ORIGINAL RESEARCH PAPER

Kinetic Studies on Simultaneous Biosorption of Divalent Copper and Hexavalent Chromium using Mallet Flower Leaf Powder

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ABSTRACT

This work aims to exploit low cost and efficient sorbent for the removal of heavy metals from the aqueous solution using Mallet Flower Leaf Powder (MFLP). MFLP is processed into a fine powder and used as a bio-adsorbent. Experiments are conducted to find out the feasibility of metal recovery process to reclaim the metals. The adsorption rates of both Chromium and Copper are lowered by 3.4% and 48.4%, respectively in contrast to those obtained when only one metal is present in the solution. The presence of Copper along with Chromium has not much affected the adsorption rates of Chromium. There is a higher adsorption rate for Chromium than for Copper at different temperatures. In the binary system, the copper adsorption rate is found to be suppressed by the presence of Cr (VI). The uptake of Cr (VI) is higher than the single system while being in the binary system, while the uptake of Cu(II) is lower in the binary system than the single system. The effect of initial concentration on the recovery of Cu(II) from loaded adsorbent decreases up to 60 mg/l where about 68% recovery was found. The maximum recovery for Cu (II) was found to be at an adsorbent dosage in the range 15-35 g; As the initial concentration of Cu (II) increases, the retention of metal on MFLP increases. The data collected are verified with the kinetic studies. The results suggested favorable removal efficiency of copper and chromium from wastewater using MFLP.

Keywords: Chromium, Copper, Fourier transform infrared analysis (FTIR), Mallet Flower Leaf powder (MFLP), Scanning Electron Microscopy (SEM).

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INTRODUCTION

Industrial effluent streams or sewage wastewaters never practically contain only one single heavy metal contaminant but are loaded with many heavy metal contaminants, which makes them sources for environmental pollution. These contaminants percolate and enter the groundwater table, contaminating the potable water drawn through the wells and other drinking water sources. The environmental degradation of land, water, and air ultimately leads to a gradual fall in the life expectancy of living organisms and thus their health and daily course are greatly affected. Besides this, the loss of valuable metals in these streams

might affect the overall economics and industrial growth of the developing nations [1-3].

Most studies of the earlier investigators are confined to the single metal loaded industrial or domestic processing waste streams; However, in the real streams, there is more than one metal as a contaminant. Studies also reported on the techniques of removing more than one metal from the waste process streams. Biosorption techniques have been successfully adopted to recover heavy metals from the effluent streams. Attempts have also been made to simultaneously remove the heavy metals from industrial effluents use organic adsorbents [4-6].

The adsorption process has drawn attention

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to the removal and recovery of metal ions from industrial effluents. The critical toxic elements present in wastewaters are Cr(VI), Cu(II), Zn (II), Ni(II), Cd(II), and Pb(II) which are entering the effluent streams from various industries like metal plating, leather industries, paper and pulp, steel alloy, ferroalloy industries, etc. Mostly Cr (VI) is highly reactive and hazardous when compared to Cr (III) compounds. Industrial wastewaters containing Cr (VI) compounds are carcinogenic, therefore causing health issues leading to tissue, liver, and kidney damage [7-9]. The systematic study and comparison between adsorption rates of both Chromium and Copper in the binary system at different temperatures, in contrast to those obtained when only one metal is present in the solution, has not been reported.

Having this in mind, experiments were conducted on the adsorption of Chromium and Copper from a binary system in which both metals of known weights are dissolved. The system is subjected to the treatment with MFLP adsorbent in order to investigate the possibility of their removal from the test solution of known concentration. pH measurement is also done; when considering the ionic nature of the solutions containing Chromium and Copper ions, studied for the simultaneous removal. A pH meter was used during experimentation for the continuous monitoring and adjustment of pH between 2 and 6 by adding 0.1N HCl and 0.1N NaOH as per the requirement [10-12].

