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Research Article

Mesolite, a Natural Adsorbent, for the Removal of Hexavalent Chromium (VI) From Aqueous Solution

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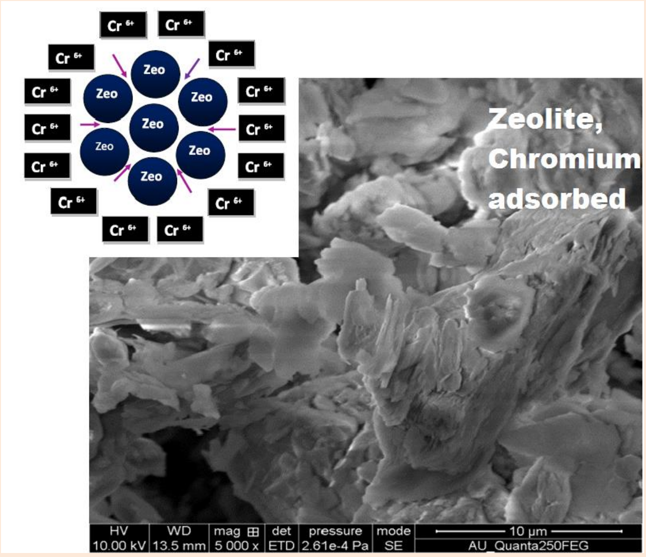
Abstract

The heavy metals present in the aquatic systems have become a serious problem. Batch sorption system using eco-friendly mesolite as adsorbent was investigated to remove chromium(VI) from aqueous solution. Scanning electron micrograph showed that the surface of the mesolite, provides a good possibility for chromium(VI) adsorption. This adsorption study showed the removal of Cr(VI) in a time duration between 120 and 150 min at pH 7.0 and 0.05 g dosage from 100 mg/L of aqueous solution. The maximum percentage removal was found to be 99.6% for Mesolite. Langmuir model showed satisfactory fit to the equilibrium adsorption data of mesolite. The kinetics of the adsorption followed pseudo second-order rate expression, which demonstrates a significant role in the adsorption mechanism. Fourier transform infrared spectroscopy confirmed the involvement of carboxylic acid and hydroxyl groups in chromium(VI) adsorption. The results indicate that the Mesolite could be used as an adsorbent for the removal of chromium(VI) from aqueous solution.

Keywords: chromium; Mesolite; adsorption; isotherm; kinetic models; FT-IR; SEM



Zeo (=meso); Zeolite = Mesolite

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Introduction

Mesolites are hydrated aluminosilicate minerals that contain alkali and alkaline-earth materials. Mesolite's unique porous nature makes it applicable in adsorption, catalysis, ion exchange, petrochemical cracking, and removal of gas and solvents. Mesolites convert solid and liquid hazardous wastes into environmentally acceptable products. Mesolites are considered to be effective adsorbents because they can adsorb heavy metals from the waste water. Therefore, the utilization of Mesolites (member of zeolite group) in various fields has grown progressively (1, 2, 3).

Mesolites have a rigid, three-dimensional crystalline structure (similar to honeycomb) consisting of a network of interconnected tunnels and cages. The general chemical formula of Mesolite is $(M^+, M^{2+})O.Al_2O_3.xSiO_2.yH_2O$. Where M^+ is usually Na^+ or K^+ ion and M^{2+} is Mg^{2+} or Ca^{2+} or Fe^{2+} ion. Rarely, Li^+, Sr^{2+} and Ba^{2+} ions may substitute for M^+ or M^{2+}. Iron (Fe^{3+}) can also substitute the metal ions into the tetrahedral framework position; x and y are the total number of tetrahedra per unit cell. The M^+ cations are exchangeable and are relatively innocuous (4). The heavy metal cations like lead, copper, cadmium and chromium can substitute into the structure of Mesolite when they come in contact with the aqueous contaminant solution. Mesolite minerals possess a high cation-exchange capacity and are not suitable for anion contaminants removal in water. Mesolites in general have high specific surface areas and their rigid framework limits shrinking and swelling. The state-of-the-art technology with regard to the use of natural Mesolites in the protection of the environment has been described (5). Zeolithic materials, because of the presence of micro pores and their large volumes as well as high thermo stability, are useful in purification of water, wastewater and soil remediation (6, 7).

As determined by the National Toxicology Programme (NTP), the International Agency for Research on Cancer (IARC), Cr (VI) is a human carcinogen (8). Disposal of Cr(III) as a dissolved species in natural waters or as sludge in soils may pose serious health risks because it can be oxidized to Cr(VI) in the environment (9). Based on the idea suggested in an earlier study we have prepared a kind of sorbent Mesolite (10, 11, 12). Hence, in this paper, we report optimization studies with different Cr(VI) ion concentration, pH, contact time, and dosage of the adsorbent over a natural Mesolite.

Experimental

Mesolite

Mesolite is chemically known as mesolite, which is hydrated sodium calcium aluminosilicate. The Mesolite used in the experiments was procured from Virbac SA. Mesolite was washed with demineralized water to remove the impurities adhered to surface and dried at 105^{0}C for 2 hours. Adsorption experiments were carried out using the Mesolite in the powdered composite form. A standard stock solution of chromium (1000 mgL^{-1}) was prepared in deionised (MilliQ) water.

Adsorption studies

Quantification of Cr(VI) reduction was determined using the 1,5-diphenylcarbazide method (13). Adsorption experiments were carried out by adding 0.05 g of Mesolite into 100 ml Erlenmeyer flasks containing 50 ml of different initial concentrations (50-250 mg/L) of chromium solution. The mixture was shaken for 120 min at 100 rpm using an orbital shaker at 25^{0}C. After filtration, the concentrations of Cr(VI) ions in aqueous solution were determined using a spectrophotometer (Hach Make: DR/2400 model) at 540 nm (14). The adsorption capacity at equilibrium (q_e) was determined (15). The removal percentage (R %) of hexavalent chromium (16) was calculated for each run as follows:

$$\text{Removal percentage} = \frac{Co - Ce}{Co} * 100 \qquad (1)$$

where, C_o and C_e represent the initial and final concentration of hexavalent chromium ion in aqueous solution. The concentrations of the samples were determined by using a calibration graph.

