Calcined *Umbonium vestiarius* snail shell as an efficient adsorbent for treatment of wastewater containing Co (II)

Rauf Foroutan¹ · Amin Oujifard² · Fatemeh Papari¹ · Hossein Esmaeili³

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Abstract

In the present study, the *Umbonium vestiarius* snail shell (UVS) was used as an abundant and low-cost resource for the removal of Co (II) from aqueous solution. The characteristics of calcined *Umbonium vestiarius* snail shell (CUVS) were analyzed using FTIR, SEM, MAP, EDAX, and BET analyses. The results showed that the specific surface area of the CUVS was obtained 17.02 m²/g which was an acceptable amount. The presence of Co (II) in the adsorbent structure was confirmed by EDAX, and Map analyses after Co (II) adsorption showed that the adsorbent successfully adsorbed Co (II) from aqueous solution. The effect of different parameters such as, contact time, initial concentration of cobalt ion, the adsorbent dose, and pH value was also investigated. The maximum efficiency of cobalt ion adsorption was measured 93.87% at a pH value of 6, contact time of 80 min, the adsorbent dose of 3 g/L, and initial ion concentration of 10 mg/L. Also, Langmuir, Freundlich, and D–R isotherm models were used to determine the most appropriate isotherm model for cobalt ion adsorption. The adsorption equilibrium data were better fitted with the Langmuir model with a maximum adsorption capacity of 93.46 mg/g. Additionally, the average free energy of adsorption was evaluated in the amount of 1.4085 KJ/mol, revealing a physical adsorption. Moreover, the kinetic behavior study showed that the experimental data follow the pseudo second order kinetic model to the value of correlation coefficient.

Keywords Cobalt ion · Aqueous solution · Snail shell · Kinetics study · Equilibrium study · Adsorption

Introduction

In recent years, the fast growth of industrialization has caused releasement of heavy metals to the environment and subsequently has become a major concern all around the world. Heavy metals are toxic and non-biodegradable and can be accumulated in food chains (Ma et al. 2017; Cojocaru et al. 2009). Exposure to heavy metals for a long time and accumulation of heavy metals in the human body can result in various side effects such as neurological disorders (Wang et al. 2016a, b). The World Health Organization (WHO)

and the International Program on Chemical Safety (IPCS) have been reported some metals such as lead, mercury, aluminum, chromium, cobalt, copper, nickel, and zinc as toxic and hazardous heavy metals. Cobalt is a toxic heavy metal that enters the environment through atomic power plants wastewater and industrial effluents (Ahmadpour et al. 2009; Al-Shahrani 2014). Discharge of this non-biodegradable toxic metal to the environment can seriously damage ecosystems. High concentration of cobalt in human body can lead to acute poisoning and various disease such as, asthma, allergies, heart damage, heart failure, paralysis, blood pressure reduction, lung irritation, bone defects, mutation in living cells (genetic changes), thyroid, and liver damage (Ahmadpour et al. 2009; Bhatnagar et al. 2010; Liao et al. 2016). According to the Canadian Environmental Research Agency, the permissible limit of Co (II) in irrigation water is 0.05 mg/L (Fang et al. 2014).

In recent years, removal of heavy metals has been received much attention over their effects on human health and the environment. Therefore, different technologies, including chemical precipitation, ion exchange, membrane

✉ Hossein Esmaeili
esmaeili.hossein@iaubushehr.ac.ir;
esmaeili.hossein@gmail.com

¹ Young Researchers and Elite Club, Bushehr Branch, Islamic Azad University, Bushehr, Iran

² Faculty of Agriculture and Natural Resources, Persian Gulf University, Bushehr, Iran

³ Department of Chemical Engineering, Bushehr Branch, Islamic Azad University, Bushehr, Iran

filtration, adsorption, and electrocoagulation have been developed to eliminate or reduce heavy metals contamination to very low concentrations (Foroutan et al. 2018a, b; Teimouri et al. 2018). However, adsorption is one of the most commonly used methods, due to the low-cost, simplicity in operation, high selectivity, as well as availability of adsorbents (Foroutan et al. 2018a, b; Zhao et al. 2018; Wang et al. 2016a, b).