In the current study, Mallet Flower Leaf Powder is used as a biosorbent for the simultaneous Biosorption of divalent copper and hexavalent chromium by conducting batch experiments.

MATERIALS AND METHODS

Preparation of the adsorbent (MFLP)

The adsorbent is prepared using mallet flower leaf powder (*Scientific Name: schefflerapucckleri*). The mallet flower leaves are collected from the campus of MVGR College of Engineering (A), Vizianagaram, Andhra Pradesh, India. These leaves are washed with normal tap water and dried in sunlight until their weight becomes constant. Then these leaves are powdered in ultra-fine grinders and screened through BSS meshes (100,150,240 mesh). The average particle size of adsorbent was maintained in the range of 100 to 240 mesh [13-15].

Batch mode adsorption studies:

Batch experiments are carried out using 250 ml conical flasks. The stock solution is diluted with distilled water to make various concentrations of metal ions solutions varying from 20-100 mg/l. The specific quantity of adsorbent (0.2-1.0 g) is added to the solution and agitated at 210 rpm in a rotary shaker for a predetermined period (5-120 min). The adsorbate was then decanted and separated from adsorbent using (Whatman no. 40) filter paper. The clear solution is collected in sample bottles and stored for analysis using Atomic Absorption Spectrophotometer (AAS). The percentage removal of metal ions is calculated as (C₀-Ce) *100/C₀, where Co and Ce (mg/l) is the initial concentration (before adsorption) and final concentration (after adsorption). The effect of pH was studied by adjusting the solution using 0.1 mol/l of NaOH or 0.1 mol/l of HCl solutions [16-18].

Simultaneous metal (Cr-Cu) removal using MFLP

MFLP was used to perform simultaneous adsorption studies from aqueous solutions of Chromium and Copper. Analytical grade of potassium dichromate and copper sulphate were used directly without further purification. A binary stock solution of 1L was prepared by dissolving the desired amounts of their corresponding salts. This stock solution was used to prepare test solutions of different concentrations containing both Cr and Cu for subsequent experimental investigations [19-21].

Batch mode desorption studies

Batch desorption studies were performed to find whether metal ions adsorption on investigated adsorbent is reversible or not. The desorption studies of metal ions using HCL and NaOH of different concentrations (0.01N, 0.1N, 0.25N) were performed. The desorption of metal ions from the adsorbent surface is maximum at 0.25N HCL and NaOH.

Moreover, it is seen that the adsorption process is irreversible. There is a difference between desorption obtained in the case of both desorbing agents HCl and NaOH by different functional groups on the MFLP surface. It is found that the adsorbent structures may be responsible for the incomplete desorption [22-24].

Table 1. Different variables studied for the recovery of metals

Parametric study	Range of variables
Initial Cr/Cu concentration, PPM/(mg/l)	20,40,60,80 and100
Adsorbent dosage, g	15,25,35,45 and 55gms

Adsorption

Recovery

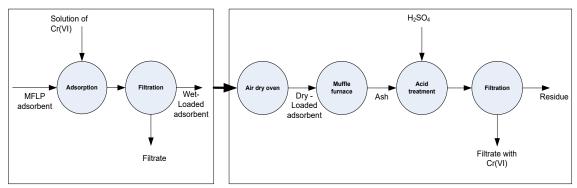


Fig. 1. Block diagram of the methodology used for recovery of chromium from loaded MFLP

Adsorption

Recovery

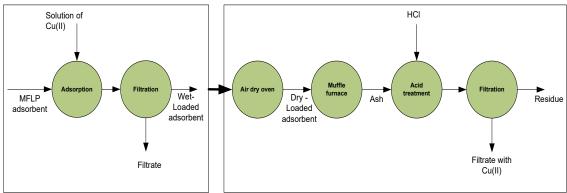


Fig. 2. Block diagram of the methodology used for recovery of copper from loaded MFLP

Recovery of Chromium / Copper from the Loaded Adsorbent

Experiments are conducted to find out the feasibility of metal recovery process to reclaim those valuable metals. Based on previous equilibrium data obtained from the batch studies, two variables, i.e dosage of MFLP adsorbent, l_a and initial concentration of Cr (VI) test solution C_o are varied for conducting experiments on recovery process (Table 1). 35 g of MFLP adsorbent is chosen for these experiments for five concentrations of Cr (VI) solutions (20, 40, 60, 80, 100 mg/l).

