Application of ZnO Nano Rods for the Batch Adsorption of Cr(VI): A Study of Kinetics and Isotherms

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Abstract: The present study reports the synthesis of nano Zinc Oxide (ZnO) and its adsorption behaviour. The ZnO obtained by precipitation method were found to be well-defined nano rods arranged like flower. The shape, size and structure of ZnO were characterized from X-Ray Diffraction (XRD), Energy Dispersive X-ray (EDX) and Scanning Electron Microscope (SEM) analysis. These nano rods were utilized for the adsorption of hexavalent chromium ions [Cr(VI)] from their aqueous solution by using batch adsorption technique. Different physico-chemical parameters such as metal ion concentration, pH, dosage level and equilibrium contact time were studied during adsorption. The amount of chromium adsorption increases with increase in adsorbent dosage, whereas the adsorption was maximum in the first 40 min with optimum value of pH 3. The kinetic of adsorption was best fitted by the pseudo-second-order rate equation. Similarly, the equilibrium adsorption data were fitted well by both Temkin and Freundlich adsorption isotherm models in comparison to Langmuir adsorption model. The adsorption of chromium was supported by EDX and SEM analysis. Moreover, the change in the SEM morphology of ZnO nano rods into nano sheets after adsorption is an interesting observation of the present investigation.

Keywords: Nano Rods, Nano Sheets, Adsorbent, Hexavalent Chromium Ions, Adsorption Isotherm, Pseudo-Second-Order Kinetics

Introduction

Rapid urbanization as well as industrialization adversely affects the environment by polluting both the atmosphere and the aquatic systems. Different industries require different types of materials for their operation and the heavy metals are found to be the most essential commodities. Industries such as mining, pharmaceuticals, tanneries, electro-plating, chemical-manufacturing units etc., generates huge amount of wastes and effluents. Again the inadequately treated effluents consist of various toxic metals such as chromium, cadmium, arsenic, nickel, lead, mercury, copper etc. The toxicities of these metals were well documented by different researchers (Förstner and Wittmann, 1985; Mukherjee, 1986; Nriago, 1988). Most of these metals were reported to be accumulated into the living tissues (Madoni et al., 1996; Oehme, 1979; Carson et al., 1986). Not only for human beings, these metals also affect in the growth of plants and animals too.

The present study is based on the separation of chromium metal from aqueous solutions. The major sources of chromium metal into the natural water systems are from tanneries, textile dyeing, metal finishing, pharmaceutics and electroplating industries. Both hexavalent and trivalent chromium are stable and exist in aqueous systems. However, hexavalent chromium is more toxic and known to be carcinogenic and mutagenic to living organisms.

There are various techniques such as ion exchange, membrane filtration, electro-chemical technologies, chemical precipitations, adsorption etc., for the effective removal of heavy metals from water (O’Connell et al., 2008; Wang et al., 2003; Sahu et al., 2009; Hashim et al., 2011). Amongst all, adsorption technique is the most preferred one due to its flexibility in designing and operation. Similarly, different types of materials were reported as effective adsorbents (Chu, 2002; Sharma and Forster, 1996; Yabe and de Oliveira, 2003; Tewari and Vivekananda, 2013). However, in the present scenario, nano based adsorbents are more convenient for the adsorption of heavy metal from aqueous solutions (Zhang and Fang, 2010; Hua et al., 2012; Mahdavi et al., 2017; Taman et al., 2015). These smart materials can separate the metals due to their increased surface to