Activated carbon has been known as the most frequently used adsorbent to remove cobalt and other heavy metal ions from aqueous solution. Despite high adsorption efficiency of this adsorbent, it has a limited practical applicability in commercial scale because of high production costs and non-renewability (Ahmadpour et al. 2009; Foroutan et al. 2017a, b). In addition to activated carbon, many other adsorbents have been used in heavy metals removal, of which, the adsorbents prepared from fungal biomass (Foroutan et al. 2017a, b; Naeimi et al. 2018), layered double hydroxides (Gu et al. 2018), boron nitride-based materials (Yu et al. 2017), egg shell (Mittal et al. 2016), peat moss (Caramalau et al. 2009), agricultural waste products (Feng et al. 2011; Anwar et al. 2010), different types of clay soils (Choi et al. 2016; Olu-Owolabi et al. 2016; Pawar et al. 2016), etc. can be mentioned.

In this study, the calcined snail shell of *Umbonium vestiarium* was used as a novel bio-adsorbent in the removal of cobalt ion from aqueous solutions. The snail shell is one of the abundant materials, generates in large amounts annually and has some convenient properties such as eco-friendly, low-cost, and availability (Dumbauld et al. 2009). So that it can be noted as an effective adsorbent to remove heavy metals from aqueous solutions. To this purpose, the effect of different parameters such as initial pH of solution, the adsorbent concentration, contact time, and the initial concentration of cobalt ion on the adsorption efficiency was investigated. Also, the characteristics of the adsorbent were analyzed using FTIR, SEM, MAP, EDAX, BET.

Experimental

Chemicals

The materials used in this study such as cobalt nitrate salt ($\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$), hydrochloric acid (HCl), and sodium hydroxide (NaOH) were all analytical grade and supplied by Merck Co. (Germany). The cobalt stock solution was prepared by dissolving $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ in double distilled water. Working solutions with certain concentrations of 10–50 mg/L were prepared by diluting cobalt stock solution with deionized distilled water. The pH of solutions was regulated by 1M hydrochloric acid and sodium hydroxide solutions. Also, the *Umbonium vestiarium* snail shell (UVS)

was prepared from Persian Gulf beaches in Bushehr province, Iran.

Measurements

Fourier transform infrared (FTIR) spectrometer (Broker victor 22) was used to determine the functional groups. The remained concentration of cobalt ions in aqueous solution was measured using a flame atomic absorption spectrometer (AAS) by acetylene-air fuel (Varian, AA240FS). The changes in the surface morphology of adsorbent, elements determination and their distribution on the adsorbent, and micrographs of the adsorbent, before and after the adsorption, were studied using EDX, SEM, and Mapping analysis, respectively. The above-mentioned analyses were done by a scanning electron microscopy instrument (SEM-TESCAN MIRA3-FEG). The surface analysis, BET surface area and pore volume of the adsorbent were carried out using a Micromeritics ASAP 2020 instrument.

Production of calcined *Umbonium vestiarium* snail shell

The UVS was collected from Persian Gulf beaches in Bushehr province, Iran. The snail shells were washed several times with water to remove dirt and any other impurities. After that, they were dried in an oven at a temperature of 105 °C for 24 h. The dried snail shells were calcined in a furnace during 4 h at 1000 °C. The calcined snail shells were ground using Moulinex mill and were then stored in polyethylene plastic bottles for use in adsorption experiments.

Adsorption studies

Batch adsorption experiments were performed in 250-ml Erlenmeyer flasks. For each sample, a certain volume of cobalt solution was added to Erlenmeyer flasks, and then was stirred at a fixed initial pH and other physico-chemical process parameters. After a certain contact time, the samples were filtered using Whatman filter paper No. 40, after which the filtrates were analyzed for residual cobalt ions using AAS instrument. The experiments were carried out at different pH values (3–9) [in which pH of the solutions were regulated by 1M NaOH and HCl and measured by using a digital pH meter (Metrohm 744)] to determine the optimized pH of adsorption. The effect of other parameters, including cobalt ion concentration in the range of 10–50 mg/L, the adsorbent dosage in the range of 0.25–6 g/L, and contact time in the range of 5–120 min were investigated at the optimized pH. All the tests were performed three times and the average of them was considered. The adsorption efficiency (R) and cobalt adsorbed on the adsorbent, q_e (mg/g), were calculated as follows:

$$R = \frac{C_0 - C_t}{C_0} \times 100, \quad (1)$$

$$q_e = \frac{V(C_0 - C_e)}{M}, \quad (2)$$

where C_0 (mg/L), C_t (mg/L), and C_e (mg/L) are the initial, final, and equilibrium concentrations of cobalt ions, respectively. M (g) is the mass of the adsorbent and V (L) is the volume of the solution.

