

Application of Red Mineral Soil as Adsorbent for Removing Cd (II) Metal Ion from Synthetic Wastewater

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ABSTRACT

This study investigates the adsorption of Cadmium (II) ions onto red mineral soil. The red mineral soil has been applied as an adsorbent for the treatment of Cadmium contaminated synthetic waste water. The adsorption study was conducted based on the parameters of pH, initial metal ion concentration, dosage amount, contact time, and temperature. The batch equilibrium experiment results reveal that, at optimized conditions of high pH (pH 6), high metal ion concentration, more interaction time with larger amount of adsorbent (red mineral soil) shows highest adsorption efficiency. The equilibrium data were best studied on Freundlich, isotherm model. The FTIR, SEM and AAS analysis is done for required adsorption studies.

Keyword: Waste water treatment, adsorbent, adsorption study, Freundlich adsorption isotherm.

INTRODUCTION

The high demand for and limited availability of clean water have drawn attention to the treatment of polluted aquatic systems^{1,2}. In these days threat of heavy metal water pollution has become most serious issues of aqueous ecosystem³ and hence aqueous contamination by toxic heavy metals is a major concern to cure. For this adsorption can be an alternative method for the treatment of heavy metal polluted waste water. The treatment of heavy metal contaminated water is of special concern due to their recalcitrance and persistence in the environment^{4,5}. In contrast to organic pollutants, heavy metals are non-biodegradable and tend to bioaccumulate in living organisms. Many of these metals are recognized for their toxicity and potential carcinogenicity⁶. Toxic heavy metals of particular concern, in treatment of industrial wastewater includes chromium, cobalt, copper, cadmium, zinc, mercury, nickel, iron, lead etc. The presence of heavy metals in amount greater than what allowed in water bodies is hazardous to living beings. Cadmium metal ion primarily enters the environment through industrial processes, such as emissions from metal refining, its application in PVC stabilization, pigments, and nickel-cadmium batteries. This metal also contaminates food and water, leading to accumulation in crops and aquatic life, with smoking further enhancing exposure. Cadmium is extremely toxic and is linked to severe health issues, including cancer, heart disease, and kidney damage. Short-term exposure can result in symptoms like nausea and high blood pressure, while long-term exposure may cause kidney stones and bone deformities. The World Health Organization sets the acceptable limit for cadmium in drinking water at

0.004 to 0.01 mg/L, but many areas, particularly in India, exceed these levels, highlighting the critical need for stringent monitoring and management to safeguard public health⁷⁻¹¹.

The removal of heavy metals from water and soil surrounding industrial facilities has long been a challenge. Various techniques have been developed to address the detoxification of aqueous waste containing heavy metals, including adsorption, reverse osmosis, electro dialysis, chemical precipitation, membrane technologies, phytoremediation, ultrafiltration, ion exchange, and activated carbon, among others¹²⁻¹⁶. This work of research represents the worth of red mineral soil as a low cost and eco-friendly adsorbent for the adsorptive removal of Cd (II) from synthetic waste water.