The experimental methodology for the recovery of Cr (VI) and Cu (II) is shown in flow

diagrams (Fig. 1 and Fig. 2). The solution mixture containing solute and adsorbent after adsorption is filtered, dried thoroughly, and kept in a furnace at a predetermined temperature. The incinerated mixture is burnt into ash. The metal contents in the ash are then leached out with suitable extracts or solvents such as Sulfuric acid and Hydrochloric acid. After metals dissolve in the solvents; the solution is filtered. The clear filtrate solution is analyzed for the solute using AAS [25-27].

Step-wise the Methodology

Step-A: Adsorption

5 liters of potassium dichromate solution of different



concentrations (20, 40, 60, 80, 100 mg/l) were taken in 5 different vessels. 35 grams of adsorbent was added to each vessel. The 5 vessels were placed in a shaker and stirred for 120 mins so that the adsorption takes place. Afterward; the contents of each vessel were filtered using filter cloth. The clear solutions were collected in sample bottles and the bottles were labeled and stored for analysis [28-30].

Step-B: Recovery

The residue on the filter medium contains MFLP on which the metal was adsorbed. The residue was allowed to dry in a hot air oven. The dried mixture of metal and the adsorbent was placed in a crucible of known weight; the crucible with its contents was kept in a muffle furnace and allowed for incineration at a temperature of around 600 to 700°C, for 2 hours. The crucible containing Ash was now kept in a desiccator for cooling. After cooling, the ash was transferred into a conical flask. 500 ml of 1M H₂SO₄ solution was added to the ash in the conical flask. After 24 hours of acid-ash reaction, the mixture solution is filtered using Whatman 40 filter paper. The residue was separated and the filtrate obtained contains the chromium metal leached out from ash. The filtrate was analyzed for its chromium metal ion content using AAS. The residue contains carbon and trace elements of metal ions and the recovery of metal ions was

RESULTS AND DISCUSSIONS

Characterization of MFLP

calculated [31-33].

Scanning electron microscopy (SEM) analysis

The characterization of the adsorbent plays an important role in any new material to be developed as an adsorbent for the recovery of heavy metals. Biosorption of metal ions using MFLP adsorbent was performed in order to study the effects of various parameters like adsorbent size, adsorbent dosage, initial metal concentration, pH, and temperature [34-36]. The MFLP was characterized by using SEM. SEM images of MFLP before and after the adsorption are shown in Fig. 3 (a,b,c,d) & (e,f,g,h) respectively.

SEM demonstrated the morphology and surface texture of MFLP at different magnifications. The adsorbent's surface morphology revealed porous and zig-zag parts for the MFLP before and after the adsorption respectively and therefore clearly indicates that active sites of MFLP are occupied by metal ions after adsorption.

Fourier transforms infrared (FTIR) analysis:

The MFLP was characterized by using FTIR. FTIR of MFLP before and after the bimetal adsorption are shown in Fig. 4 (a,b).

FTIR images revealed porous and zig-zag parts for the MFLP before and after the adsorption respectively and thus clearly indicate that active sites of MFLP are occupied by metal ions after adsorption.

Simultaneous metal (Cr-Cu) adsorption using MFLP Effect of time on percent removal of Cr(VI) & Cu(II) in a binary system

To understand the competitive nature of hexavalent Cr and divalent Cu in the mixture, the adsorption data on metal recovery were plotted against time at three temperatures 283, 303, and 323 K and shown in Fig. 5.