The adsorption capacity for each concentration of hexavalent chromium at equilibrium was determined by the following expression.

$$\text{Adsorption capacity} = qe\frac{(mg)}{(g)} = \frac{Co - Ce}{m} * V \qquad (2)$$

where, V is the volume of solution in litres and m is the mass of the adsorbent used in grams. Triplicate experiments were carried out for adsorption study and the mean values were reported.

Optimization of adsorption of Cr(VI) over Mesolite

To optimize the best adsorption condition, the effect of heavy metal concentration, adsorbent dosage, pH and contact time in relation to each other were studied. The optimum adsorbent dosage was arrived at by doing various trials by keeping metal concentration as 100 mg/L and maintaining the pH as 7. In the next set of experiments, the adsorbent dosage and metal concentration were kept as 0.05 g and 100 mg/L respectively, and the pH was raised to fix the optimum pH. The solution pH was adjusted using 0.5 mol L^{-1} HCl or 0.5 mol L^{-1}NaOH. The solution pH before and after the adsorption was determined. By keeping the adsorbent dosage as 0.1g and pH 7, concentration of metal ions was varied. In every trial, after adsorption, the sorbate was decanted and separated from the sorbent by centrifugation and the supernatant was analyzed for the residual metal concentration. Batch experiments were performed in triplicate and mean values are presented.

Modelling of Adsorption Isotherms

Adsorption isotherms explain the interaction of a sorbate molecule to the sorbent and are considered to be critical parameters for designing sorption systems. The adsorption equilibrium data at 27 ± 1°C were modelled using Langmuir and Freundlich isotherms to study the mode of interaction of Cr(VI) ions with Mesolite when the metal solution phase and sorbent solid phases are in equilibrium. Langmuir (equation 3) and Freundlich (equation 4) isotherms were plotted by using standard straight-line equations.

$$\frac{Ce}{qe} = \frac{Ce}{Q\mathrm{max}} + \frac{1}{Kad} * Qmax \qquad (3)$$

$$logqe = \log Kf + \left(\frac{1}{n}\right) \log Ce \qquad (4)$$

where, q_e(mg g^{-1}) is the amount of metal ion adsorbed and Ce (mg/L) is concentration at equilibrium. Q_{max}(mg g^{-1}),b (L mg^{-1}) and K_{ad} (L mg^{-1}) are Langmuir isotherm parameters. K_f and n are Freundlich isotherm parameters (17).

The Temkin isotherm assumes that the heat of adsorption of all the molecules in the layer decreases linearly with coverage due to adsorbent–adsorbate repulsions. The Temkin isotherm equation is represented by:

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

where, B = RT/b, b is the Temkin 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).

Adsorption kinetics

Kinetic experiments were carried at equilibrium conditions. The aqueous samples were withdrawn at preset time intervals and the concentrations of Cr(VI) ions were determined spectrophotometrically. Different models have been used to describe the metal uptake rate. Pseudo-first order (Lagergren kinetic model) and pseudo-second order model (Ho kinetic model) were applied to the sorption data. The model with the highest correlation coefficient value (R^2), close to unity was considered to be the best fit.

Zeta potential study

In order to determine whether surface charge of the Mesolite changed with respect to pH, zeta potential tests were conducted using nano particle analyzer (Horiba Scientific, Japan). Mesolite (0.5 g) was suspended in 20 mL of buffer solutions with pH of 4, 5, 6, 7, 8, and 9 and was allowed to settle for about 30 min. Each sample was then tested three times, with the machine taking 5 readings for each run. The output data were in the form of mobility, zeta potential, and conductance.

Fourier transform-infrared spectroscopic analysis

FTIR spectrometer (IR affinity-1: Shimadzhu, Japan) was used to identify the functional groups on the Mesolite before and after Cr(VI) sorption under experimental conditions. Prior to FTIR analyses, the Mesolite was dried at 60°C for 24h. The spectra were obtained in the range from 4000 to 500 cm^{-1} with a resolution of 8 cm^{-1}. The resulting spectra were used to identify the functional groups based on their characteristic absorbance peaks.

Scanning electron microscopy

Interacted and non-interacted logarithmic phase cells were analyzed microscopically. A pinch of Mesolite powder was fixed on the 10 mm metal stub using carbon tape (18). The samples were then sputter coated with gold under vacuum in argon atmosphere. The analysis was made at 20 kV using tungsten filaments. The surface morphology of the coated sample was observed by a Quanta FEI 250 scanning electron microscope.

EDAX analysis

The surface elemental analysis of non-interacted log phase Mesolite and Cr(VI) interacted log phase Mesolite was carried out by Energy Dispersive X-ray spectroscopy (EDAX). The gold sputtered samples were analyzed and the spectra were recorded using Quanta FEI 250 equipment.

Results and discussion

Characterization of Mesolite

Natural Mesolite contains a complement of exchangeable sodium, potassium, and calcium ions in an organic matrix (4). The characteristics of the Mesolite sample (**Table 1**) are given as follows.

Table 1 Characteristics of Mesolite

Characteristics	Values
pH	9.3
EC (ds/m)	2.01
Water holding capacity (%)	56.35
Zeta potential	-5.6 mV
Particle size	
SP Area ratio	1
Mean	378.0 nm
Standard Deviation	31.5 nm
Mode	376.8 nm

The pH value (9.0) was found to be alkaline. The electrical conductivity of Mesolite was 2.01dsm^{-1}. Zeta potential study is a measure of charge stability and controls all particle-particle interaction within a suspension. The water holding capacity of Mesolite was found to be 56.35. The zeta potential of Mesolite was found to be -5.6 mV. The stability behaviour of Mesolite falls under rapid coagulation category. If the zeta potential is low, attraction exceeds repulsion and the dispersion diminishes and flocculates. The particle size in terms of SP ratio (Surface area of a particle per cm^3) of Mesolite is found to be one. The statistical functions like mean, standard deviation and mode of particle size are found to be 378.0 nm, 31.5 nm and 376.8 nm, respectively.