Results and discussion

Characteristics of the adsorbent

The results of FT-IR spectra analysis for UVS and CUVS before and after adsorption are shown in Fig. 1. According to the results, some peaks are observed in the range of 3400–3600/cm which exhibit stretching vibrations of O–H and N–H functional groups in the structure of UVS, respectively (Khoo and Esmaeili 2018). The functional group of C–H was identified at the wavenumber of 2921.93/cm, whereas after calcination and also using CUVS in Co (II) adsorption, the vibrations were transmitted to 2924.16 and 2924.22/cm, respectively. Moreover, in the range of 2850/cm no vibrations were observed. However, a low intensity peak was detected at the wavenumber of 2856/cm after calcination for CUVS, which can be referred to C–H functional group. Sharp peaks with different intensity in the range of 706–1475/cm in the UVS indicate the vibrations of C=O and O–C–O functional groups (Khoo and Esmaeili 2018). Furthermore, the changes in the intensity and the range of

FTIR peaks after calcination and adsorption can be due to the removal of some compositions in the structure of UVS and the adsorption of Co (II) as well.

Figure 2 represents the images obtained from SEM, EDAX, and Map analyses for UVS and CUVS before and after Co (II) adsorption. It was found from the results that the snail shell before calcination (Fig. 2a) has fewer pores and roughness in comparison to CUVS (Fig. 2d). Hence, it can be concluded that increasing in the pores, roughness, and active sites of UVS during calcination can be an impressive factor in Co (II) adsorption from aqueous solutions. Also, calcium was found to be the most constitutive part of UVS, as shown in Fig. 2b, c, which can be very effective in Co (II) adsorption. As seen in Fig. 2e, f, density and the amount of calcium and oxygen increased in the surface of UVS after calcination. These changes are also detected in FTIR spectra analysis. Figure 2g illustrates some changes in the CUVS surface after adsorption which can be attributed to the cobalt ion replacement on CUVS surface. The presence of Co (II) in the structure of adsorbent prepared from snail shell was confirmed by EDAX, and Map analysis after Co (II) adsorption (Fig. 2h, i), demonstrating that the snail shell is successfully adsorbed cobalt ions from aqueous solution.

According to BET analysis, the specific surface area and the pore volume of the CUVS adsorbent were obtained 17.02 m²/g and 0.038463 cm³/g, respectively. Other characteristics of the adsorbent are presented in Table 1. Isotherm linear plot and BJH adsorption cumulative pore volume of CUVS are also shown in Fig. 3. All the amounts express penetration of cobalt ions into the pores of CUVS. The pores of UVS are calcined and its nearly high surface area can be led to the adsorption and transferring of Co (II) from aqueous solution to the adsorbent.

Effect of initial pH on adsorption

The initial pH of the solution is one of the most important parameters in metal ions adsorption which the adsorption mechanism is highly dependent on this parameter (Khoo and Esmaeili 2018). In addition to changing the adsorbent surface charges, it also affects the ionization degree and cobalt ions form. Cobalt has different forms at different pHs (e.g., Co²⁺, Co(OH)₂, Co(OH)⁺, and Co(OH)³⁻). Figure 4 shows the effect of initial pH on the adsorption efficiency by the CUVS adsorbent in the range of 3–9. According to Fig. 4, the efficiency of Co (II) adsorption increased by increasing the initial pH from 3 to 6. This increment can be attributed to H⁺ reduction present in aqueous solution and also competition decrement of H⁺ and Co (II) ions for replacement on the active sites of adsorbent (Hadi et al. 2013). At pH values greater than 6, the adsorption efficiency of Co (II) decreased which can be caused by forming a cobalt ion complex with hydroxide (OH⁻) in aqueous solution. This can be resulted

Fig. 1 FTIR spectra of UVS (a), CUVS before adsorption (b), and CUVS after adsorption (c)