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volume ratio. Nano metal oxides such as of titanium, iron, magnesium, aluminium, copper, zinc etc, were used by many researchers for the removal of toxic metals (Recillas et al., 2011; Agrawal and Sahu, 2006; Mahdavi et al., 2012; Sheela et al., 2012). Beside these, certain doped nano and micro-based metal adsorbents were also studied for the separation of different metals (Shenashen et al., 2017; Zolfaghari et al., 2013). These materials are promising adsorbents for their high selectivity and activities towards the target components (Henglein, 1989; El-Sayed, 2001). Metal oxides along with carbon based nano adsorbents show efficiency due to their increased surface area and optimal magnetic properties (Aillon et al., 2009). Certain low cost mesoporous adsorbents (Warkocki et al., 2015; El-Safy and Shenashen, 2013), along with sensor-based adsorbents were also reported for the adsorption of various toxic metals (El-Safy et al., 2013; 2012). Review of literature showed that ZnO nano particles are effective for the removal of hazardous metals and contaminants from waste water (Gupta et al., 2015; Wang et al., 2010; Alsawata et al., 2017; Hosseini et al., 2016). Moreover, this oxide is an eco-friendly, economical and easily synthesized nano adsorbent to be employed as an adsorbent. Apart from toxic metals, these adsorbents were also found to remove various dye-based contaminants from wastes (Zafar et al., 2018; Dehghani and Mahdavi, 2015; Konicki et al., 2018). In addition to these, certain nano ZnO doped with other metals have also been reported as adsorbents (Ghiloufi et al., 2016; Meng et al., 2015). Similarly, investigations involving ZnO nano rods were also carried out for the removal of toxic metals (Ghaedi et al., 2015; Yuvaraja et al., 2018). But, however, study related to ZnO with similar morphology as in the present study for chromium adsorption is found to be scarce in literature. Moreover, ZnO nano rods in flower arrangement are also a rare phenomenon to study. The objective of the present investigation involved with such ZnO nano rods with sufficient porosity for the adsorption of Cr(VI) from its aqueous solutions. As an extension work of our previous studies with the synthesis of ZnO nano particles by various methods (Venugopal and Kamila, 2017), here we report the utilization of the nano ZnO obtained from only one synthesis method for its uniqueness.

Materials and Methods

Analytical grade zinc sulphate, sodium hydroxide, potassium dichromate were used in the experiment and were of AR grade with more than 99% purity. Concentrated nitric acid is obtained from Merck India. The chemicals were used as received without any further purification. Deionized double distilled water was used throughout the experiment.

Synthesis of ZnO Nano Particles

Zinc oxide nano particles were synthesized by precipitation method using zinc sulphate and sodium hydroxide (Venugopal and Kamila, 2017). To the aqueous solutions of zinc sulphate (0.1 M), 0.2 M sodium hydroxide solution was added drop wise with constant stirring till the pH becomes 11. This stirring was then continued for around seven hours to get a white colour dense precipitation. The precipitates were centrifuged and dried at 100°C for 4 h. These samples were kept for overnight to dry and then it is ground to make fine powders of zinc oxide. This was then characterized for the shape, size and arrangement from XRD, EDX and SEM analysis. The X-ray diffraction spectra were taken by RIGAKU smart lab X-ray Diffractometer using CuKα radiation $\lambda = 1.5405$ Å and X-rays generator operating at 40 kv. The scanning range was maintained within 20-100 deg with the scanning speed of 5° min⁻¹. The elemental composition, shape and structures of the particles have been carried out from EDX and SEM analysis by using GEMINI ULTRA 55 instruments.

Batch Adsorption Studies

A synthetic stock solution of hexavalent chromium (1000 mg/L) was prepared from potassium dichromate by dissolving 2.829 mg in 1L deionized water (Mekonnen et al., 2015; Bhattacharyya et al., 2006). From this stock solution, required concentrations of chromium solutions were prepared for adsorption study.

In the batch adsorption process, the metal ions were added to the calculated amount of adsorbents in 250 mL Erlenmeyer flasks and were shaken under constant condition using rotary shaker to allow sufficient time for reaching adsorption equilibrium. The pH of the solution was adjusted by using 0.01 M HNO₃ and 0.01 M NaOH solutions. The initial metal ion concentration (C₀) has been varied in the range 100-500 mg/L with pH 3 and 0.05 g adsorbent dose. The shaking time was for 60 min at 30°C. The effect of initial pH on adsorption was studied in the range of 2.5-4.5 keeping the chromium ion concentration as 100mg/L and adsorbent dose as 0.05 g at 30°C for 60 min shaking. Similarly, the effect of contact time (30, 40, 50, 60,70 min) has been carried out for 100 mg/L chromium with 0.05g of adsorbent at pH 3. Besides, the variation of adsorbent dosage has also been carried out in the range 0.02-0.1 g keeping the chromium concentration as 100 mg/L with 60 min shaking at 30°C.

After adsorption, the solution contents were centrifuged and the supernatant liquid was taken for absorption study from UV-visible spectrophotometer (ELICO made SL-159 UV-visible spectrophotometer)
using Di-Phenyl Carbazide complex technique (DPC). The adsorbents were separated by using Whatman 41 filter paper [CAT No 1441-070]. These spent adsorbents were used for SEM, EDX analysis to know the morphology and elements. Similarly, Fourier Transform Infrared Analysis (FTIR) of ZnO nano particles has been done for both before and after adsorption. This analysis determines the vibrational frequency changes of the functional groups in the adsorbent.