Optimization of sorption parameters

Effect of chromium concentration

Effect of initial concentration was studied by varying the Cr(VI) concentration, from 50 to 250 mgL^{-1} with 0.05g of adsorbent, at a contact time interval of 10 mins up to 150 mins. The amount of metal ion adsorbed by Mesolite increased with increasing initial metal concentration. A significant amount of metal ions was adsorbed at high initial metal concentration that can be related to two main factors, namely, high probability of collision between metal ions and the sorbent surface and high diffusion rate of metal ions onto sorbent surface (**Figure 1**).

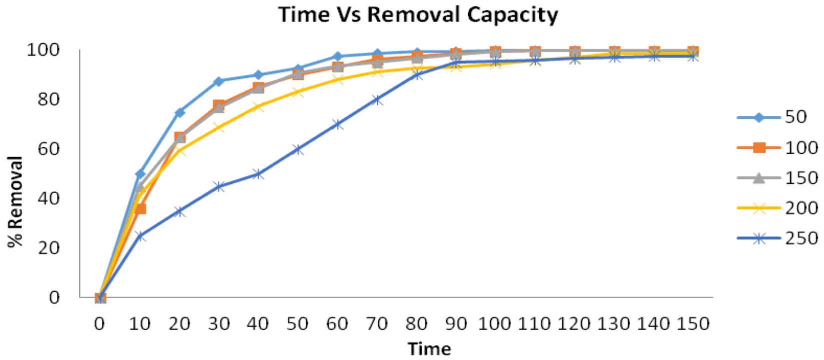

Figure 1 Effect of concentration on the removal of Cr(VI) by mesolite. (Note: Experimental conditions: pH=7; adsorbent dose=0.05 g; Contact time= 150 mins; Triplicate experiments were carried out and mean values were reported)

The high initial metal concentration accelerates the driving force and reduces the mass transfer resistance (19). The time for equilibrium adsorption remains unchanged, and shows maximum adsorption at 100mg/L (20). In this study, there was an increase in the adsorption and then it becomes constant. The percentage adsorption of Cr(VI) increased with an increase in time while the equilibrium time varied for different Cr(VI) concentrations.

Effect of adsorbent dosage

Adsorbent dosage is a factor that determines the sorbent-sorbate equilibrium of the system for metal removal. In order to investigate the effect of dosage on the Cr(VI) sorption, different amounts of the Mesolite (0.05 to 0.5 g) were suspended in 25 mL Cr(VI) solution. The removal of Cr (VI) was found to be highest at 1.5g dose (21). The results from this study showed that the percentage adsorption of Cr(VI) is dependent on the dose of the adsorbent from 0.05g to 0.5g for a fixed concentration of 100 mgL^{-1} of Cr(VI), pH of 7 and at a time interval of 0 to 150 min (**Figure 2**).

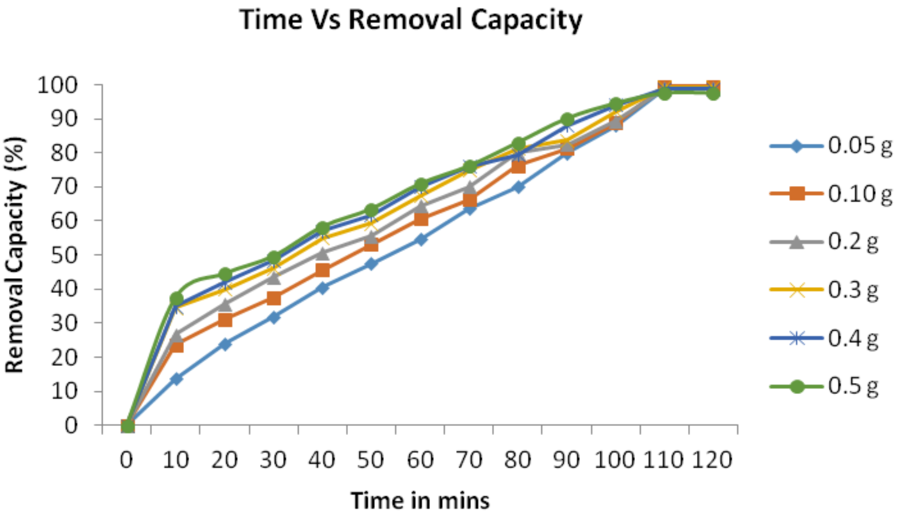

Figure 2 Effect of dosage on the removal of Cr(VI) by mesolite. (Note: Experimental conditions: pH=7; concentration=100 ppm; Contact time= 120 mins; Triplicate experiments were carried out and mean values were reported)

The removal of chromium was 97.5% with 0.5 g of Mesolite per litre of the solution, and it is 99% with 0.05 g of Mesolite per litre. At a low adsorbent dose, all active sites of the Mesolite are fully exposed and get occupied by the Cr(VI) ions that are in excess, saturating the surface and yielding higher adsorbed value (22).

Effect of pH

Effect of pH on adsorption of chromium(VI) ion was studied by changing the pH from 2 to 8 and maintaining adsorbent dosage and metal concentration as 0.05 g and 100 mg/L, respectively. The experiment was repeated for different contact times in the increments of 10 mins up to 120 mins (**Figure 3**).