The data showed adsorption rates of both Chromium and Copper are reduced by 3.4% and 48.4% respectively in contrast to those obtained when only one metal is present in the solution at a temperature 303 K. The same trend could be seen at any temperature. The presence of Copper along with Chromium has not affected the adsorption rates of Chromium significantly.

Effect of time on metal uptake of Cr(VI)-Cu(II) in a binary system at different temperatures

The plots of the data on metal uptake drawn against time for the binary metal [Cr(VI)-Cu(II)] system at temperatures 283 K, 303 K, and 323 K are shown in Fig. 6 (A, B, C) respectively. The data trends to show higher adsorption rates for Chromium than for Copper at different temperatures; However, this may be attributed to the valence level of hexavalent Chromium, which exhibits more affinity to the charged surface of the MFLP adsorbent when compared to divalent Copper.

The vacant sites of adsorbent (MFLP) are the adsorption sources of Cr(VI) and Cu(II) at the pore structure of adsorbent particles. Competitive preferential metal adsorption between the metal ions under study depends on the rates of attachment and detachment of both metal ions on vacant and occupied active sites simultaneously. The whole mechanism of the binary metal adsorption system is understood by the measure of metal uptake of the adsorbent over the period. The experiments were conducted at three different temperatures in order to understand the effects of temperature on metal

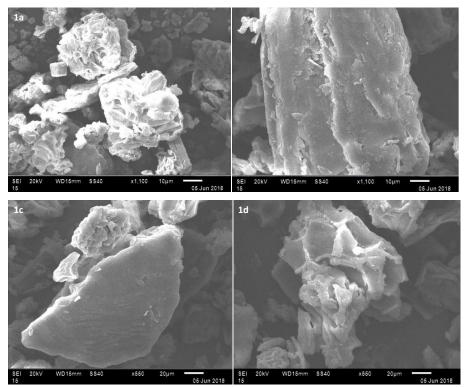


Fig. 3 (a -d). SEM micrographs of MFLP before Adsorption

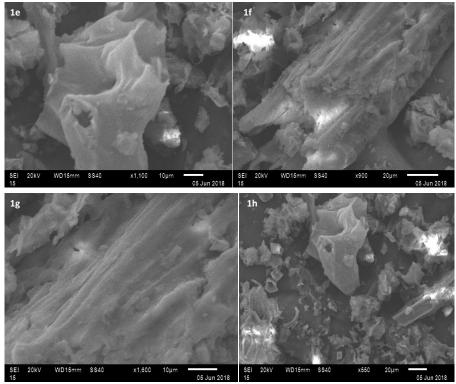


Fig. 3 (e-h). SEM micrographs of MFLP after Adsorption

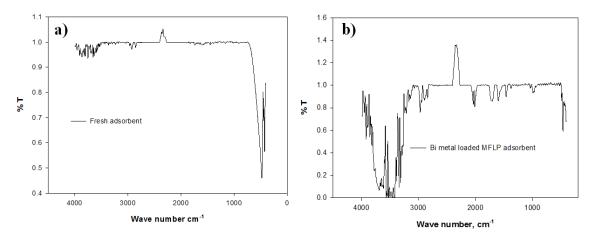


Fig. 4. FTIR image of a) pure adsorbent and b) bimetal loaded adsorbent

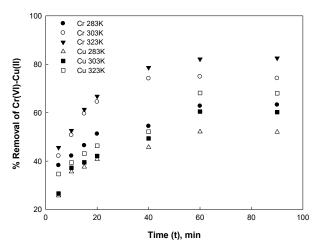


Fig.5. Effect of time on percent removal of Cr(VI) & Cu(II) in a binary system

uptake. These data points are shown in Fig. 6.

