Lagergren, 1898),

$$\text{Log}(q_e - q_t) = \text{log } q_e - (k_1/2.303) t \quad (9)$$

Where q_t and q_e are the amounts of ion adsorbed at time t and at equilibrium (mg/g), respectively. k_1 is the rate constant of pseudo-first-order adsorption process (min^{-1}). The plot of $\text{log}(q_e - q_t)$ versus t were used to determine the first-order rate constant k_1 and equilibrium adsorption capacity q_e from the slope and the intercept.

The pseudo-second-order kinetic model by Ho and McKay (1998) with the linear form is represented as:

$$T/q_t = 1/(k_2 q_e^2) + (1/q_e) t \quad (10)$$

Where k_2 is the equilibrium rate constant of pseudo-second-order adsorption (g/mg.min). If the plot of t/q_t versus t gives a linear relationship, that means the pseudo-second-order equation is applicable, and then k_2 and q_e can be calculated from the slope and intercept of the line.

The adsorption data may also be analyzed using the Elovich isotherm equation (Liang et al., 2010) which has the linear form:

$$q_t = 1/\beta \ln(\alpha\beta) + (1/\beta) \ln t \quad (11)$$

Where α is the initial sorption rate constant (mg/g.min), and the parameter β is related to the extent of surface coverage and activation energy for chemisorptions (g/mg). The constants, α and β can be obtained from the slope and intercept of the plot of q_t versus $\ln t$.

The intraparticle diffusion model was also tested and the initial rate constant for intraparticle diffusion is obtained using the following equation (Annadurai et al., 2002):

$$q_e = C + k_{int} t^{1/2} \quad (12)$$

where k_{int} is the intraparticle rate constant (mg/g.min^{1/2}). **Figure 5** represents the effect of contact time on Sr(II) adsorption on the three concerned adsorbents: OP, NaOP and KOP. As shown in Fig. 5, the uptake of Sr(II) increased sharply at time 0-60 min then became almost stable, which denoted attainment of equilibrium. The phenomenon may be attributed to the fact that, initially, all active sites on the adsorbents surface were vacant and the solution concentration was high. After that period, few active sites on the adsorbent surface were available, so only a slight increase in the metal uptake was observed (Liu and Liu 2008).