The pH of the solution significantly affects the amount of metal ion adsorbed onto Mesolite as it influences the adsorption phenomenon. It is observed that increase in the solution pH from 2 to 8 had increased adsorption of the amount of Cr(VI). The optimal pH value for removal of 0.05 g L^{-1} of Cr(VI) by the Mesolite was pH 7.0 (99.8% removal). But the adsorption of Cr (VI) on rice husk carbon increases with the decreased pH of the solution, this study reveals that the adsorption of Cr (VI) on mesolite increases with the increased pH of the solution (8). The reason might be the pH of the aqueous solution governs the speciation of metals and the properties of the surface. Cr(VI) exists in various oxoanionic forms in aqueous solution depending upon the solution pH. Between pH 1-6, Cr(VI) exists in the form of ($HCrO_4^-$), which dimerizes to ($Cr_2O_7{}^{2-}$) with the release of a water molecule. And, above pH 6, Cr(VI) exists in the form of ($CrO_4{}^{2-}$). At low pH, the molecular form ($HCrO_4^-$) is predominantly adsorbed species, whereas at higher pH values the ionized form is preferentially adsorbed (CrO_4^{2-}). $HCrO_4^-$ species has one negatively charged location (23, 24) and it is believed that it only requires one exchange site on the surface of the Mesolite (25). Similar studies conducted for the adsorption of lead and cadmium suggested that at higher pH (above the isoelectric point; pH 3.0), binding sites begin to deprotonate that makes different functional groups available for positively charged metal binding (26). Present study finds a befitting support that the significance of using Mesolite as an adsorbent lies in the fact that an optimum amount of Cr(VI) was adsorbed at pH 7, which is the natural pH of all natural water bodies (27) **.**

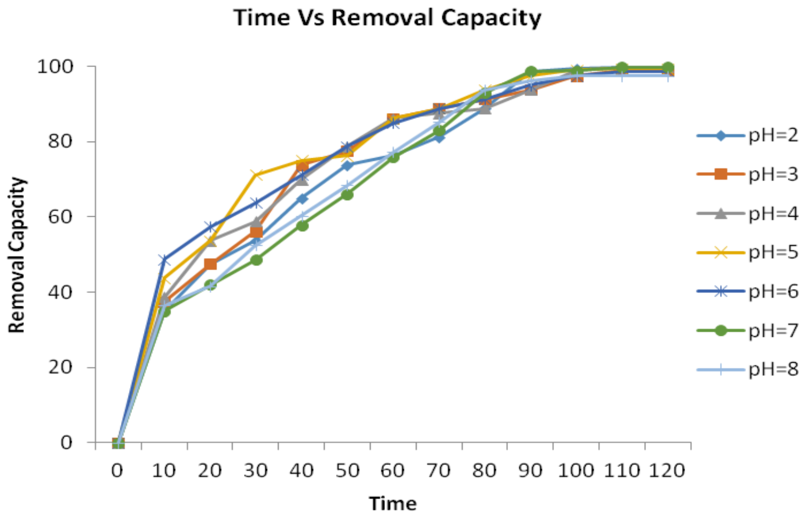

Figure 3 Effect of pH on the removal of Cr(VI) by mesolite. (Note: Experimental conditions: concentration=100 ppm; Contact time= 120 mins; dosage =0.05 g; Triplicate experiments were carried out and mean values were reported).

Adsorption isotherms

The isotherm results of Mesolite at a constant temperature of 30°C were analyzed using three important isotherms including the Langmuir, Freundlich, Temkin models (**Table 2**).

Table 2 Langmuir, Freundlich, and Temkin isotherm constants for chromium ion adsorption by mesolite

Parameter	**Langmuir isotherm constant**			**Freundlich isotherm constant**			**Temkin Isotherm constant**		
	Q_{max} (mg/g)	B	R^2	K_f (mg/g)	n (L/mg)	R^2	A (L/g)	B (J/mol)	R^2
Concentration variation	258.68	2.020	0.994	142.90	2.889	0.960	3.47	139.86	0.9744
pH variation	89.04	5.776	0.998	245.42	0.0284	0.810	3.59	1.449	0.8520
Dosage variation	99.50	1.843	0.999	99.42	0.0022	0.976	2.53	0.837	0.6392
Note: Triplicate experiments were carried out and mean values were reported									

The Langmuir isotherm is valid for monolayer adsorption onto a surface containing a finite number of identical binding sites (28, 29). Langmuir adsorption isotherm assumes that the adsorbent surface has a specific number of equivalent sorption sites, and the monolayer adsorption occurs without interaction between sorption sites (30, 31). The maximum adsorption corresponds to a saturated monolayer of solute molecules on the adsorbent surface, with no lateral interaction between the adsorbed molecules. An important characteristic of the Langmuir isotherm is expressed in a dimensionless constant equilibrium parameter, RL. The RL value indicates the shape of the isotherm and is given in the following equation.

$$RL = \frac{1}{(1 + b\ Co)}$$

It is observed that the RL values between zero and one indicate a favourable adsorption process, one indicates a linear adsorption, zero indicates irreversible adsorption, while an RL value greater than one signifies an unfavourable adsorption process. The value of RL for the Cr(VI) obtained by adsorption on Mesolite lies between 0 and 1 showed favorable adsorption (16). This implies that the adsorption of Cr(VI) on Mesolite is a favourable as the RL values obtained at all initial concentrations lie between zero and one (**Figure 4**) validating the applicability of the Mesolite for Cr(VI) removal (32).

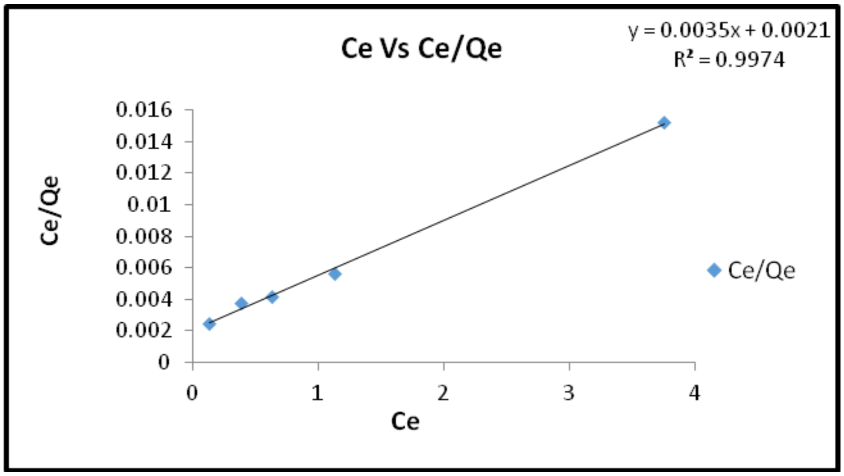

Figure 4 Langmuir isotherm of Cr(VI) adsorption by Mesolite at pH=7, dosage= 0.05g. (Note: Triplicate experiments were carried out and mean values were reported)

The Freundlich isotherm model assumes that the removal of metal ions occurs on a heterogeneous adsorbent surface and can be applied to multilayer adsorption (28, 33, 34). This isotherm was applied in order to determine the adsorption intensity of Mesolite for the removal of chromium. The R^2 value obtained from Freundlich isotherm was found to be 0.960 (**Figure 5**).