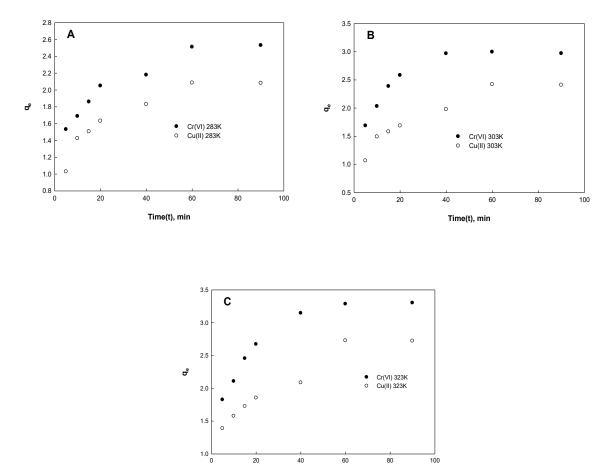
The effect of time profile with % removal at three temperatures of the binary Cr-Cu sorbate solution gives the amount of metal adsorbed in three cases, in which, preferentially more Cr(VI) was found to get adsorbed in the presence of Cu(II). The time of contact, in turn, decides the extent of metal dissolved. It is likely to influence the transportation of the metal ion towards the active sites at the inner pores.

Metal uptake is controlled by the surface diffusion initially, up to 40 mins of contact (agitation) time. The patterns after 40 mins suggest that the adsorption process is under the control of pore diffusion so that the system approaches equilibrium between the adsorption and desorption phenomena. As Cr(VI) has less ionic radii than

Cu(II), more Cr (VI) ions are transported to the surface pores for adsorption in preference to Cu (II) ions at higher temperatures.

Comparison of a single and binary system on metal uptake

In the binary system, the copper adsorption rates are found to be suppressed by the presence of Cr(VI). At any temperature, Cr(VI) is more adsorbed by the MFLP adsorbent than Cu(II) in contrast to the single metal solution system, whereas the Cu(II) adsorption rates are more than those of Cr(VI) in a single system (Fig. 7). It is also observed that the uptake of Cr(VI) is higher in the binary system than the single system, while the uptake of Cu(II) is lower in the binary system than the single system.



 $Fig.\ 6\ Effect\ of\ time\ on\ metal\ uptake\ of\ Cr(VI)-Cu(II)\ in\ a\ binary\ system\ at\ different\ temperatures$

Time(t), min

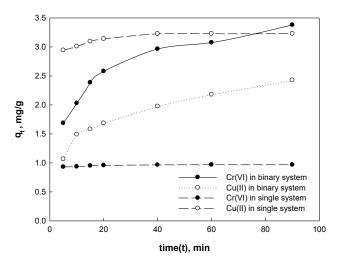


Fig. 7 Comparison of a single and binary system on metal uptake

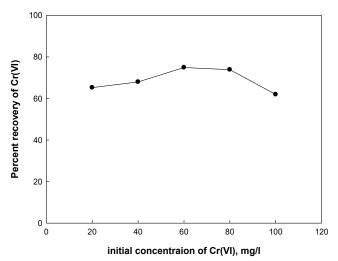


Fig. 8 % recovery w.r.t initial concentration of Cr(VI)

Desorption Studies

MFLP has a good adsorption capacity. For this reason, it is necessary to find out the desorption characteristics of metal ions from MFLP. Experiments are conducted in order to investigate the desorption studies by proper treatment of the adsorbent without disturbing or damaging the structure of adsorbent. This would facilitate the re-use of the adsorbent. The regeneration of the adsorbent renders any commercial adsorption process economic and viable.

The adsorbent after adsorption is treated with suitable desorbents, normally acids or bases. In some cases, water could also be used as a successful desorbent.

