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A study of the factors affecting the adsorption of cobalt ions onto Pakistani coal powder from solutions

Riaz Qadeer

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Abstract Large deposits of coal are abundantly available in Pakistan. An attempt has been made to check its efficacy for the cobalt ions from aqueous solutions in order to exploit the locally available naturally occurring cheaper material for the decontamination/removal of metal ions from nuclear and industrial effluents. The adsorption behavior of cobalt ions on coal powder has been studied as a function of various physicochemical parameters i.e., stirring speed, shaking time, pH, concentration of cobalt ions, temperature, etc. Conditions for the uptake of cobalt ions were established. Adsorption dynamics models such as intra-particle diffusion model, pseudo-first order kinetic model (Lagergren's equation) and pseudo-second order kinetic model were applied to the adsorption data to elucidate the adsorption process and its mechanism. Results reveal that the adsorption mechanism is predominantly diffusion and both intra-particle and boundary layer diffusion seem significant in the rate controlling step. The adsorption process is best accounted for using pseudo second order kinetic model and the overall rate of adsorption process appears to be controlled by more than one step, namely the external mass transfer and intra-particle diffusion mechanism. The existence of two slopes in the Freundlich plot also confirms the surface diffusion and intra-particle diffusion modes of adsorption. The Langmuir isotherm equation was obeyed well in the whole range of cobalt ions concentration with high value of correlation coefficient ($r^2 = 0.999$). The adsorption energy (E_a) calculated from D–R isotherm was 6.756 kJ/mol indicating physical nature of adsorption. The adsorption of cobalt ions increased with the increase of temperature and thermodynamic parameters such as ΔH, ΔS and ΔG were calculated. Results suggested that the cobalt ions adsorption on coal powder is endothermic (ΔH 33.90 kJ/mol) and spontaneous (negative ΔG values) process. The adsorption of other metal ions on coal powder was studied at optimized condition for cobalt ions to check its selectivity. Consequently, cobalt ions can be removed from Zr, Ru Eu, Er, Sm, Gd, Dy, Ce, U, and Th ions, where as Cs, Cr and Sr ions reduces the adsorption of cobalt ions by co-adsorption and their reducing affect is in the order of Sr > Cr > Cs.

Keywords Cobalt ions · Coal powder · Adsorption · Aqueous solution · Kinetics · Thermodynamics · Selectivity

Introduction

Radioisotope of cobalt i.e., Co^{60} ($t_{1/2} = 5.30$ days) is produced during the burn up of nuclear fuel in a reactor, and is of great concern from the environment point of view. Traces of this radionuclide may remain in the waste solution generated in the chemical processing laboratories, and causes adverse situation for the human and living creatures when the waste solution is released into the hydrosphere. This radionuclide is highly toxic and is not biodegradable; therefore it must be removed from the waste effluents prior to its secure disposal. There is a need for a suitable economically method to treat the effluents generated in the chemical processes laboratories before its dispose off. Methods used for the recovery of metal ions are chemical precipitation, electro-deposition, ion exchange, reverse osmosis and adsorption, and these methods have their own advantages and disadvantages. The traditional chemical precipitation is the most economical but is inefficient for

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R. Qadeer (✉)
PAEC, P.O. Box 1611, Islamabad, Pakistan
e-mail: drriazqadeer@yahoo.com

dilute solutions. Ion exchange and reverse osmosis are generally effective but have rather high operational and maintenance cost. Recently, adsorption has become a widely used technique to treat the effluents due to its simplicity, potential to regeneration and sludge-free operation and production of high quality treated effluents. The adsorption process is quite selective and effective and very low levels of metals can be removed from aqueous solution/wastewater. Moreover, it can be attractive technique if the adsorbent used can be synthesized cheaply and/or make use of naturally occurring local materials as adsorbent. Well designed adsorption processes have high efficiency resulting in high quality effluents after treatment which can be recycled or disposed off safely.