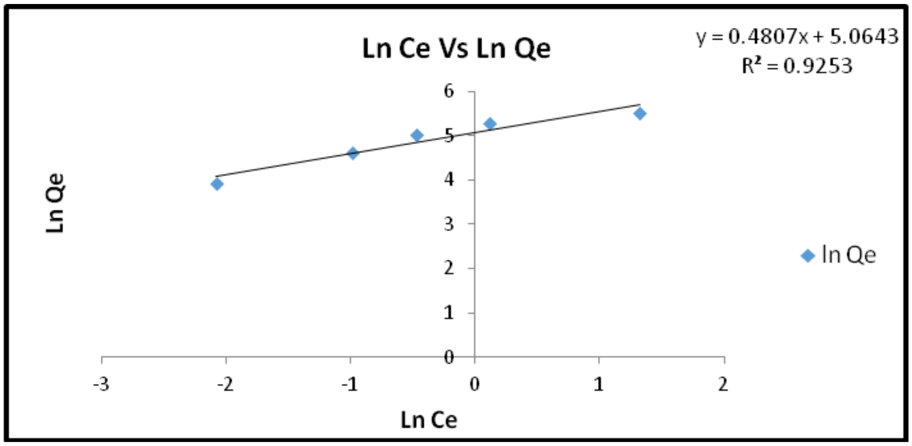

Figure 5 Freundlich isotherm of Cr(VI) adsorption by Mesolite at pH=7, dosage= 0.05g. (Note: Triplicate experiments were carried out and mean values were reported)

The Temkin isotherm model was also applied to the experimental data, unlike the Langmuir and Freundlich isotherm models, this isotherm takes into account the interactions between adsorbents and metal ions adsorbed (35). This isotherm was applied by a linear plot of q_e against $\ln C_e$ and the constants B and A were calculated from the slope and intercept respectively (**Figure 6**).

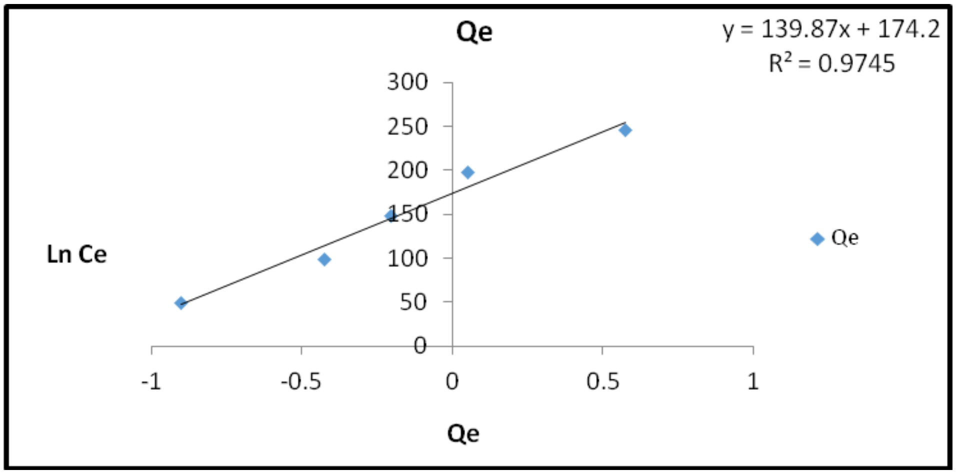

Figure 6 Temkin isotherm of Cr(VI) adsorption by Mesolite at pH=7, dosage= 0.05g. (Note: Triplicate experiments were carried out and mean values were reported).

Calculated values of A and B are subsequently used for estimating Temkin constants related to the maximum adsorption capacity and energy of the adsorption (36). In this study, the R^2 value for Temkin isotherm is 0.9744. The Temkin isotherm parameters A, B and R^2 are presented in Table 2. A previous study revealed that Langmuir model fitted the experimental data better than the Freundlich model (37). In this study also comparison of isotherms revealed the Langmuir as the best fit (R^2 = 0.994) followed by Temkin (R^2 = 0.974) and Freundlich (R^2 = 0.964) isotherms.

Kinetic model

To find the potential rate-controlling steps involved in the process of biosorption of Cr(VI) onto Mesolite, both pseudo first-order and pseudo second-order kinetic models have been used to fit the experimental data. The pseudo-first-order kinetic model was described by Lagergren (38), where, q_e (mg g^{-1}) and q_t (mg g^{-1}) are the amounts of the Cr(VI) adsorbed on the adsorbent at equilibrium and at time t, respectively; and k_1 (min^{-1}) is the rate constant of the first order model. A straight line of $\ln(q_e{-}q_t)$ versus t suggests the applicability of this kinetic model; q_e and k_1 can be determined from the intercept and slope of the plot, respectively (**Figure 7**).