The percentage of metal ions desorbed was determined by the following equation.

$$\% Desorption = 100 \times \frac{V_D C_D}{q_e m}$$
 (1)

Where,

C_D= concentration of metals ions desorbed

V_D= Volume of desorbed solution

m = mass of the adsorbed used for the study

q_e =Adsorption capacity of the adsorbent (metal uptake)

The % desorption of metal ions indicates the suitability of MFLP as a good adsorbent.

The mechanism involved in Desorption

Desorption is the opposite of adsorption. Metal loaded adsorbent, after reaching equilibrium, is treated with given normality (known concentration) of NaOH / HCl for desorbing the metal ions. This

is akin to the solid-liquid leaching or extraction process.

As and when the metal loaded adsorbent is added to NaOH, the concentration gradient between the sorbate on the adsorbent and sorbate in the desorbent initiates the desorption process. The basic nature of the desorbent solution facilitates the detachment of sorbate metal ions. As the concentration of NaOH is increased by 2.5 fold, the % desorption increased significantly by about 40-45 %.

Recovery of metal ions from the loaded adsorbent Recovery of Chromium from the loaded adsorbent

The effect of initial concentration on the recovery of Cr(VI) from the loaded adsorbent is observed to be up to 80 mg/l and nearly 76% recovery was found (Fig. 8). Thereafter, this declined to 60% as the concentration reaches 100 mg/l. The data were shown at constant adsorbent dosage, while pH was maintained at 6 and 303K temperature. For Cu (II), the maximum recovery was observed at 20 – 40 mg/l. Improvements were not seen beyond these values of C_0

The increase in the % recovery with an increase in MFLP dosage was observed from 15g to 35g; thereafter, it remained constant beyond 35g (Fig. 9). Thus for Cr, the maximum recovery was found to be at an adsorbent dosage in the range 15-35 g.

The ratio of Chromium adsorbed to the Chromium recovered increased as the initial concentration varied from 20 mg/l to 100 mg/l. At 20 mg/l most of the adsorbed Cr(VI) was recovered.

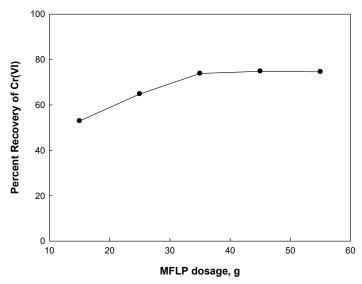


Fig. 9 % recovery w.r.t initial concentration of Cr(VI)

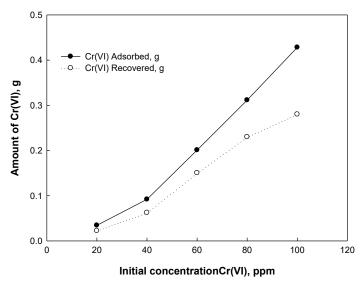


Fig. 10 Recovery of Chromium(VI) from the loaded adsorbent

As the initial concentration of Cr(VI) increased, retention of metal on MFLP also increased; hence, showed a decline in the % recovery of Chromium (Fig. 10).

Recovery of Copper from the loaded adsorbent:

The effect of initial concentration on the recovery of Cu(II) from the loaded adsorbent is observed to decrease up to 60 mg/l where about 68% recovery was found. Thereafter this increased to 71% as the concentration reaches 100 mg/l (Fig. 11). The data were shown at constant adsorbent

dosage, while pH was maintained at 6 and 303K temperature. For Cu (II) the maximum recovery was observed at 20 – 40 mg/l. Improvements were not seen beyond these values of $C_{_{\odot}}$

The increase in the % recovery with an increase in MFLP dosage was observed from 15g to 35g, afterward, it increased gradually beyond 35g. Therefor for Cu, the maximum recovery was found to be at an adsorbent dosage in the range 15-35 g (Fig. 12).