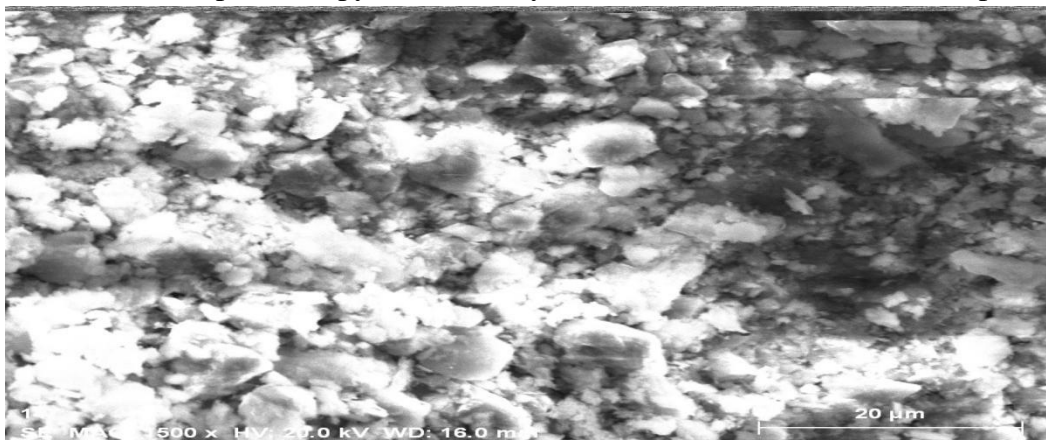
MATERIAL AND METHODS

Collection of samples

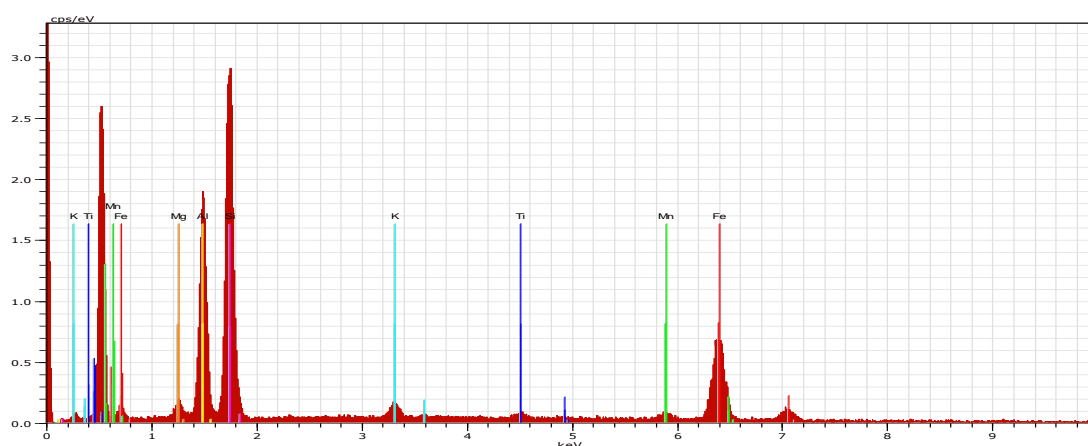
Red mineral soil was collected from the Berinag region in the Pithoragarh district of the Kumaun Hills in Uttarakhand.

Preparation of adsorbent

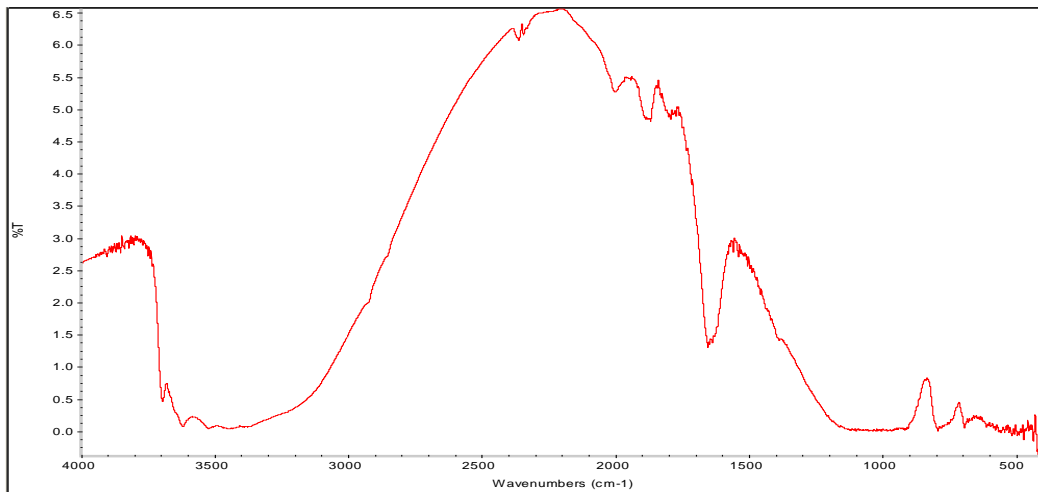
The red mineral soil collected was filtered and air-dried for a week in the laboratory at room temperature. The dried soil then grinded by mixer grinder and sieved by 2 mm sieve to get desired size adsorbent particles. The physio-chemical properties of soil are determined by usual laboratory methods and standard techniques. Scanning electron microscopy (SEM) characterization of the red soil was performed, and Fourier-transform infrared spectroscopy (FTIR) analysis was conducted on the soil sample.