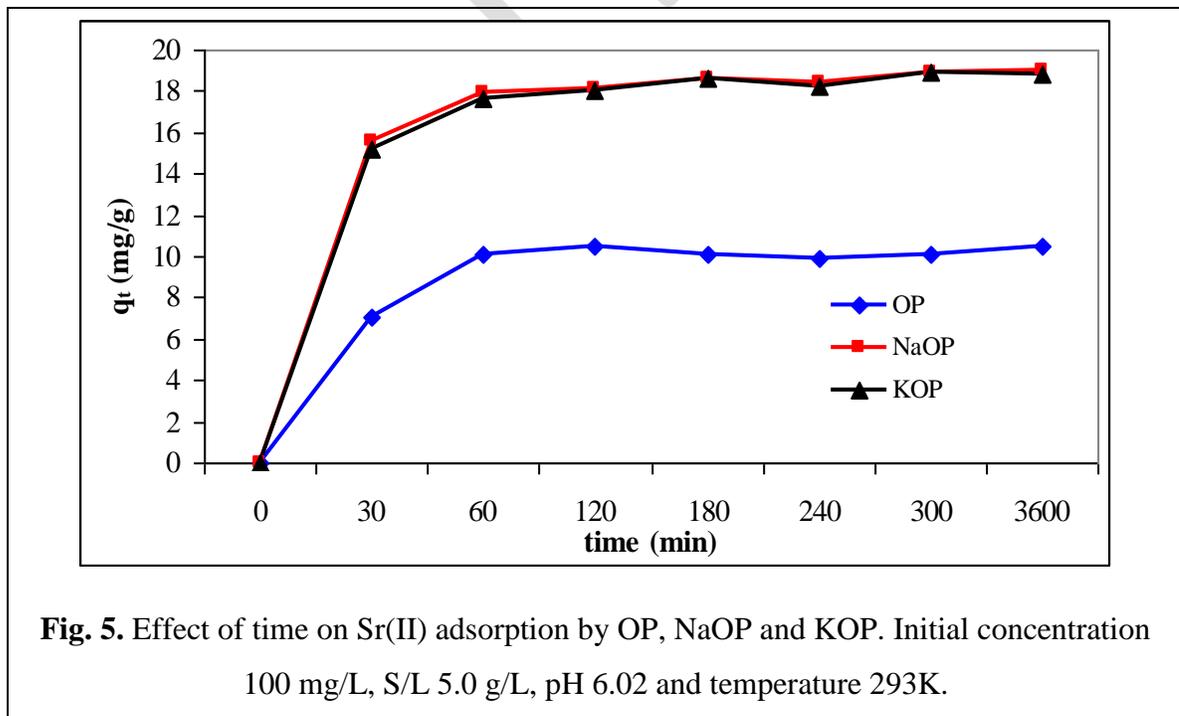
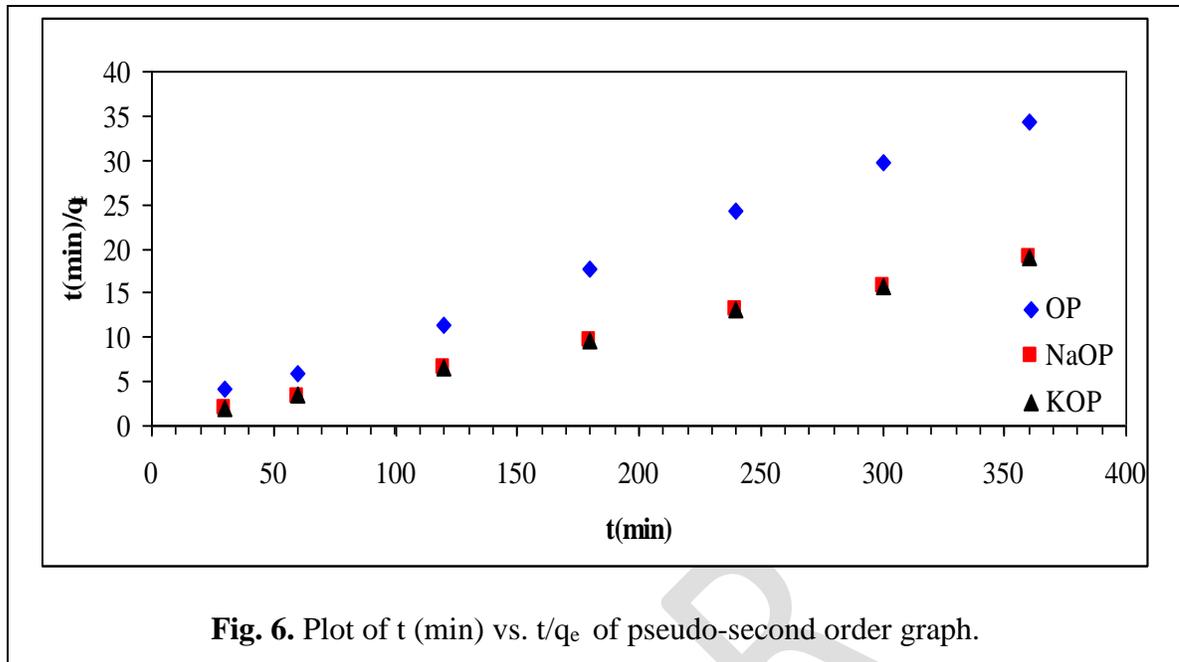


Table 3 represents the constants of kinetics models for strontium adsorption on OP, NaOP and KOP. The obtained data in **Table 3** revealed that pseudo-second order equation provides the best correlation coefficient (**Figure 6**) with extreme high values (>0.99). In addition, the calculated q_e values are also compatible with the experimental data in the case of pseudo-second-order kinetics. The obtained data were 10.52, 19.30 and 19.19 for OP, NaOH and KOP, respectively, while the experimental data were 10.77, 19.67 and 19.63 for the same order. These propose that the adsorption data are well represented by pseudo-second-order kinetics and it supports the assumption that the chemical adsorption is the rate-limiting. The reaction mechanism may be partly a result of the ion exchange between strontium and the carboxylic and hydroxyl groups on the orange peel surface (Liang et al., 2010).