Large deposits of coal are abundantly available in Sindh Province of Pakistan. An attempt has been made to check its efficacy for cobalt ions from aqueous solutions in order to exploit the locally available naturally occurring cheaper material for its decontamination or removal from nuclear and industrial effluents. The present paper reports the results of a systematic study undertaken to optimize different physicochemical parameters to simulate the best conditions for the removal/pre-concentration of cobalt ions from aqueous solutions using locally available coal powder. Adsorption of cobalt ions onto solid has long been investigated using various inorganic and organic sorbent such as magnetite [1], alumina (γ-Al_2O_3) [2], kaolinite [3], sepiolite [4, 5], clay [6–8], ion-exchange resin [9, 10], sheep manure [11], attapulgite [12], hydroxyapatite/zeolite composite [13], metal oxide-solution interface [14], soil [15], industrial waste [16], pre-treated arca shell biomass [17], grapheme [18], activated carbon [19, 20] and South African coal fly-ash [21]. No data are available on its adsorption on Pakistani coal.

Experimental

Materials

Coal sample was collected from the Sangharsh District, Province of Sindh, Pakistan. It was grounded to an extent to obtain a homogenous powder. Sieve analysis was performed to measure the average particle size of the coal powder. The results are given in Table 1. Coal powder was dried at 110 °C before use and stored in a desiccator. The coal powder was characterized for various parameters using different techniques and the results are reported in Table 2. Cobalt nitrate (M/s Merck, Product No. B55141 115) was used to prepare stock solutions of cobalt ions in doubly distilled water. Buffer solutions of different pH supplied by M/s Fluka were used during this study.

Instruments

Siemen's wavelength dispersive X-ray fluorescence (XRF) spectrometer (SRS-200) equipped with Cr-X-ray tube, soller slit with angular divergence of 0.15°, LiF(100) crystal, NaI(Tl) scintillation counter was used for measuring the cobalt concentration in solutions with error within 2 %. Metrohm pH meter-605 and Hetofrig shaker (M/s Heto Birkerod, Denmark) was used during adsorption studies.

Procedure

Adsorption measurements were carried out via a batch technique at room temperature 23 ± 1 °C where otherwise specified. Accordingly, 10 ml of cobalt solution of known concentration were shaken at a fixed speed with known amount of dry coal powder in 250 ml reagent glass bottle for a given time period. The solution was then filtered through Whatman filter paper No. 40 (Circular, 14.0 cm). The first 2–3 ml portion of the filtrate was rejected because of the adsorption of cobalt ions on filter paper. The concentration of cobalt ions in the filtrate was determined by means of the XRF and was corrected for losses due to adsorption on the walls of the glass bottles by running blank experiments (i.e., without coal powder added). The distribution coefficient (K_D) was computed using the following relation:

$$K_D\ (\mathrm{ml/g}) = \frac{C_0 - C}{C} \times \frac{V}{m} \quad (1)$$

where C_0 and C are the initial and equilibrium cobalt ions concentrations in solution (µg/ml), K_D is the distribution coefficient (ml/g), V is the volume of the cobalt ion solution (ml) and m is the amount of the coal powder (g) used.

Results and discussion

The adsorption of cobalt ions from aqueous solutions on coal powder was examined by optimizing various physicochemical parameters such as shaking speed, shaking time, pH, concentration of cobalt ions and temperature using batch technique. The adsorptions of other metal ions on activated charcoal were also carried out to check the competitive adsorption and selectivity for cobalt ions.

Influence of stirring speed

Initial study was performed to assess the influence of stirring speed on the adsorption of cobalt ions by coal powder. This was performed by shaking 10.0 ml of 50 µg/ml cobalt ions solution with 0.1 g coal powder at different

Table 1 Sieve analysis result: weight distribution of coal powder

Mesh size (μm)	Weight retained (g)	% of weight retained
200	0.37	0.82
140	0.76	1.68
70	10.78	23.96
50	28.97	64.38
30	3.36	7.47
−30	0.20	0.44
	44.44	98.75