SEM image of Red Soil



Graph 1: Presence of metals in soil



Graph 2: FTIR of Red Soil

Preparation of Synthetic waste water

The synthetic waste water was synthesized by preparing stock solution of Cd (II) by dissolving appropriate amount of Cadmium salt $CdCl_2 \cdot H_2O$ in double distilled water. The pH of stock solution was adjusted by adding 0.1N HCL.

Adsorption studies

The adsorption studies were performed using Batch equilibrium method to determine the amount of Cd (II) ion adsorbed by red mineral soil, influenced by contact time, temperature, pH, and adsorbent dosage. In a conical flask of 250 ml, a requisite amount of soil adsorbent was treated with synthetic waste water solution of known metal ion concentration (Analysed by AAS). The flask was regularly shaken for the desired contact time at a fixed revolution of 200 rpm for all the experiment.

The adsorption efficiency for metal ions was calculated by formula:

$$\text{Adsorption efficiency} = \frac{C_0 - C_e}{C_0} * 100$$

Where C_0 and C_e are the initial and final (or equilibrium) metal ion concentrations respectively.

Adsorption isotherm

The equilibrium relationship between the adsorbent and adsorbate is characterized by adsorption isotherms. In this study, the equilibrium data were analysed using the Freundlich adsorption isotherm model.

Freundlich Isotherm Equilibrium:

Adsorption of Cd (II) ions on heterogeneous surface of the red mineral soil follows Freundlich isotherm model. and this model can apply for multilayer adsorptions. The linear form of Freundlich isotherm can be written as-

$$\text{Log } q_e = \text{log } k_f + \frac{1}{n} \text{log } C_e$$

For the adsorption of Cadmium (II) on the red mineral soil the logarithm values of q_e (solute adsorbed per unit weight of adsorbent) and C_e equilibrium concentration.

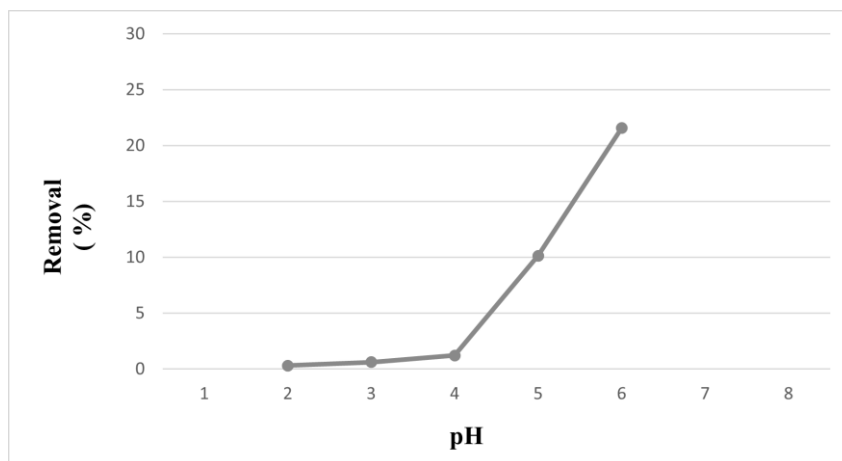
RESULTS

Effect of pH of solution

pH is one of the most important parameters affecting the adsorption process by different adsorbent. For the Cadmium (II) ion adsorption, at presumed lowest pH 2 the removal efficiency is 0.30% and it increases slightly to 0.62% at pH 3. The increasing pH shows a gradual increase in the removal efficiency as it is 1.21% at pH 4, at pH 5 it reached to 10.14%. On increasing to pH 6 the removal efficiency of 21.57% was achieved. The graph 3, shows removal efficiency of soil adsorbent as a function of pH of solution for Cd (II) ions is in the table 1, which illustrate the adsorption of Cd (II) is increasing with increase in the pH value of working solution.