Fig. 2 Map, EDAX, and SEM analysis for UVS (a–c), CUVS before adsorption (d–f), and CUVS after adsorption (g–i)

Table 1 Main characteristics of UVS and CUVS adsorbent used in this study

Surface area	
Single point surface area at p/p^0	16.1276 m ² /g
BET surface area	17.0151 m ² /g
Langmuir surface area	24.0205 m ² /g
t -Plot external surface area	18.2647 m ² /g
Pore volume	
Single point adsorption total pore volume of pores less than 703.576 Å diameter at p/p^0	0.038463 cm ³ /g
t -Plot micropore volume	–0.000842 cm ³ /g
BJH desorption cumulative volume of pores between 17.000 Å and 3000.000 Å diameter	0.049094 cm ³ /g
BJH desorption cumulative volume of pores between 17.000 Å and 3000.000 Å diameter	0.048881 cm ³ /g
Pore size	
Adsorption average pore width (4 V/A by BET)	90.4211 Å
BJH adsorption average pore width (4 V/A)	88.811 Å
BJH desorption average pore width (4 V/A)	74.553 Å

Fig. 3 Isotherm linear plot of CUVS (a), BJH adsorption cumulative pore volume of CUVS (b)

Fig. 4 Effect of solution initial pH on the cobalt adsorption (temperature: 30 °C, adsorbent dose: 2 g/L, cobalt concentration: 10 mg/L, mixing intensity: 200 rpm, contact time: 60 min)

Fig. 5 Effect of contact time and initial cobalt concentration on Co (II) removal by CUVS (temperature: 30 °C, adsorbent dose: 2 g/L, solution pH: 6, mixing intensity: 200 rpm)

by the functional group changes on the adsorbent surface or hydrogen bonding, which is shown as follows:

where R and M are the calcined snail shell and cobalt ion, respectively. Sedimentation of cobalt ions leads to a reduction in the amount of Co (II) in aqueous solution. Consequently, the amount of Co (II) decreases for replacement on the active sites of the adsorbent which does not use of the whole capacity and the active sites of the adsorbent. Hence, based on the results, the maximum adsorption efficiency of Co (II) was determined at the initial pH of 6.

Effect of contact time and initial concentration of cobalt on adsorption

The contact time is one of the parameters perceived to be a strongly effective parameter in the adsorption process. The effect of contact time on cobalt adsorption using CUVS is depicted in Fig. 5. It is obvious from this figure that Co (II) adsorption increased by increasing the contact time in the range of 5–80 min. Although, at the primary contact times, the growth of adsorption efficiency was faster than that at the final ones, which can be due to the unsaturated active sites of the adsorbent and the availability of enough surface for Co (II) adsorption on CUVS. Therefore, the maximum adsorption efficiency was achieved 92.32% at the contact time of 80 min.

The initial concentration of metal ions, as a mass transfer driving force between the solid (adsorbent) and solution phase, plays a major role in adsorption process. Figure 5 demonstrates the effect of various initial concentrations of cobalt ion on the adsorption efficiency. It is clear from Fig. 5 that the adsorption efficiency of cobalt ion decreased by increasing the initial ion concentration. At low concentrations of cobalt ion, the ratio of the adsorbent active sites to the ions present in solution is high. Also, the ions in the aqueous solution can be able to be interacted with prepared adsorbent and be removed from the aqueous solution (Foroutan et al. 2017a, b). The results evidently indicate that the removal efficiency decreased from 92.32 and 84.65% with increasing the initial cobalt concentrations from 10 to 50 mg/L, respectively, which is ascribed to the competition of cobalt ions to relocate on active sites of the adsorbent.

Effect of adsorbent dosage on adsorption

The adsorbent dosage is an impressive factor which can effect on the efficiency and capacity of adsorption. The effect of CUVS dosage on Co (II) adsorption efficiency is illustrated in Fig. 6. The results evidently show that Co (II) adsorption efficiency was increased by the increment of the adsorbent dosage (0.25–3 g/L). Also, no significant changes were observed at higher doses. Furthermore, the adsorption capacity reduced from 17.492 to 1.5858 mg/L with increasing the adsorbent dosage from 0.25 to 6 g/L, respectively. These findings express that at lower adsorbent dosages, there are more interactions between cobalt ion and the adsorbent and also the more active sites of adsorbent are used. The fixed adsorption efficiency and decreasing of the adsorption capacity can be attributed to the particles aggregation and collision of those particles with each other. In sequence, the number of active sites and enough spaces for cobalt ion adsorption decreases. The maximum efficiency of cobalt ion

adsorption was obtained 93.87% at the adsorbent dosage of 3 g/L.