Total weight of the coal taken = 45.0 g; weight lost during sieving = 0.56 g; % weight lost during sieving = 1.25 %; vibration speed = 50 vibration/min

Table 2 Determined values of parameters of coal powder

Bulk density	0.442 g/cm^3
Tap density	0.845 g/cm^3
True density	1.135 g/cm^3
Surface area	2.388 m^2/g (BET-nitrogen adsorption)
Average particle size	50 μm
Carbon contents	64.7 %
Sulphur contents	3.13 %
Trace level impurities (XRF and leaching)	Ca (1840 ppm), Rh (9.0 ppm), Ti (30.0 ppm), Mn (37.0 ppm), Fe (4430.0 ppm) and Zn (137.0 ppm)
pH	5.85
XRD	Amorphous
Moisture	8.89–10.21 %

stirring speed (rpm). Figure 1 shows the variation of distribution coefficient (K_D) with stirring speed. This indicates that K_D attains constant value around 200 rpm. Therefore, 200 rpm was selected in all the subsequent studies.

Influence of shaking time

Figure 2 represents the variation of the distribution coefficient (K_D) of cobalt ions on coal powder with shaking time. This study was performed by shaking 10 ml of 50 μg/ml cobalt ions solution with 0.1 g coal powder for different intervals of time. This figure indicates that the adsorption takes place in two distinctive stages. The first stage adsorption seems slightly rapid and the second stage adsorption is relatively slow. These two stages are indicative of surface adsorption and intra-particle diffusion phenomena, respectively. After the initial adsorption of cobalt ions on the surface of the coal powder, the cobalt ions slowly diffuses into the pores of the coal powder and attains constant values after 120 min after which the adsorption remains uniform representing the attainment of equilibrium. Therefore, 120 min shaking time was selected in all subsequent studies. The time variation curve is smooth and continuous and this indicates the formation of monolayer coverage on the outer interface of the coal powder [22].

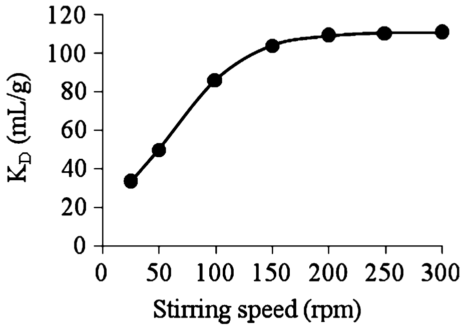

Fig. 1 Variation of distribution coefficient with stirring speed

Adsorption dynamics

The adsorption dynamics models such as intra-particle diffusion model, pseudo-first order kinetic model (Lagergren's equation) and pseudo-second order kinetic model were applied to the adsorption data in order to elucidate the adsorption process and its mechanism.

Generally, the metal ions are most probably transferred from the bulk of the solution to the solid phase through intra-particle diffusion/transportation process, which is often rate controlling step in many adsorption processes. The possibility of the intra-particle diffusion was explored by using the intra-particle diffusion model proposed by the Weber and Morris [23] as:

$$X_t = k_d(t)^{1/2} \tag{2}$$

where X_t is the amount of cobalt ions adsorbed on coal powder surface at any time t, k_d is the intra-particle diffusion rate constant, was employed to the experimental data depicted in Fig. 2. Plot of X_t versus $t^{1/2}$ for cobalt ions is shown in Fig. 3.

This figure indicates two distinct regions; an initial portion of the curve corresponds to the external surface adsorption and the second less sloping linear portion indicates the gradual adsorption stage leading to the equilibrium. The first stage of the adsorption is due to the boundary layer diffusion effects and a second portion is due to the intra-particle diffusion [24]. The intercept of the plot give an idea about the boundary layer thickness and is directly proportional to the intercept i.e., larger the intercept greater is the boundary layer thickness/effect. Similar observations of double nature plots were also observed previously by other workers on various adsorbate–adsorbent systems studied [25–28]. This indicates that the mechanism of the adsorption of cobalt ions on to coal