The amounts of adsorption \([q_e \text{ (mg/g)}]\) at equilibrium and adsorption efficiency or percentage of removal (%) were calculated by using the following expressions (Alsawata et al., 2017):

\[
q_e (\text{mg} / \text{g}) = \frac{(C_o - C_e)V}{m}
\]

\[
\% = \frac{C_o - C_e}{C_o} \times 100
\]

where, \(C_o\) is the initial metal ion concentration and \(C_e\) is the final metal ion concentration, \(q_e\) is the amount of adsorbate adsorbed on the surface of the adsorbent, \(V\) is the volume of solution (L), \(m\) is the mass of adsorbent (g) (Oliveria et al., 2005). This removal percentage and amount of adsorption were investigated for different parameters such as metal ion concentration, effect of pH, adsorbent amount and mixing time. Besides, the experimental data obtained were fitted into different adsorption isotherm models such as Langmuir, Freundlich and Temkin isotherm models in order to determine the sorption performance and capacity of the adsorbent.

**Results and Discussion**

**Characterization of Nano Particles**

The XRD pattern of zinc oxide nanoparticles shows (Fig. 1) well defined peaks located at Bragg angles, \((2θ) = 31.75, 34.35 \text{ and } 36.23\). All these characteristic peaks are in high intensity corresponding to planes having miller indices (100), (002) and (101). These peaks indicate that the products obtained are pure and good in crystalline nature. Besides, these data also provide the information about the formation of hexagonal wurtzite structure for ZnO nanoparticles [Ref:JCPDS file no. 36-1451]. The average crystallite size, \(D\) was calculated by using Debye-Scherrer equation as below (He et al., 2008):

\[
D = \frac{K\lambda}{\beta \cos\theta}
\]

where, \(K\) is Scherrer constant and the crystallite shape factor, \(λ\) represents the wavelength of X-ray source 1.5405 Å used in XRD, \(β\) is full width at half maximum of diffraction peak and \(θ\) is the Bragg angle of intense peak. The calculated average crystallite size was found to be 37nm. Similarly, EDX analysis gives details of elemental composition of zinc and oxygen. The SEM morphology provides (Fig. 2) well-defined rod shaped structures of ZnO nanoparticles in the range of 49-140nm. The surface morphology plays an important role of an adsorbent for its capacity to adsorb. This depends on the surface structure of the adsorbent. In the present study the structure of nano particles obtained were of well-defined nano rods arranged in flower type. It has been observed that after adsorption, there is a significant change of the surface in presence of Cr(VI). Besides, there is increase in particle size from nano to micro after adsorption (1.49 μm). The presence of chromium is supported by EDX analysis (Fig. 3 and Table 1).

The FTIR for ZnO nano powder as well as with chromium after adsorption have been carried out in the range 400-4000cm\(^{-1}\) (using KBr pellet method with 0.4 cm\(^{-1}\) resolution in Perkin Elmer make instrument). This technique is a direct method for the identification of functional groups on the surface of the adsorbent where the adsorption depends on the porosity and the surface area of the adsorbent. The FTIR spectra of ZnO show several significant adsorption peaks (Fig. 4). Before adsorption, the vibration band at 485 cm\(^{-1}\) was related to ZnO (Zaka et al., 2011; Hong et al., 2009). Similarly the band shown at 1508 cm\(^{-1}\) was assigned to be of O-H bending vibrations and this has been shifted to 1514 cm\(^{-1}\) after adsorption. As per the literature, hydroxyl groups were identified by the characteristic broad peak in the range 3750-3250 cm\(^{-1}\). This is due to the stretching vibrations of OH bonds (Jamhour et al., 2016). Presently, the same has been observed at 3357 cm\(^{-1}\) before adsorption and there is shifting of peak (3337cm\(^{-1}\)) for ZnO-Cr after adsorption.

**Table 1: Elemental compositions of zinc oxide nano particles before and after adsorption**

| SL No. | ZnO                  | C         | Wt % | At% | O         | Wt % | At% | Zn         | Wt % | At% | Cr         | Wt % | At% |
|--------|----------------------|-----------|------|-----|-----------|------|-----|------------|------|-----|------------|------|-----|
| 1      | Nano particles before adsorption |            | 18.85 | 46.65 | 11.87 | 22.01 | 69.28 | 31.43 | ---- | ---- | ---- | ---- | ---- |
| 2      | Nano particles after adsorption | 11.50 | 24.68 | 32.77 | 52.82 | 50.07 | 19.99 | 5.07 | 2.51 | ---- | ---- | ---- | ---- |
Adsorption Mechanisms

Effect of Metal Ion Concentration

The initial metal ion concentration \( (C_0) \) was varied in the range between 100-500 (mg/L) at pH 3 and at 30°C using 0.05 g adsorbent. There was decrease in metal removal with increase in initial metal ion concentration. It may be due to limited number of active sites of the adsorbent that become saturated with increasing metal concentration (Alswata et al., 2017).