Table 1: Effect of solution pH on removal of Cd (II) ion onto red soil

Initial metal ion concentration (mg/L)	Final metal ion concentration (mg/L)	pH	Removal efficiency (%)
10.00	9.970	2	0.30
10.00	9.938	3	0.62
10.00	9.879	4	1.21
10.00	8.986	5	10.14
10.00	7.843	6	21.57



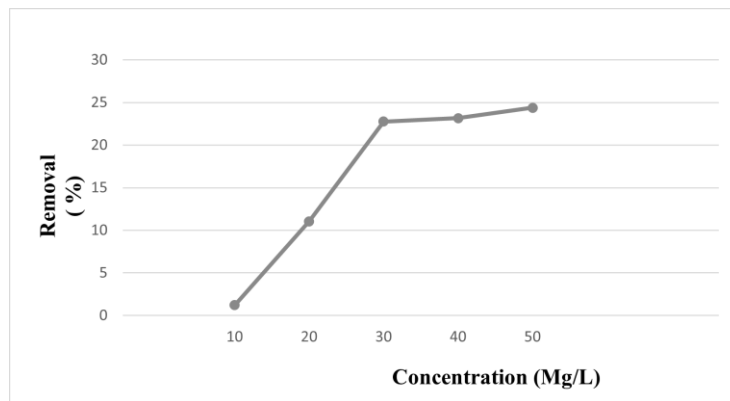
Graph 3: Effect of pH of solution

Effect of Cadmium (II) ion concentration

The effect of metal ion concentration for Cadmium (II) ion the removal efficiency is found 1.21% at 10mg/L metal ion concentration. The efficiency increases to 11.04% at 20mg/L concentration. With increase in concentration shows increase in efficiency as 22.77% at 30mg/L, 23.16%, at 40mg/L at 50mg/L adsorption efficiency to 24.39%. There is gradual increase in removal efficiency with rise in the temperature of adsorbent, may due to increase in rate of ion exchange reaction. But the small increase removal efficiency on high concentration is due to saturation of adsorbent sites. The removal efficiency of red soil adsorbent with variation of metal ion concentration for Cadmium (II) is shown in graph 4.

Table 2: Effect of metal ion concentration on removal of Cd (II) ion onto red soil

Initial metal ion concentration (mg/L)	Final metal ion concentration (mg/L)	Removal efficiency (%)
10.00	9.879	1.21
20.00	18.896	11.04
30.00	27.723	22.77
40.00	37.684	23.16
50.00	47.561	24.39



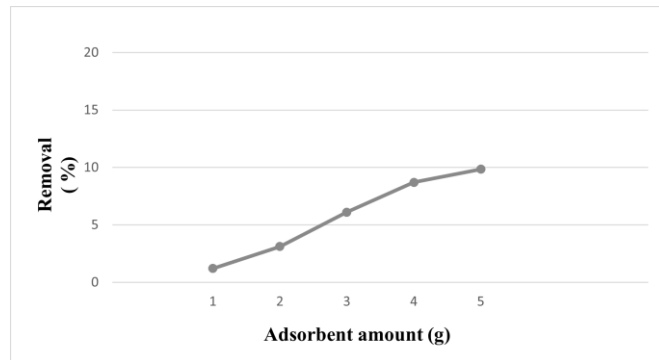
Graph 4: Effect of metal ion concentration

Effect of adsorbent dosage

Adsorbent dosage effect was studied by treating requisite adsorbent dosage (in g.) of red soil powder (1.0, 2.0, 3.0, 4.0 and 5.0) with 100 ml of working solution containing 10mg/L concentration of Cadmium (II) at 200 rpm. The pH for these studies was adjusted to 4. After 20 minutes the adsorbent was filtered out and the filtrate is analysed for metal ion concentration by atomic absorption spectrophotometer. For Cadmium (II) ion adsorption, 1.21% removal efficiency observed with 1 g adsorbent dosage and it increases to 3.11% with adsorbent dosage 2 g. The removal percentage further increases to 6.11% for 3 g, 8.70% for 4g of adsorbent. It reaches to maximum 9.84% at highest adsorbent dosage of 5 g. from graph 5 it is clear.