Table 3. Values of parameters of each kinetic model used

kinetic Model	Adsorbents	Parameter	R ²
Pseudo-first-order	OP	$q_e=1.39$ $k_1=0.004$	0.294
	NaOP	$q_e =3.01$ $k_1=0.005$	0.817
	KOP	$q_e = 3.21$ $k_1=0.005$	0.770
Pseudo-second-order	OP	$q_e =10.52$ $k_2=0.012$	0.997
	NaOP	$q_e =19.31$ $k_2=0.008$	0.999
	KOP	$q_e =19.19$ $k_2=0.007$	0.999
Elovich	OP	$\alpha=0.15 \times 10^3$ $\beta=1.02$	0.549
	NaOP	$\alpha=3.5 \times 10^4$ $\beta=0.84$	0.820
	KOP	$\alpha=9.7 \times 10^3$ $\beta=0.77$	0.836
Intraparticle-diffusion	OP	$k_{int}=0.156$	0.418
	NaOP	$k_{int} = 0.202$	0.714
	KOP	$k_{int} = 0.219$	0.723



Thermodynamic studies

Thermodynamic considerations of an adsorption process are necessary to deduce whether the process is spontaneous or not. The Gibbs free energy change, ΔG° , is an indication of spontaneity of a chemical reaction so it is an important criterion for spontaneity. Both energy and entropy factors must be considered in order to determine the Gibbs free energy of the adsorption process. If ΔG° is a negative quantity at a given temperature, then the reactions occur spontaneously. The free energy of an adsorption process, considering the adsorption equilibrium constant K_C is given by the following equation:

$$\Delta G^\circ = - RT \ln K_C \quad (13)$$

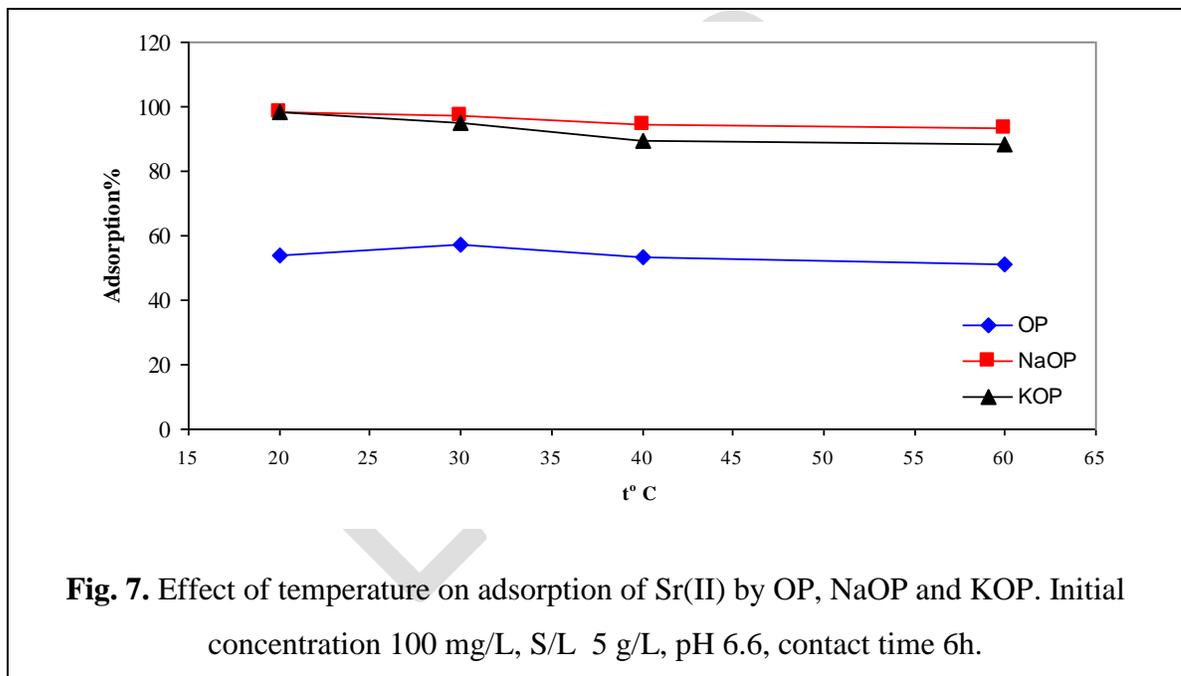
where ΔG° is the standard free energy change (J/mol), R is the gas constant (8.314 J/mol.K), and T is the absolute temperature (K). Considering the relationship between ΔG° and K_C change in equilibrium constant with temperature can be obtained as follows (Annadurai et al., 2002):

$$K_C = C_\delta / C_e \quad (14)$$

where C_d is mg of adsorbate adsorbed per liter and C_e is the equilibrium concentration of solution (mg/L). According to thermodynamics, the Gibb's free energy is also related to the enthalpy change (ΔH°) and entropy change (ΔS°) at constant temperature by the van't Hoff equation which can be written as:

$$\ln K_C = - \Delta G^\circ/RT = - (\Delta H^\circ/RT) + (\Delta S^\circ/R) \quad (15)$$