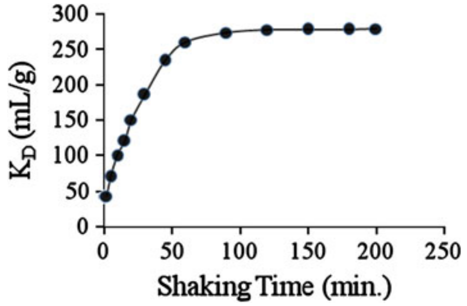

Fig. 2 Variation of distribution coefficient of cobalt ions on coal powder with shaking time

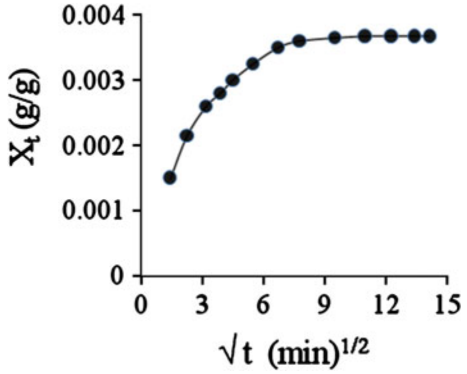

Fig. 3 Weber–Morris equation plot for the adsorption of cobalt on coal powder

powder is predominantly diffusion and the values of boundary layer diffusion rate constant, intra-particle diffusion rate constant and boundary layer thickness are calculated as 4.0×10^{-4} (g/g/(min)$^{1/2}$), 7.0×10^{-6} (g/g/(min)$^{1/2}$) and 0.0011 (g/g), respectively. The overall kinetics of the adsorption process is based on surface adsorption and intra-particle diffusion phenomena. The contribution of the intra-particle diffusion phenomena is low as compared to the surface phenomena, but its importance could not be ignored. Since the intra-particle diffusion process is slow, it is assumed to be the rate controlling step [29].

The pseudo-first order kinetics model, proposed by Lagergren [30], was found adequate in describing the adsorption process in most of the cases [31, 32]. This equation was employed for studying the dynamics of the cobalt ions adsorption on coal powder in the form:

$$\log(X_e - X_t) = \log X_e - K_1 \cdot t/2.303 \qquad (3)$$

where X_e and X_t are the amounts of cobalt ions adsorbed per g of coal powder at apparent equilibration and at time t respectively, K_1 is the rate constant for cobalt ions adsorption (min^{-1}) The linear plot of log (X_e–X_t) versus t obtained, Fig. 4, apparently shows the appropriateness of the above equation and subsequently the first order nature of the process involved. The values of K_1 and X_e were calculated as 0.048/min and 0.0019 g/g respectively, and correlation coefficient ($r^2 = 0.992$). X_e value determined from the intercepts of Lagergren's plot does not match with the experimental X_e value (i.e., 0.00365 g/g). Non-conformity of X_e value indicates that the Lagergren's equation (pseudo-first order kinetics model) cannot account for the cobalt ions adsorption on coal powder [33].

The pseudo-second order kinetic model [31] has been applied to analyze the adsorption data. The expression for pseudo-second order kinetic model is as follows:

$$t/X_t = 1/K_2X_e^2 + t/X_e \qquad (4)$$

where K_2 is the pseudo-second order rate constant (g/g min), X_t, X_e and t have already been defined above. Linear plot, Fig. 5, was obtained between t/X_t versus t with high value of correlation coefficient ($r^2 > 0.9999$).Values of K_2 and X_e were computed from the slope and intercept of the linear plot as 66.715 (g/g min) and 0.00377 g/g, respectively. There is also a good agreement between the experimental X_e values (i.e., 0.00365 g/g) and those obtained from the slope of the plot (i.e., 0.00377 g/g) indicating that the adsorption of cobalt ions on coal powder follows the pseudo-second order kinetic expression well.