Table 3: Effect of adsorbent dosage on removal of Cd (II) ion onto red soil

Initial metal ion concentration (mg/L)	Final metal ion concentration (mg/L)	adsorbent dosage (g)	Removal efficiency (%)
10.00	9.879	1	1.21
10.00	9.689	2	3.11
10.00	9.398	3	6.11
10.00	9.130	4	8.70
10.00	9.016	5	9.84



Graph 5: Effect of adsorbent dosage

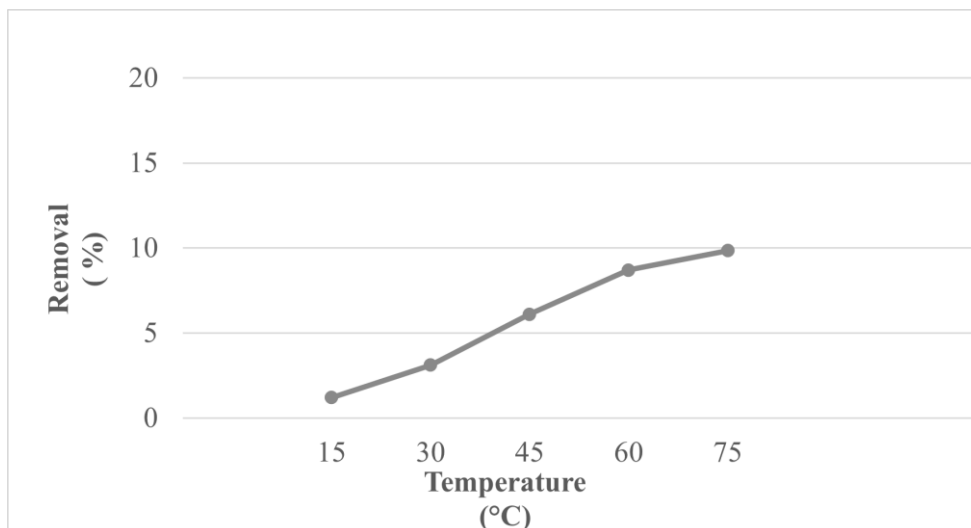
Effect of Temperature

The removal efficiency is found 1.21% at 15°C. The efficiency slightly increases to 2.88% at 30°C. Rising temperature shows increases in efficiency as 4.78% at 45°C, 7.89% at 60°C. At 75°C adsorption efficiency reached to 8.56%.

There is a gradual increase in removal efficiency with rise in the temperature may due to increase in ion exchange reaction. Graph 6 shows the gradual increase adsorption variation with temperature.

Table 4: Effect of temperature for removal of Cd (II) ion onto red soil

Initial metal ion concentration (mg/L)	Final metal ion concentration (mg/L)	Temperature (°C)	Removal efficiency (%)
10.00	9.879	15	1.21
10.00	9.712	30	2.88
10.00	9.522	45	4.78
10.00	9.211	60	7.89
10.00	9.144	75	8.56