Modeling study

Adsorption kinetics

The kinetics of adsorption is used to define the mechanism of adsorption processes, for instance, adsorption on the surfaces, chemical reactions, and diffusion mechanisms. There are various models to investigate the adsorption kinetics, however, the pseudo first order and pseudo second order kinetic models are two types of equations have been commonly used in the literature (Foroutan et al. 2018a, b; Teimouri et al. 2018). The linear form of pseudo first order model can be defined by the following equation (Wang et al. 2018):

$$\ln(q_e - q_t) = \ln q_e - k_1 t, \quad (3)$$

where q_e is the amount of adsorbed ion at equilibrium state (mg/g), q_t is the amount of adsorbed ion at any time (mg/g), and k_1 is the rate constant of pseudo first order kinetic model (1/min). The value of k_1 can be calculated from the slope of $\ln(q_e - q_t)$ plot versus t drawn at different concentrations of cobalt ion (10–50 mg/L) and the q_t value was determined in the range of 3.53–19.94 mg/L using pseudo first order (Fig. 7a). The results show that the determined adsorption capacity (q_t) data have lower values than the amounts of experimental adsorption capacity (q_e). Thus, the pseudo first order model is unable to describe the kinetic behavior of cobalt ion adsorption by CUVS (Yadav et al. 2014). Other parameters have been reported in Table 2.

The pseudo second order model is another kinetic model which is used to study the kinetic behavior of different bio-adsorbents. The linear form of pseudo second order model can be defined as follows (Wang et al. 2018):

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{t}{q_e}, \quad (4)$$

where k_2 is the rate constant of pseudo second order model (mg/g min). To calculate the constants and kinetics model parameters, it was used of t/q_t versus t as shown in Fig. 7b. The adsorption capacity (q_t) for cobalt ion concentrations of 10–50 mg/L using the pseudo second order model was achieved in the range of 4.9091–23.4741 mg/g. As seen in Table 2, the data obtained for q_t are mainly close to the experimental data, affirming high ability of the pseudo second order model to describe the adsorption behavior of cobalt ion by CUVS.

Also, the correlation coefficients (R^2) calculated from the pseudo second order model were so much higher (>0.99 in all of the concentrations) than those for the pseudo first order model which confirms that the experimental data are best

Fig. 6 Effect of adsorbent dosage on cobalt removal efficiency from aqueous solution (temperature: 30 °C, adsorbent dose: 10 mg/L, solution pH: 6, contact time: 80 min)

Fig. 7 Kinetic models for cobalt ion adsorption by CUVS **a** pseudo first order model, **b** pseudo second order model

Table 2 Kinetic parameters from fitting the experimental data to the kinetic models for cobalt ion adsorption by CUVS

Kinetic models	Parameter	Co (II) ion concentration (mg/L)				
		10	20	30	40	50
Pseudo first order	K_1 (/min)	0.0654	0.0553	0.0553	0.0534	0.0527
	$q_{e(cal)}$ (mg/g)	3.5335	6.6578	11.4089	15.8853	19.9354
	R^2	0.9876	0.971	0.9215	0.9207	0.9211
Pseudo second order	K_2 (g/mg min)	0.0331	0.0146	0.0088	0.0057	0.0018
	$q_{e(cal)}$ (mg/g)	4.9091	9.756	14.4717	19.0839	23.4741
	R^2	0.9996	0.9996	0.9996	0.9991	0.9992
	$q_{e(exp)}$ (mg/g)	4.6285	9.168	13.5534	17.704	21.645

fitted to the pseudo second order model. Additionally, the rate constant of pseudo first order model was greater than that for pseudo second-order model.

Adsorption isotherms

The isotherms of adsorption can provide some useful information about distribution of the adsorbed molecules between solid and liquid phases and also some information about the interaction between adsorbate and adsorbent at a constant temperature (Zhu and Row 2011; Javadian et al. 2013). In this study, Freundlich, Langmuir, and Dubinin–Radushkovich adsorption isotherms were used to analyze the isotherm behavior of cobalt ion adsorption by the adsorbent.