Influence of pH

The pHs of the adsorptive medium is one of the most important parameter controlling the uptake of metal ions from solutions and it affect the surface charge of the adsorbent, degree of the ionization and speciation of the adsorbate. Therefore, the pH effect on the adsorption of cobalt ions was investigated in the pH range of 1–9. This study was performed at cobalt ions concentration 50 μg/ml, amount of coal powder 0.1 g, shaking time 120 min and shaking speed 200 rpm. Figure 6 shows the variation of distribution coefficient (K_D) with pH of the solution.

It is obvious from this figure that the uptake of cobalt ions increases gradually with the increasing pH up to a

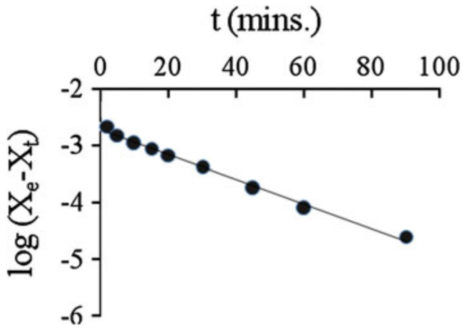

Fig. 4 Lagergren's equation plot for cobalt ions adsorption on coal powder

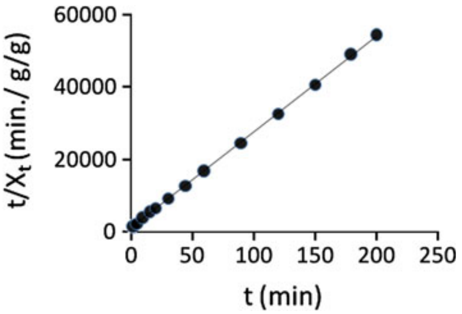

Fig. 5 Pseudo-second order plot for cobalt ions adsorption on coal powder

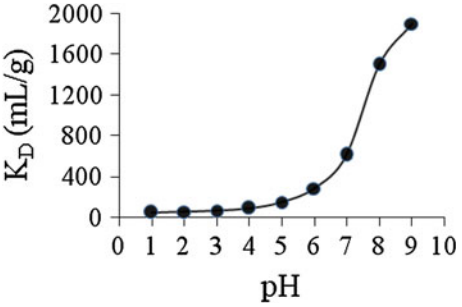

Fig. 6 Variation of K_D (ml/g) with pH for cobalt ions adsorption on coal powder

value of 7 and became more pronounced above pH 7. The results clearly indicate that both the surface charge density of the adsorbent and charge of the cobalt ions present depend on pH and the difference in the extent of the adsorption are also associated with the chemical state of the cobalt ions in the adsorptive state. The cobalt ions in aqueous solution may undergo hydration, hydrolysis and precipitation/polymerization. Lower pH results in the protonation of the adsorbent surface, which leads to the extensive repulsion of cobalt ions and result in the lower adsorption of cobalt ions. With the increase in pH, the surface protonation of the adsorbent is decreasing resulting in a lower coulombic repulsion of cobalt ions, leading to the enhancement of cobalt ions adsorption. Above pH 7, precipitation of cobalt ions start to form the hydroxide due to which sharp increase in the uptake of cobalt ions was observed. Based on these results, a pH 7 value was selected in all the subsequent experiments. At this pH the removal of cobalt ions is due to the adsorption and not due to hydroxide formation and/or precipitation.

Influenced of cobalt ions concentration

The effect of the cobalt ions concentration on its own adsorption on coal powder was investigated at optimized conditions of shaking time (120 min), stirring speed (200 rpm) and pH 7. The concentration of cobalt ions was varied from 25 to 400 µg/ml. Figure 7 shows that distribution coefficient (K_D) decreases with the increase of cobalt ions concentration. The recovery of the cobalt ions is more in low concentration as compared to its recovery in high concentration range. This is because that the initially more unoccupied active sites are available on the adsorbent surface and cobalt ions adsorbed on those active sites first yielding high values of K_D. As the concentration of cobalt ions increases, the adsorption decreases due to the prior occupation of the active sites and saturation of the adsorbent surface.