Effect of pH

The pH of the system controls the adsorption capacity, because this influences the surface properties of the adsorbent and ionic forms of the chromium metal in solution. Presently, the initial pH on adsorption was studied in the range 2.5-4.5 keeping the initial chromium ion concentration as 100 mg/L and adsorbent dose as 0.05 g at temperature 30°C. The optimal pH for chromium removal is found to be 3. At higher pH the separation is less probably due to formation of metal hydroxide. Similarly at low pH, the metal binding sites become positively charged due to H\(^+\) ions concentration and thus there is repulsion effect towards chromium ions (Singanan, 2011). Alswata et al. (2011) reported the similar observation for the removal of metal ions at acidic range. It is because of the H\(^+\) ions in the solution that compete with metal ions for acidic sites on the adsorbents surface (Mahdavi et al., 2012). Similarly, according to Attia et al. (2010), the adsorption of chromium was maximum at less pH whereas it decreases at higher pH.

Fig. 1: X-Ray diffractogram of ZnO nano particles: (a) Sample XRD pattern and (b) standard XRD pattern

Fig. 2: (A) SEM morphology of ZnO Nano particles before adsorption (B) SEM morphology of ZnO Nano particles after adsorption
**Effect of Mixing Time**

Contact time is an important factor in batch adsorption process. The extent of chromium removal was found to be increased first up to 40 min. of mixing and then the adsorption decreases. Initially the vacant surface sites are available for adsorption but they become saturated with the metal adsorption with the time. More over it would be difficult to be occupied due to repulsive forces between the bulk phases and the solute molecules on the solid (Alswata et al., 2017; Kumar et al., 2011; Alothman et al., 2013).

**Effect of Adsorbent Doses**

The effect of adsorbent dosage on the adsorption was studied in the range 0.02-0.1 g. It has been found that the removal of Cr(VI) increases with the increase in adsorbent dosage. This increment might be due to the larger surface area and availability of more adsorption sites, whereas the adsorption amount decreases with the adsorbent. This is because of the adsorptive capacity of adsorbent available was not fully utilized at a higher adsorbent dosage in comparison to lower adsorbent dosage. The percentage of removal of Cr(VI) with respect to all parameters and adsorption at equilibrium, \( q_e \) are presented in Fig. 5 and 6, respectively.

**Adsorption Isotherm Models**

Adsorption isotherms are important to describe the adsorption behaviour of solute on the specific adsorbents. The equilibrium of adsorption is one of

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Fig. 3: (A) EDXA image of ZnO Nano particles before adsorption (B): EDXA image of ZnO Nano particles after adsorption

Fig. 4: FTIR of ZnO Nano particles and Cr(VI) ions adsorbed with ZnO Nano particles
the physico-chemical aspects that is used for the evaluation of adsorption process as a unit operation. These models help in studying the nature of the adsorbent, surface area of the adsorbent, adsorbate-adsorbent interactions and moreover the adsorption capacity of the adsorbent (Alswata et al., 2017). They also indicate the distribution of adsorbable solute between the liquid and solid phases at various equilibrium (Oliveria et al., 2005).

Langmuir isotherm assumes monolayer adsorption onto a surface containing a finite number of adsorption sites of uniform strategies without transmigration of adsorbate in the plane surface (Hameed et al., 2007). Once a site is filled, no further adsorption can take place at that site. This is indicative of the saturation point or the achievement of maximum adsorption by the surface. The linear form of this isotherm is presented as (Okoli and Ezuma, 2014; Anah and Astrini, 2018; Langmuir, 1918):

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{q_m K_L C_e} \tag{4}$$

where, $q_e$ is amount of metal adsorbed (mg/g), $C_e$ is concentration after adsorption (mg/L), $q_m$ is maximum monolayer coverage capacity (mg/g), $K_L$ is Langmuir constant (L/mg). A linear plot of $(1/q_e)$ against $(1/C_e)$ with slope $(1/K_L q_m)$ and intercept of $(1/q_m)$ shows the satisfaction of the Langmuir model for adsorption. The constants $K_L$ and $q_m$ relate to the energy of adsorption and maximum adsorption capacity, respectively.