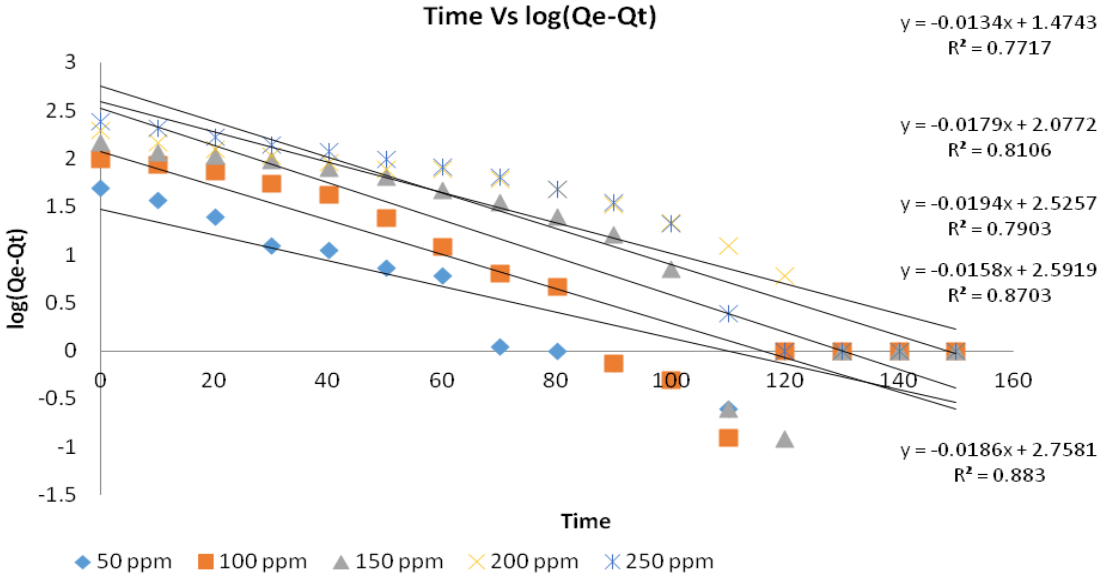

Figure 7 Lagergren's first order kinetic plots for biosorption of Cr(VI) by Mesolite. (Note: Triplicate experiments were carried out and mean values were reported)

It is important to note that the qe(exp)must be known for the application of this model. Table 3 shows the pseudo-first-order constants, q_e and k_1, along with the corresponding correlation coefficients. The calculated q_e(cal) value was not in good agreement with the experimental value of q_e (exp). These observations suggested that the pseudo-first-order model is not suitable for modeling the adsorption of Cr(VI) onto Mesolite (20).

The pseudo-second-order model is based on the assumption that the rate-limiting step is chemical sorption or chemisorptions involving valence forces through sharing or exchange of electrons between sorbent and sorbate as covalent forces (39, 40), where k_2 (g mg^{-1} min^{-1}) is the rate constant of the second-order equation; q_t(mg g^{-1}) is the amount adsorbed at time t(min). If second-order kinetics is applicable, the plot of t/qt against t shows a straight line; q_e and k_2 can then be obtained from the slope and intercept of the plot, respectively (**Figure 8**). The k_2 and q_e values, along with the corresponding correlation coefficients have been presented in **Table 3**.

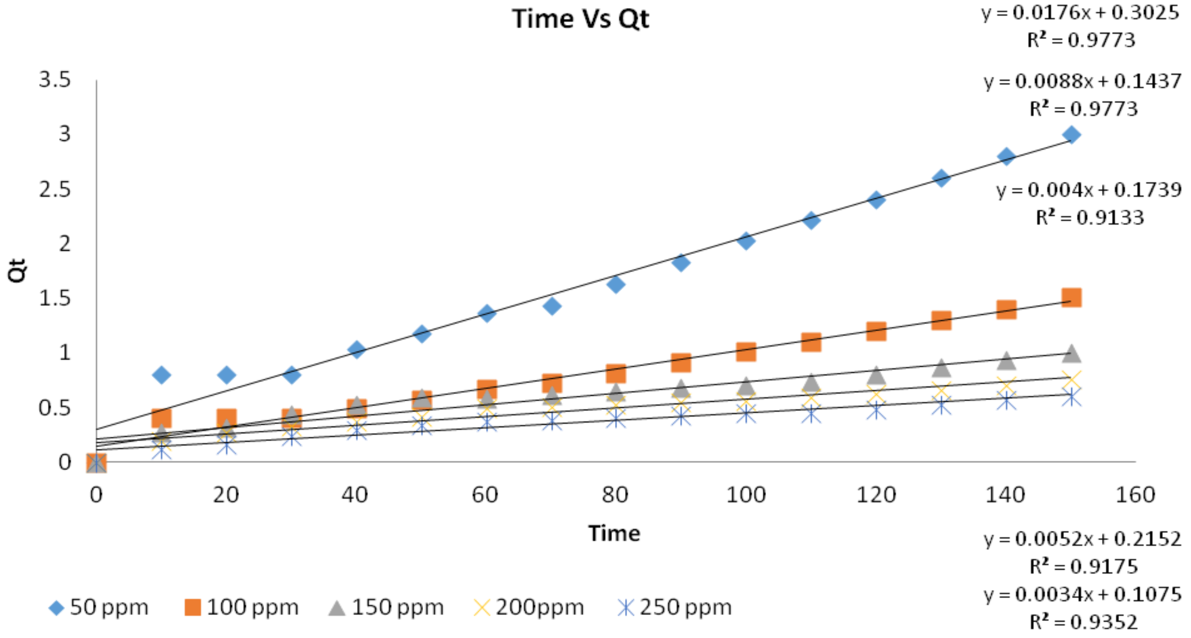

Figure 8 Ho's pseudo second-order kinetic plots for biosorption of Cr(VI) by Mesolite. (Note: Triplicate experiments were carried out and mean values were reported)

Table 3 Adsorption kinetics for Cr(VI) on mesolite

Conc. (ppm)	**qe (Expt)**	**Pseudo-first order**			**Pseudo-second order**		
		q (Calc.)	K_1	R^2	q (Calc.)	K_2	R^2
50	49.875	29.80728	-0.03091	0.7717	56.83364	0.05817	0.977344
100	99.625	119.4661	-0.04114	0.8105	113.068	0.061535	0.977309
150	149.375	335.5336	-0.04465	0.7903	191.4569	0.024268	0.917452
200	198.875	390.7741	-0.03628	0.8702	251.049	0.022907	0.913316
250	246.25	572.9462	-0.04275	0.883	293.1341	0.031727	0.935188

Note: Conc.-Concentration; Expt.-Experimental; Calc.-Calculated
Triplicate experiments were carried out and mean values were reported

The correlation coefficient was nearly equal to unity. The results indicated that the pseudo-second-order adsorption mechanism is predominant for the adsorption of Cr(VI) onto Mesolite and it is considered that the rate of the Cr(VI) adsorption process may be controlled by the chemisorptions process.