Adsorption models

The concentration dependence of the adsorption of cobalt ions was tested using different adsorption isotherm models in order to develop an equation which accurately represented the result and could be used for design purposes. Several isothermal equations are available for analysis. In this study, the abilities of three widely used isotherms, the Freundlich, Langmuir and Dubinin–Radushkevich (D–R) isothermal equations were assessed by employing to the experimental equilibrium data.

The Freundlich equation was used in the linearized form:

$$\log X = \log K_f + 1/n \log C \tag{5}$$

where X and C have already defined above, K_f is a parameter of the Freundlich isotherm related to quantity of the adsorption per gram of the solid at equilibrium (g/g), n is a dimensionless constant related to explain the extent of adsorption and the adsorption intensity between the adsorbate concentration and the adsorbent. The value of $1/n$ ranging between 0 and 1 is a measure of adsorption intensity or surface heterogeneity. It becomes more heterogeneous as its value gets closer to zero and a value of $1/n$ below 1 indicates a normal Langmuir isotherm while $1/n$ above 1 is indicative of cooperative adsorption [33, 34]. The Freundlich plot of log$C$ versus log X (Fig. 8) show some curvature in the higher concentration range points towards the validity of the Freundlich equation is concentration dependent and could be better represented by more than one

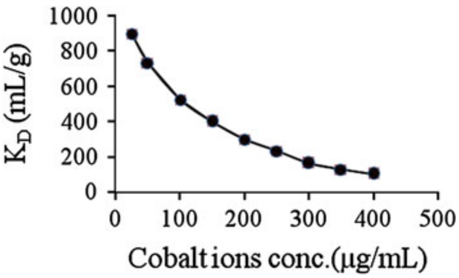

Fig. 7 Variation of distribution coefficient (K_D) with cobalt ions concentration

straight line. First straight line was obtained in the concentration range of 25–200 μg/ml whereas the second is valid in the concentration range of 250–400 μg/ml. Other investigators [35, 36] also obtained data that exhibit such behavior. The existences of two slopes represent two different modes of adsorption i.e., surface diffusion and the intra-particle diffusion [37]. The numerical values of $1/n$ calculated as 0.64 and 0.16 from respect slopes are less than one, indicative of Langmuir type behavior of the adsorption process.

The Langmuir equation was applied in the form:

$$C/X = 1/K_L X_m + C/X_m \tag{6}$$

where X and C have been already defined, X_m is the measure of monolayer capacity and K_L is a parameter of Langmuir isotherm related to the heat of adsorption. A straight line was obtained by plotting *C/X* against C (Fig. 9), indicating the conformity of the data in the entire concentration range studied, and monolayer coverage of the cobalt ions at the outer surface of the coal powder. Values of constant X_m and K_L, calculated from the slope and intercept of the plot were 0.023 g/g and 38.813 g/l, respectively. The correlation coefficient (r^2) of linear regression was found to be 0.999.

The Langmuir isotherm constant, K_L can be used to predict whether an adsorption system is favorable or unfavorable by mean of R_L, a dimensionless constant referred to as separation factor defined by [9]:

$$R_L = 1/(1 + K_L C_0) \tag{7}$$

The parameter (R_L) suggests the type of isotherm to be irreversible ($R_L = 0$), favorable ($0 < R_L < 1$), unfavorable ($R_L > 1$) and linear ($R_L = 1$). The calculated values of R_L as 0.507, 0.341, 0.205, 0.146, 0.114, 0.093, 0.079, 0.068, and 0.065 for initial concentration of 0.025, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, and 0.40 g/l respectively, are less than 1 indicating the favorable adsorption of cobalt ions on coal powder.