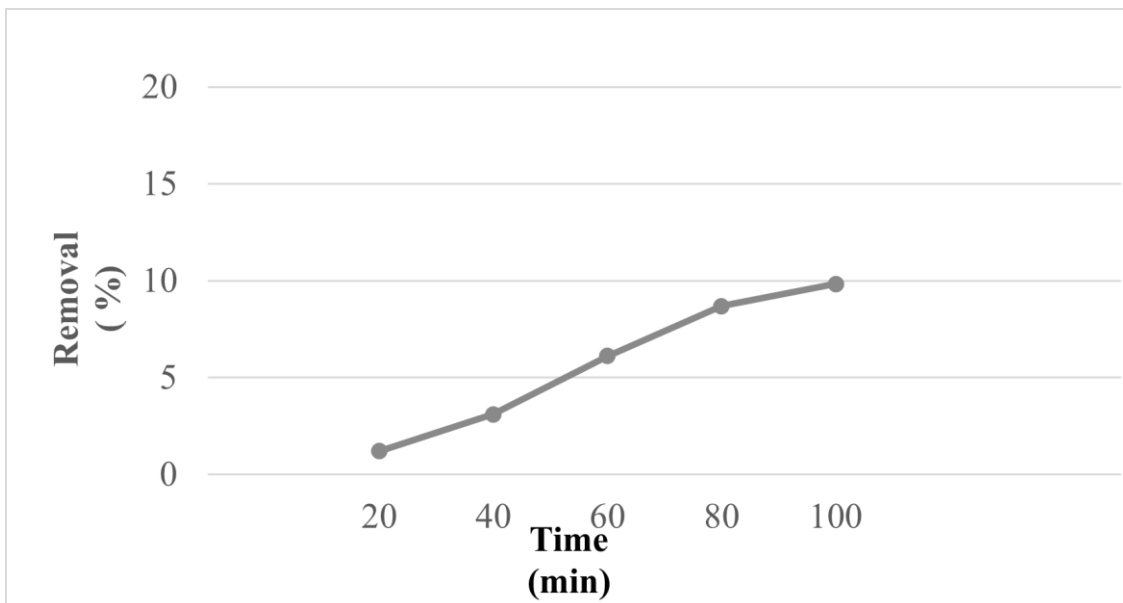
Graph 6: Effect of temperature

Effect of Contact time

For Cadmium (II) ion adsorption, the increase in contact time shows a regular improvement in the removal efficiency. The removal efficiency 1.21% is observed for 20 minutes and it increases to 8.32% for 40 minutes. The increasing contact time shows a regular increase in the removal efficiency as it is 14.21% for 60 minutes, for 80 minutes it reached to 15.17%. For contact time 100 minutes the 18.57% removal efficiency is obtained. The more interaction between the available binding sites and metal ions may be responsible for this trend of removal efficiency.

Table 5: Effect of Contact time for removal of Cd (II) ion onto red soil

Initial metal ion concentration (mg/L)	Final metal ion concentration (mg/L)	Contact time (min)	Removal efficiency (%)
10.00	9.879	20	1.21
10.00	9.168	40	8.32
10.00	8.579	60	14.21
10.00	8.483	80	15.17
10.00	8.143	100	18.57



Graph 7: Effect of contact time

Freundlich adsorption isotherm studies

Adsorption of the metal ion on heterogeneous surface of the adsorbent follows the Freundlich isotherm model. Adsorption of Cadmium metal ion on the red soil the logarithmic values of q_e (solute adsorbed per unit weight of adsorbent) and C_e (equilibrium concentration of solute in solution) are given in table 6.

Table 6: Values of log Ce and log qe for Cadmium onto red soil

Metal	Log qe (mg/g)	Log Ce (mg/L)
Cadmium	-0.917	0.995
	0.043	1.276
	0.357	1.443
	0.364	1.576
	0.387	1.677

Value of KF (adsorption Capacity) of Cadmium was 1.372, the adsorption intensity (1/n) was 0.446, and the regression value (R²) in Freundlich isotherm equilibrium was 0.856.

DISCUSSION

From the removal efficiency (%) result we got adsorption of Cd (II) onto red soil was highest at 50 ppm metal ion concentration i.e; 24.39% and lowest at pH 2 parameter i.e; 0.30%, and in all parameters like pH, temperature , adsorbent dosages, contact time and on metal ion concentration on increasing the values we have seen the removal efficiency gradually increasing.

CONCLUSION

Soil is a fundamental component of terrestrial ecosystems and is a highly complex, heterogeneous medium composed of the soil matrix, soil water, and soil air. Heavy metal ions are among the most toxic inorganic pollutants found in contaminated water, originating either from industrial activities or anthropogenic sources. Adsorption is a cost-effective process for their treatment in heavy metal polluted water. The primary interfaces involved in heavy metal adsorption in soils are predominantly inorganic colloids, such as clays and metal oxides.

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