The Langmuir isotherm model assumes that the uptake of metal ions and other pollutants occurs by a monolayer adsorption without any interaction between metal ions adsorbed by active sites of the adsorbent (Javadian et al. 2013; Sarvestani et al. 2016). The Langmuir isotherm model is given by the following equation (Wang et al. 2018):

$$\frac{1}{q_e} = \left(\frac{1}{k_l q_{\max}} \right) \frac{1}{C_e} + \frac{1}{q_{\max}}, \quad (5)$$

where q_e is the amount of adsorbed ion at equilibrium state (mg/g), C_e is the equilibrium concentration of cobalt ion in aqueous solution (mg/L), $q_{\max}$ is the maximum adsorption capacity (mg/g), and k_l is the Langmuir constant (L/mg).

Another important parameter used to reveal the principal properties of the Langmuir model called separation factor or equilibrium parameter (R_L) which has been defined as below:

$$R_L = \frac{1}{1 + k_L C_0}, \quad (6)$$

where C_0 is the initial concentration of cobalt ion in aqueous solution (mg/L). The value of R_L portends the isotherm type to be either undesirable ($R_L > 1$), irreversible ($R_L = 0$), linear ($R_L = 1$), and desirable ($0 < R_L < 1$) (Mousavi et al. 2018).

Freundlich isotherm is an experimental model to describe the adsorption process at heterogeneous and multilayer surfaces of adsorbent (Kizilkaya et al. 2010; Mahini et al. 2018). The linear form of this model is given by the following equation (Wang et al. 2018):

$$\ln q_e = \ln k_f + \frac{1}{n} \ln C_e, \quad (7)$$

where q_e is the amount of adsorbed ion at equilibrium state (mg/g), C_e is the equilibrium concentration of metal ion in aqueous solution (mg/L), k_f and $1/n$ are the constants of the Freundlich model that express the adsorption capacity and adsorption intensity, respectively. The values of n and k_f were calculated from the slope and intercept of the $\ln q_e$ plot versus $\ln C_e$ (Fig. 8b). The value of n , reported in the range of 1–10, indicates the interactions between the metal ion

and the adsorbent. This parameter also expresses the adsorption type. Accordingly, the n values of 1 express the linear adsorption, the n values higher than 1 express favorable and physical adsorption, and the n values less than 1 express favorable and chemical adsorption (Foroutan et al. 2017a, b).

The Dubinin–Radushkevich model has been offered as another isotherm model which is not based on the assumption of homogeneous surface or constant adsorption potential but is used to predict the nature of adsorption process (physical or chemical) (Rangabhashiyam and Selvaraju 2015). The linear form of this model can be calculated from the following equation:

$$\ln q_e = \ln q_m - \beta \epsilon^2, \quad (8)$$

where β (mol^2/J^2) and q_m (mg/g) are the D–R constants and ϵ is the Polanyi potential, which can be determined from the following equation:

$$\epsilon = RT \ln \left(1 + \frac{1}{C_e} \right), \quad (9)$$

where R is the universal gas constant ($8.314 \text{ J/mol} \cdot \text{K}$) and T is the temperature (K).

The values of D–R constants, β and q_m , were calculated from the plot of $\ln q_e$ versus ϵ^2 (Fig. 8c). β value states the average free energy (E) which can be calculated by the following relationship:

$$E = \frac{1}{\sqrt{2\beta}}. \quad (10)$$

The average free energy of adsorption ascertains the adsorption nature. If the E value is between 8 and 16 KJ/mol , the adsorption process is of an ion exchange type (chemical nature), and for the values lower than 8 KJ/mol , the adsorption process can be assumed as a physical one (Nghah et al. 2012).

The calculated adsorption constants and correlation coefficients from well-known Freundlich, Langmuir, and D–R adsorption isotherms are reported in Table 3 for Co (II) adsorption by CUVS. The results showed that a significant amount of 93.4579 mg/g was reported for the maximum adsorption capacity of Co (II) by CUVS. Table 4 shows a comparison between the maximum adsorption capacity of Co (II) ion using different adsorbents and the adsorbent used in this study. As shown in this Table, the obtained maximum adsorption capacity by CUVS is more than that for the other adsorbents which shows the high capacity of this adsorbent. Also, the value of R_L obtained 0.67024, exhibiting a desirable adsorption process for Co (II) adsorption by CUVS.