The linearized form of Dubinin–Radushkevich (D–R) isotherm equation is:

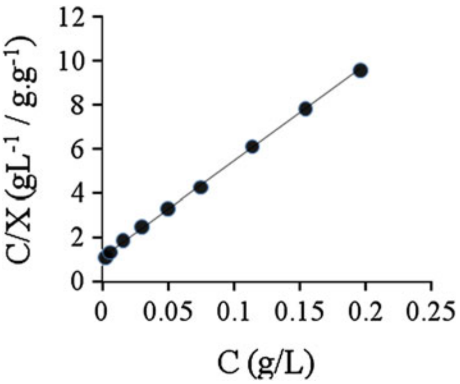

Fig. 9 Langmuir plot for the adsorption of cobalt ions adsorption on coal powder

$$\ln X = \ln X_m - B\varepsilon^2 \tag{8}$$

where $\varepsilon = RT \ln(1 + 1/C)$, B is the constant related to the adsorption energy, R is the gas constant and T is temperature in Kelvin. The quantities X, X_m and C have their previously defined meanings. A straight line was obtained upon plotting ln X versus ε^2 (Fig. 10), indicating that the adsorption of cobalt ions on coal powder also obeys the D–R isothermal equation in the entire concentration range studied. Values of X_m and B, calculated from the intercept and slope of the plot were 0.0271 g/g and -0.011 kJ^2/mol^2, respectively. The correlation coefficient (r^2) of linear regression was found to be 0.997. The magnitude of X_m (0.0271 g/g) calculated from D–R plot matches fairly well with the X_m (0.023 g/g) determined from Langmuir isotherm equation. From the value of B, the adsorption energy (E_a) of cobalt ions is calculated using the following equation:

$$E_a = 1/\sqrt{(-2B)} \tag{9}$$

The calculated value of E_a was found to be 6.756 kJ/mol, indicates that the adsorption process is physical in nature [38].

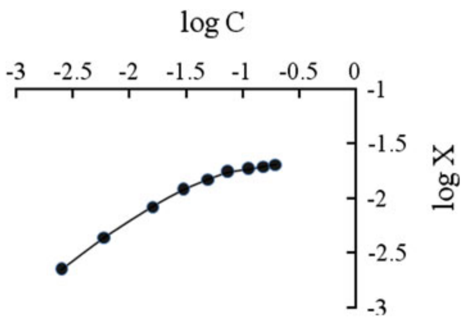

Fig. 8 Freundlich plot for cobalt ions adsorption on coal powder

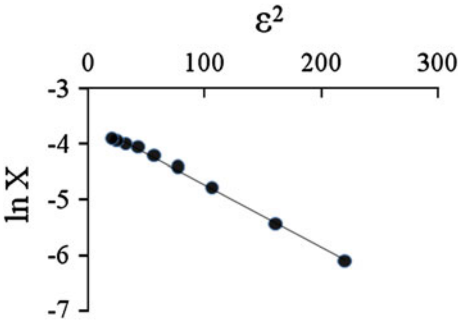

Fig. 10 D–R plot for the adsorption of cobalt ions on coal powder

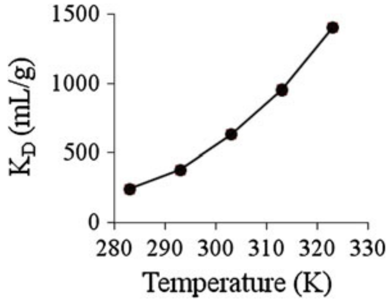

Fig. 11 Influence of temperature on K_D for the adsorption of cobalt ions on coal powder

Influence of temperature

The dependence of K_D for cobalt ions adsorption on coal powder was studied in the temperature range of 10–50 °C in step of 10 °C at optimized conditions and 100 μg/ml cobalt ions solution. The extent of the cobalt adsorption as a function of temperature is shown in Fig. 11, which indicates that the K_D values increases with an increase in temperature, suggesting that the adsorption of cobalt ions on coal powder is an endothermic process. The increasing temperature will increase the rate of diffusion of cobalt ions across the external boundary layer and in the internal pores of the coal powder due to the activation of the adsorbent surface and/or the enlargement of the pore size, resulting higher values of K_D with rise in temperature.