The Freundlich model is based on the adsorption behaviour of a heterogeneous surface in multilayer coverage. It is considered to be the most popular adsorption model for a single solute system of monolayer adsorption (Freundlich, 1928). As per Freundlich model the degree of site occupation increases with the decrease in the binding strength. So the stronger binding sites are occupied first followed by the weaker binding sites. The linear form of Freundlich isotherm model is given as (Freundlich, 1907):

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \tag{5}$$

where, $K_f$ is the Freundlich constant and the indicator of adsorption capacity whereas $\frac{1}{n}$ is the strength of adsorption process or adsorption intensity. These constants were determined from the slope and intercept from the plot of log $q_e$ (mg/g) against log $C_e$ (mg/L).

![Fig. 5](image_url)

**Fig. 5:** (A) Effect of adsorbate concentration (mg/l) on adsorption of Cr(VI) ion. (B) Effect of pH on adsorption of Cr(VI) ion. (C) Effect of contact time (min) on adsorption of Cr(VI) ion. (D) Effect of adsorbent dose (g) on adsorption of Cr(VI) ion.

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Similarly, Temkin isotherm model is based on the heat of adsorption of adsorbate molecules, which would decrease linearly with the increase in coverage of the adsorbent surface due to adsorbate-adsorbent interactions. This isotherm is used for heterogeneous surface energy systems (Mohamed et al., 2008; Atar et al., 2012) and the linear form of this isotherm model is given as (Temkin and Pyzhev, 1940; Akpomie et al., 2015):

\[ q = B \ln A + B \ln C_e \]  \hspace{1cm} (6)

where, \( B = RT/b \), \( b \) is the Tempkin constant related to heat of sorption (J/mol), \( A \) is the Temkin isotherm constant (L/g), \( R \) is the gas constant (8.314 J/mol K) and \( T \) is the absolute temperature (K). The constants \( A \) and \( B \) are calculated from the intercept and slope of the linear plot of \( q_e \) (mg/g) against \( \ln C_e \). All the isotherms are shown in Fig. 7 and the constants are presented in Table 2.

The applicability of each model is determined by comparing the correlation coefficient, \( R^2 \). The higher the value of \( R^2 \), the better is the goodness of the fit (Adeogun et al., 2012). In the present study, \( R^2 \) values of Temkin and Freundlich isotherm models are found to be more than that of Langmuir isotherm model. Furthermore, one of the adsorption constants for Langmuir isotherm is negative, which indicates the unsuitability of this isotherm for the present study. This also reveals that heterogeneous adsorption is the preferred technique than homogeneous adsorption. The value ‘\( n \)’ from the Freundlich model indicates the degree of non-linearity between solution concentration and adsorption. According to literature, when \( n = 1 \), the adsorption is supposed to be of linear type and if it is more than 1, the adsorption is considered to be a physical process whereas it becomes chemical process when the value is less than 1 (Alswata et al., 2017).

**Kinetics of Adsorption**

Kinetics of adsorption is one of the most important characteristics that is responsible for the efficiency of adsorbents. The adsorbate can be transferred from the solution phase to the surface of the adsorbent in several steps. In order to study the mechanism of the process and potential rate controlling steps, the kinetics of adsorption onto adsorbent were analyzed by using different kinetic models. For such analysis, two kinetic models were applied in the present investigation. The kinetics of chromium adsorption on ZnO nano particles were analyzed by fitting the data into the Lagergren’s first order model and pseudo second order equation to know the correlation coefficients (\( R^2 \)). Pseudo-first order kinetics that generally describes the initial stage of the adsorption process is given as Equation 7 (Lagergren, 1898). Similarly, the pseudo-second order kinetics, which provides better description of the whole adsorption process and based on the adsorption capacity, is expressed as Equation 8 (Ho and McKay, 1999; Anbia and Parvin, 2011):

\[ \log (q_e - q) = \log k_1 - \frac{k_1}{2.303} t \]  \hspace{1cm} (7)

\[ \frac{t}{q} = \frac{1}{k_2 q_e^2} + \left( \frac{1}{q_e} \right) t \]  \hspace{1cm} (8)

where, \( q_e \) is the amount of Cr(VI) adsorbed (mg.g\(^{-1}\)) at equilibrium time and \( q \) is the amount of Cr(VI) adsorbed (mg.g\(^{-1}\)) at time \( t \) (min). \( k_1 \) and \( k_2 \) are the first order rate constant (min\(^{-1}\)) and second order rate constant (g.mg\(^{-1}\).min\(^{-1}\)), respectively.