Fourier transform infrared analysis (FT-IR)

FTIR serves as an important tool for determining and analyzing the various functional groups present in an organic compound(41) .The FT-IR spectra of Mesolite before and after adsorption of chromium have been shown in **Figure 9**.

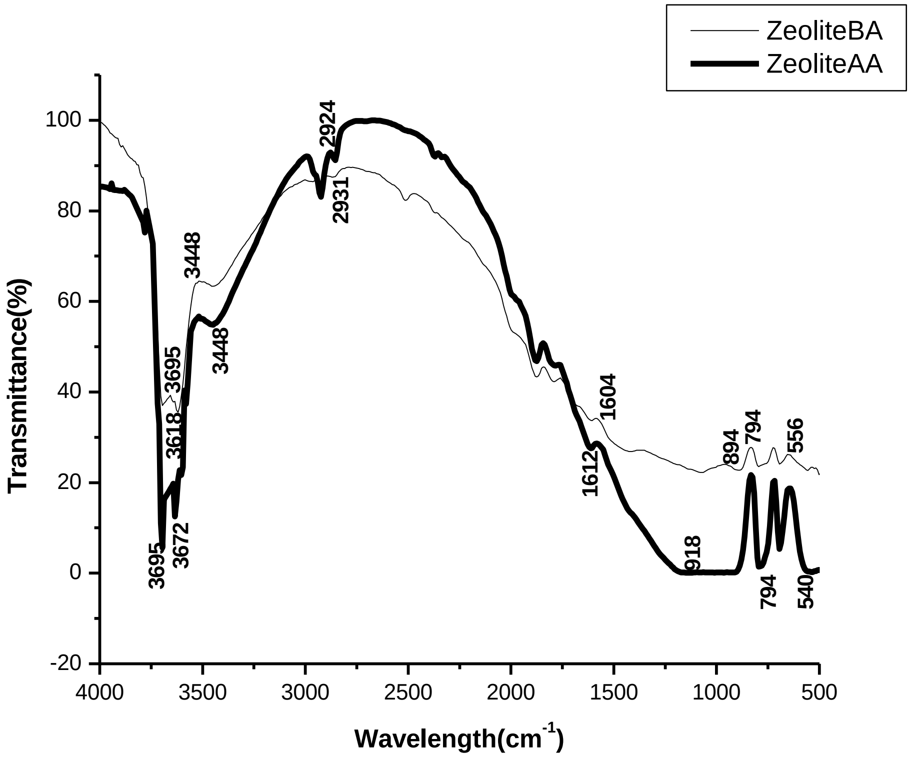

Figure 9 FTIR spectra of mesolite before and after Cr(VI) adsorption. (Note: Mesolite BA and Mesolite AA refers to 'before adsorption' and 'after adsorption Cr(VI), respectively)

The spectra of adsorbents were measured in the range of 4000-500 cm^{-1}. The FTIR spectra obtained revealed that there were various functional groups detected on the surface adsorbents before and after adsorption. **Table 4** presents the fundamental peaks of the adsorbents before and after Cr(VI) adsorption. Some peaks were shifted, disappeared and some new peaks were also detected. These band shifts indicate that the bonded –OH groups and COOH groups in particular play a major role in chromium (VI) sorption (38).

Table 4 Variation in vibration frequencies of mesolite and corresponding functional groups before and after adsorption

Mesolite Frequeny (cm^1)	**Chromium adsorbed mesolite frequency (cm^{-1})**	**Type of vibration**	**Functional group**
3695	3695	O–H stretch	hydroxo complexes M-OH
3618	3672		
3448	3448	O–H stretch, H–bonded	hydroxy bonded alcohols, phenols
2931	2924	O-H stretch	Phenols
1604	1612	C=O stretch	carboxylic acid salts
894	918	-COOH(dimer)	carboxylic acids
794	794	CO_2^-scissor Vibration	carboxylic acid salts
556	540	C-H	branched alkanes

A previous study revealed that the unassociated hydroxyl groups absorb strongly in the region 3670-3580 cm^{-1} (42). The frequency at 3695 cm^{-1} in FTIR spectrum of loaded and unloaded Mesolite indicates the OH stretch vibration with the presence of hydroxo complexes. The broadness of the vibrational frequencies indicates inter- and intra-molecular hydrogen bonding in the Mesolite (43). A peak observed at 3618 cm^{-1} was due to the stretching vibrations of O–H bonds. After Mesolite adsorption an increase in the frequency (3672 cm-1) indicates the adsorption of chromium. Moreover, hydrogen bonded (3448 cm^{-1}) peak was observed in both the loaded and unloaded Mesolite. Apart from this, a characteristic peak at 2931 was observed due to the presence of phenolic O-H stretching mode in the unloaded Mesolite. After adsorption a small shift to 2924 cm^{-1} due to adsorption of chromium. C=O stretching vibration of carboxylic acid salts is seen at 1604 cm^{-1}. An increase in frequency (1612 cm^{-1}) was observed after adsorption. The peaks at 894 and 918 cm^{-1} are due to characteristic vibrations of COOH group before and after adsorption of chromium. The characteristic peak at 556 cm^{-1} before and 540 cm^{-1} after chromium adsorption indicates the presence of branched alkanes. A shift in the frequency confirms the adsorption of Cr(VI) ions.