The thermodynamic quantities ΔH, ΔS and ΔG for cobalt ions adsorption were calculated from the K_D values using following relations [22].

$$\ln K_D = \Delta S/R - \Delta H/RT \tag{10}$$

and

$$\Delta G = RT \ln K_D \tag{11}$$

A plot of ln K_D versus $1/T$ is found to be linear as shown in Fig. 12. ΔH and ΔS were determined from the slope and intercept of the plot and was found to be 33.90 kJ/mol and 165.20 J/K mol, respectively. The values of the free energy of specific adsorption, ΔG were calculated as −12.90, −14.94, −16.23, −17.84, and −19.45 kJ/mol at temperature 283, 293, 303, 313, and 323 K, respectively. The negative values of ΔG suggest that the adsorption nature is spontaneous. Decrease in ΔG values with increasing temperature reveals that the adsorption process is favorable at higher temperature. The positive value of ΔH indicates the endothermic nature of the adsorption process. The positive value of ΔS suggests a high degree of disorderliness at solid–solution interface during the adsorption process cobalt ions on coal powder.

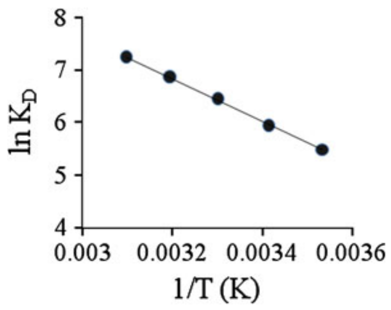

Fig. 12 Plot of ln K_D versus $1/T$ for cobalt ions adsorption on coal powder

Table 3 K_D (ml/g) values of other metal at optimized conditions for cobalt ions adsorption on coal powder

Metal	K_D (ml/g)
Co	610
Cs	65
Cr	150
Sr	650
Ru	Precipitated
Zr	Precipitated
U	Precipitated
Th	Precipitated
Eu	Precipitated
Er	Precipitated
Sm	Precipitated
Gd	Precipitated
Ce	Precipitated
Dy	Precipitated

Adsorption of other metal ions at optimized condition for cobalt ions (selectivity)

The adsorption efficiency of coal powder is sometimes affected by the presence of other metal ions in aqueous solutions by their co-adsorption or by negative adsorption along with the metal ions of interest. Therefore, using the optimized adsorption parameters for the uptake of cobalt ions from solutions, the adsorption of other metal ions was also studied. The results are summarized in Table 3. This indicates that Zr, Ru Eu, Er, Sm, Gd, Ce, U, and Th ions were precipitated at pH 7, therefore the separation of the cobalt ions from these metal ions could be achieved. However, the Cs, Cr and Sr ions induced negative effects on cobalt ions adsorption and would be co-adsorbed along with cobalt ions on coal powder. The Sr ions reduce the uptake of cobalt ions more than the Cr and Cs ions.

Conclusions

This study demonstrates the potential of coal powder for the adsorption of cobalt ions from solutions. The conditions for the uptake of cobalt ions were established as stirring speed 200 rpm, shaking time 120 min (equilibration time) and pH 7. The recovery of the cobalt ions from solution is favorable in low concentration. The adsorption mechanism is predominantly diffusion and both intra-particle and boundary layer diffusion seem significant in the rate controlling step. The adsorption process is best accounted for using pseudo second order kinetic model and the overall rate of adsorption process appears to be controlled by more than one step, namely the external mass transfer and intra-particle diffusion mechanism. The existence of two slopes in the Freundlich plot also confirms the surface diffusion and intra-particle diffusion modes of adsorption. The Langmuir isotherm equation was obeyed well in the whole range of cobalt ions concentration with high value of correlation coefficient ($r^2 = 0.999$). High temperature favors the adsorption of cobalt ion onto coal powder, indicating the endothermic nature of adsorption process. Separation of cobalt ions can be achieved from Zr, Ru Eu, Er, Sm, Gd, Dy, Ce, U, and Th ions at pH 7 where as Cs, Cr and Sr ions induced negative effect on cobalt ions recovery from solutions. Pakistani coal powder could be used as an adsorbent for the effluent treatment, especially for the removal of metal ions.

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