Using the equation (15), the values of entropy change (ΔS°) and enthalpy change (ΔH°) can be calculated from the intercept and slope of the plot of $\ln K_C$ versus $1/T$. The results of the thermodynamic studies of the strontium adsorption process are recorded in Tables 4 and graphically demonstrated in **Figure 7**.



For the three adsorbents under the studies, the negative ΔG° value obtained from the equation (18) confirmed that the feasibility and the spontaneous nature of the adsorption process. Sr(II) gave negative values for both ΔH° and ΔS° . The negative enthalpy values (ΔH°) indicates that the adsorption process is exothermic. The magnitude of ΔH° may give an idea about the type of adsorption. Two main types of adsorption are physical and chemical. Basically, the heat evolved during physical adsorption is of the same order of

magnitude as the heats of condensation, i.e., 2.1–20.9 kJ/mol, while the heats of chemisorption generally falls into a higher range of 80–200 kJ/mol (Liang et al., 2010).

From **Table 4**, the absolute values of ΔH° for NaOP and KOP are 30.3 and 38.11 kJ/mol, respectively, which therefore indicate that Sr(II) adsorption by NaOP and KOP may be attributed to a physico-chemical adsorption process rather than a pure physical or chemical adsorption process. On the other hand, the absolute value of ΔH° for OP is only 3.29 kJ/mol, which indicates the Sr(II) adsorption process onto OP surface is a pure physical process. Negative values of ΔS° indicate a decrease in randomness at the solid/solution interface during the adsorption process while low values of ΔS° indicate that no significant change on entropy occurs.

Table 4. Values of thermodynamic parameters for the adsorption of Sr(II) by OP, NaOP and KOP.

Adsorbent	T(K)	Kc	ΔG° (kJ/mol)	ΔH° (kJ/mol)	ΔS° (J/mol K)
OP	293	1.17	-0.38	-3.29	-9.36
	303	1.32	-0.70		
	313	1.14	-0.33		
	333	1.04	-0.11		
NaOP	293	60.35	-9.99	-30.30	-70.79
	303	32.33	-8.76		
	313	16.73	-7.33		
	333	13.58	-7.22		
KOP	293	52.48	-9.65	-38.11	-99.52
	303	19.58	-7.49		
	313	10.42	-6.10		
	333	7.52	-5.58		

For all adsorbents, OP, NaOP and KOP, it was found that the magnitude of ΔG° decreases as the temperature increases. The decrease in adsorption with rise in temperature may be due to weakening of adsorptive forces between the active sites of adsorbent surface and adsorbate species and also between the adjacent molecules of the adsorbed phase or because the mobility of strontium ions in the solution increases with increase in temperature (Liang et al., 2010). However, the magnitude of ΔG° for both NaOP and KOP is higher than values obtained for OP which reflects the effectiveness of treatment.

Conclusion

From this study it can be concluded that modification of orange peel (OP) with NaOH and KCl can effectively remove Sr(II) from aqueous solution. The orange peel adsorbent which modified with NaOH (NaOP) shows a little better adsorption ability for Sr(II) than those modified with KCl (KOP). PH study revealed that maximum Sr(II) removal could be achieved at pH 6.6. The experimental data perfectly fitted the Langmuir isotherm with regression coefficient $R^2 > 0.99$ for all adsorbents (OP, NaOP and KOP).

Moreover, the experimental data was found to be fit better with the pseudo-second order kinetic model with extreme high values of regression coefficient ($R^2 > 0.99$). The negative value of $\Delta G^\circ, \Delta H^\circ$ confirms that Sr(II) adsorption is a spontaneous and an exothermic adsorption process and the negative value of ΔS° indicates a decrease in randomness at the solid/solution interface during the adsorption.

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