Fig. 8 Linear equation of isotherm models **a** Langmuir, **b** Freundlich, **c** D–R for Co^{2+} adsorption by CUVS

Table 3 Results of adsorption isotherms for the adsorption of cobalt onto CUVS

Isotherm models	Parameters	Co (II)
Langmuir isotherm	q_m (mg/g)	93.4579
	K_L (L/mg)	0.0492
	R^2	0.8322
	R_L	0.67024
Freundlich isotherm	n	1.2103
	K_f ($\text{mg/g (L/mg)}^{1/n}$)	4.0084
	R^2	0.8937
D–R isotherm	E (KJ/mol)	1.4085
	q_m (mg/g)	12.8751
	$\beta \times 10^{-5}$ (mol^2/J^2)	0.0252
	R^2	0.9196

Table 4 A comparison between different adsorbents to remove cobalt ion

Sorbent	Adsorption capacity (mg/g)	References
Alginate nanoparticles	6.2	Esmaeili and Beni (2015)
Polyvinyl alcohol/chitosan magnetic	14.4	Zhu et al. (2014)
Chrysanthemum indicum flower raw	14.8	Vilvanathan and Shanthakumar (2015)
Hydroxyapatite	20.9	Smičiklas et al. (2006)
Graphene oxide	21.3	Lingamdinne et al. (2016)
Watermelon rind	23.3	Vilvanathan and Shanthakumar (2015)
Chitosan	30.5	Liao et al. (2016)
Acacia nilotica leaf carbon	35.5	Vilvanathan and Shanthakumar (2015)
Tin antimonate	30.1–44.4	Zhang et al. (2016)
New bifunctionalized chitosan	41.2	de Almeida et al. (2016)
Chrysanthemum indicum flower biochar	45.4	Vilvanathan and Shanthakumar (2015)
Almond green hull	45.5	Ahmadpour et al. (2009)
Graphene oxide	43.6–52.7	Wang et al. (2018)
Chitosan–chloroacetic acid	59.1	Liao et al. (2016)
Triethylenetetramine-modified chitosan	59.5	Liao et al. (2016)
Modified corn silk by dilute nitric acid	90.1	Yu et al. (2016)
Calcined <i>U. vestiarium</i> snail shell	93.47	Present study

The n value from Freundlich isotherm was achieved higher than 1 which shows a favorable physical adsorption process. The value of E from D–R isotherm was reported 1.4085 kJ/mol confirming the physical adsorption. Also, the amount of q_m was obtained 12.8751 mg/g. Additionally, the correlation coefficients (R^2) showed that the D–R isotherm model was the best model to describe the isotherm behavior of the adsorbent and the model was better fitted with experimental data.

Conclusions

In the present study, *Umbonium vestiarium* snail shell was primarily calcined and then used as an effective adsorbent in cobalt ion removal from aqueous solution. The batch adsorption study was carried out and the effect of different parameters such as initial pH of solution, contact time, adsorbent dosage, and initial cobalt concentration was investigated. The results showed that the adsorption efficiency is considerably dependent on the initial pH. The maximum adsorption efficiency was obtained 93.87% at the initial pH of 6, the contact time of 80 min, the initial cobalt concentration of 10 mg/L, and the adsorbent dosage of 3 g/L. Freundlich, Langmuir, and D–R isotherm models were used to study the adsorption isotherms. The experimental data were better described by Langmuir model, with higher R^2 value than those for Freundlich and D–R model. The maximum adsorption efficiency from Langmuir and D–R model was achieved 93.46 mg/g and 12.87 mg/g, respectively. The n value for Co (II) adsorption by CUVS was calculated 1.2103, affirming

physical nature of the adsorption process. The pseudo first and pseudo second order models were used to investigate the adsorption kinetics. According to the findings from kinetics model, the experimental data were best fitted to the pseudo second order model. Additionally, the pseudo second order kinetic model had a higher correlation coefficient in comparison to the pseudo first order model; moreover, the calculated maximum adsorption capacity (q_m) from the pseudo second order model had more conformity with experimental adsorption capacity (q_{exp}).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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