For first order kinetics, the value \( k_1 \) is obtained from the slope of the linear plot of \( \log (q_e - q) \) against time where the linear plot indicates the applicability of Lagergren’s model. Similarly, for second order kinetics, the values of \( q_e \) and \( k_2 \) can be determined by the slope and intercept of the linear plot of \( t/q \) against time (Fig. 8).

In the present study, for pseudo first order rate kinetics, the \( q_e \) and the rate constant, \( k_1 \) values were found to be 18.96 mg.g\(^{-1}\) and 0.002 min\(^{-1}\), respectively. The regression coefficient, \( R^2 \) for this model was determined as 0.694. Similarly, for pseudo second order, the \( q_e \) and rate constant, \( k_2 \) were 21.5
mg.g\(^{-1}\) and 0.004 g.mg\(^{-1}\).min\(^{-1}\), respectively. The regression coefficient, R\(^2\) was found to be 0.999. The plot for pseudo first order model was not linear and the R\(^2\) value is much less in comparison to that of pseudo second order kinetic model. This indicates that the pseudo second order kinetic model provided good correlation for the adsorption of chromium onto nano ZnO in the present study. Review of literature reveals that the second order rate kinetic is indicative of chemical adsorption involving valency forces through sharing the exchange of electrons between the adsorbent and the metal ions (Idris et al., 2013).

| Table 2: Adsorption constants of Langmuir, Freundlich and Temkin isotherms for Cr (VI) adsorption |
|----------------|----------------|----------------|
| Langmuir isotherm | Freundlich isotherm | Temkin isotherm |
| q\(_m\) (mg/g) | K\(_L\) (L/mg) | R\(^2\) | 1/n | K\(_f\) (mg/g) | R\(^2\) | b | λ (L/mg) | R\(^2\) |
| 0.00165 | -76.313 | 0.9381 | 5.597 | 6.824×10\(^\alpha\) | 0.992 | 85.106 | 3.162 | 0.998 |

Fig. 7: (A) Langmuir adsorption isotherm for adsorption of Cr(VI) (B) Freundlich adsorption isotherm for adsorption of Cr(VI) (C) Temkin adsorption isotherm for adsorption of Cr(VI)

Fig. 8: (A) First order kinetics of Cr(VI) adsorption (B): Pseudo second order kinetics of Cr(VI) adsorption
Conclusion

In this investigation, ZnO nano rods were prepared and characterized for their shape, size and purity successfully. The prepared nano particles were studied for the removal of Cr(VI) from aqueous solution in batch adsorption technique. The optimum parameters for the removal of Cr(VI) from 100 mg/L aqua solutions were found to be at pH 3, 0.1 gm of adsorbent dose and 40 minutes of agitation, respectively. The SEM morphology of adsorbent before and after adsorption indicates the adsorption of chromium metals over the adsorbents by changing their shape from nano rods to nano sheets. Freundlich and Temkin isotherm models have provided better fit for this metal ion to the experimental data rather than Langmuir model indicating heterogeneous adsorption as the preferred technique over homogenous adsorption. The value of n in Freundlich isotherm again reveals the adsorption to be chemical rather than physical process. In addition, the adsorption kinetics shows that the mechanism followed the pseudo-second-order kinetic model indicating chemical adsorption to be the preferred one. This is an added supplement to the findings from isotherms. Moreover, the present investigation revealed that the nano rods could be used as an adsorbent for the removal of toxic metal like Cr(VI) from aqueous solutions/effluents. Furthermore, these nano materials are non-toxic, eco friendly and can easily be synthesized from very basic precursors. However, extensions of the present investigations are to be carried out further to make these nano adsorbents for actual applicability for the industrial effluents.

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Author’s Contributions

Sushma Kamath: Sushma is the first author and she did all the experimental work along with data collection.

Venu Gopal Vishwakarma Ramanjaneyalu: Venu Gopal’s contribution includes coordination of data analysis and supporting the experimental work.

Susmita Kamila: Susmita is the supervisor and the corresponding author. Her contribution includes Research planning, organisational design and framework of the manuscript.

Ethics

No ethical issue/conflict is involved related to this work.

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