SEM and EDAX analyses

The scanning electron microscopy (SEM) images of Mesolite before chromium (VI) adsorption and after chromium (VI) adsorption are shown in **Figure 10a** and **10b**. The surface morphology revealed that both were found to be irregular and porous and thus would facilitate the adsorption of metal ions on the different parts. The SEM micrographs showed that pores with different sizes and different shapes that existed on external surface of Mesolite (Figure 10a). The micrograph of Mesolite after chromium (VI) adsorption shows a reduction in number of pores, pore space and surface area available (Figure 10b). This result corroborates the earlier findings (44, 45).

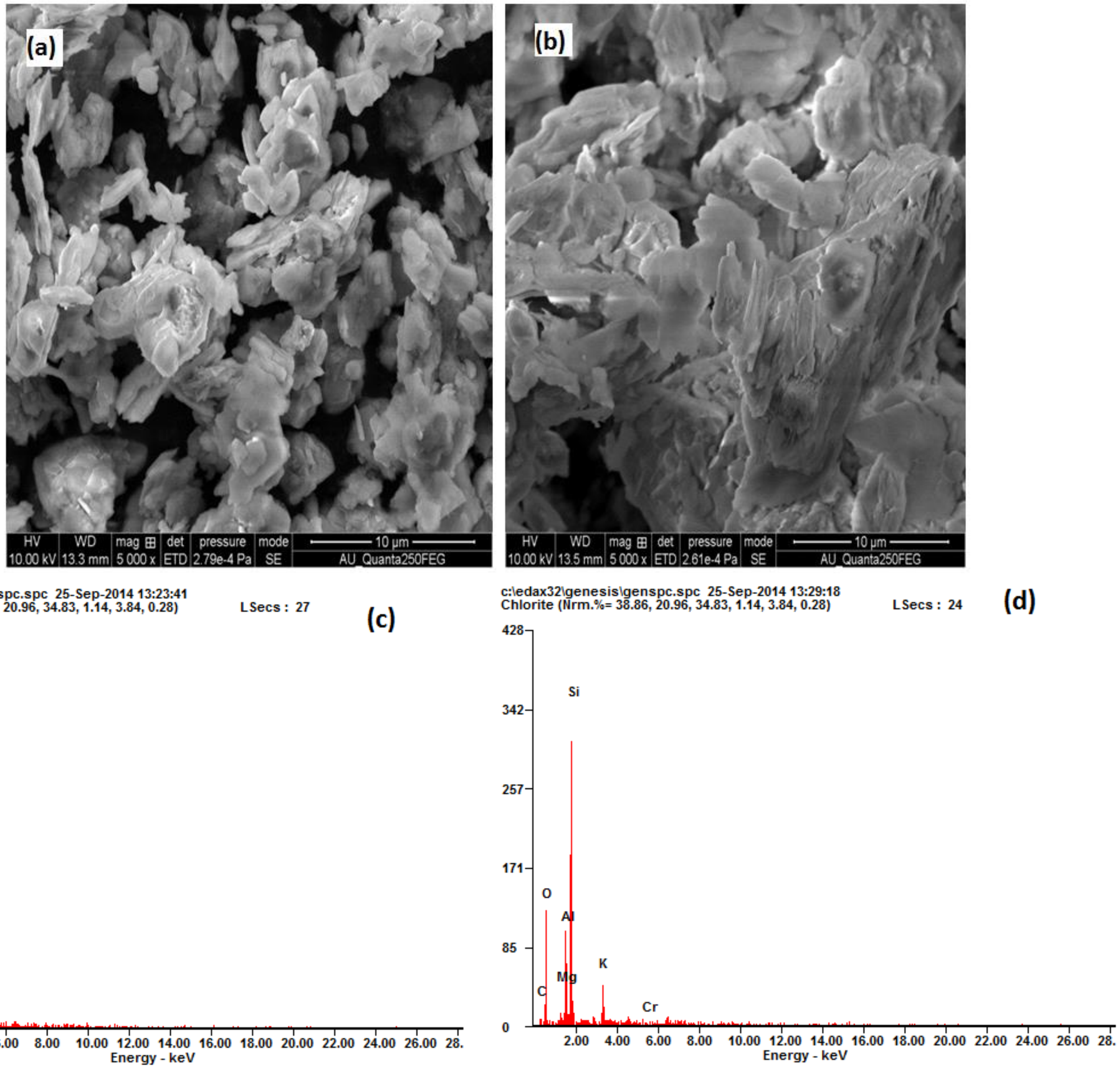

Figure 10 (a) SEM micrograph of Mesolite before Cr(VI) adsorption, (b) SEM Micrograph of Mdesolite after Cr(VI) adsorption, (c) Energy dispersive spectrum of mesolite before Cr(VI) adsorption, (d) Energy dispersive spectrum of mesolite after Cr(VI) adsorption

However, the presence of sample of Mesolite after adsorption of Cr was observed. It has been found from Figure 10c that unloaded Mesolite has carbon, oxygen, magnesium, aluminum, potassium and silicon on its surface, whereas in Figure 10d new chromium peak was observed along with already adsorbed ions in the loaded Mesolite.

Conclusion

Based on the results of the present study and scientific information supported from the literature it is concluded that the Mesolite is effective and inexpensive adsorbent for the removal of Cr(VI) from aqueous solutions. The removal of Cr(VI) from aqueous solutions strongly depends on the contact time, initial concentration, pH, temperature and adsorbent dose. The adsorption study showed considerable potential for the removal of Cr(VI) (99.6%) between 120 and 150 min from 100 mg/L of aqueous solution. The maximum adsorption capacity was obtained at solution pH 7.0 and the dosage was found to be 0.05 g. The Langmuir, Freundlich and Temkin adsorption models are used to represent the experimental data in which Langmuir isotherm model fitted very well to this study. The kinetics of Cr(VI) adsorption onto Mesolite followed the pseudo-second-order model. It is clear that Mesolite could be a good adsorbent and can be used for the removal of Cr(VI) from waters contaminated with industrial wastes.

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