The ratio of the adsorbed Copper to the recovered Copper increased as the initial concentration was



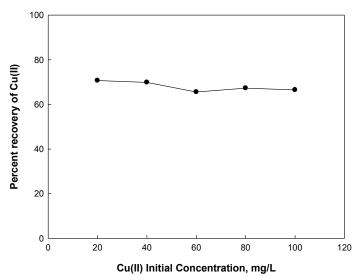


Fig. 11 % recovery w.r.t initial concentration of Cu(II)

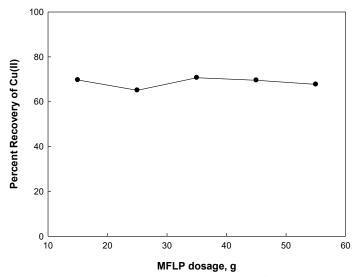


Fig. 12 $\,\%$ recovery w.r.t initial concentration of Cu(II)

varied from 20 mg/l to 100 mg/l. At 20 mg/l most of the adsorbed Cu(II) was recovered. As the initial concentration of Cu(II) increased, the retention of metal on MFLP also increased, therefore a decline in the % recovery of Copper was observed (Fig. 13).

The calculated data on the recovery of Chromium and Copper are compiled and shown in Tables 2 and 3.

Adsorption kinetics Pseudo-first-order model

The reaction rates of the adsorbate-adsorbent

system would provide good information for the design of a practical operating system in order to get better yields of removal/recovery from heavy metal ions either toxic or non-toxic from the effluent streams; within a given time constraint, Processing times could be optimized for quick and efficient removal or recovery processes. This information could be derived from the knowledge of the kinetics of reactions occurring between the adsorbent and adsorbate.

With this in mind, kinetic studies of adsorbentadsorbate system of reactions have been carried out in order to arrive at a suitable mechanism of

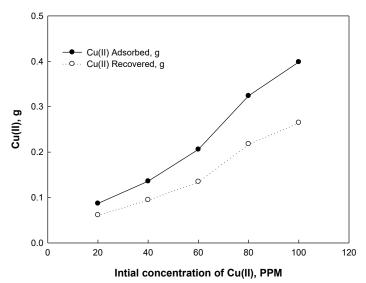


Fig 13. Recovery of Cu(II) from the loaded adsorbent

Table 2. Recovery data for Chromium

Volume, V	Initial concentration, Co	Wt of adsorbent, m	Adsorbate concentration infiltrate, Co	Percenta ge of adsorpti on	Metal uptake, q	Concentration after acid dissolved	The metal present in adsorbent before acid treatment	After acid treatment	Percentag e recovery
I., ml	PPM	G, g	mg/L	%	mg/g	mg/L	g	g	%
5	20	35	13.1	34.5	0.98	0.45	0.0345	0.0225	65.22
5	40	35	21.6	46	2.62	1.25	0.092	0.0625	67.93
5	60	35	19.8	67	5.743	3.01	0.201	0.1505	74.88
5	80	35	17.7	77.87	8.90	4.6	0.3115	0.23	73.84
5	100	35	14.38	85.62	12.23	5.6	0.4281	0.28	65.41

Table 3. Recovery data for Copper

Volume, V	Initial concentration,	Wt of adsorbent, m	Adsorbate concentration infiltrate, C	Percentage of adsorption	Metal uptake, q	Concentration after acid dissolved	The metal present in adsorbent before acid treatment	After acid treatment	Percentage recovery
L, ml	PPM	G, g	mg/L	%	mg/g	mg/L	g	g	%
5	80	15	44.1	44.87	11.96	1.9	0.1795	0.095	52.92
5	80	25	36.8	54	8.64	2.8	0.216	0.14	64.81
5	80	35	17.7	77.87	8.90	4.6	0.3115	0.23	73.83
5	80	45	15.84	80.2	7.128	4.8	0.3208	0.24	74.81
5	80	55	16.72	79.1	5.75	4.72	0.3164	0.236	74.58

the reactions. Rates depicting the yields could be predicted from the different kinetic models provided, based on the order of adsorbentadsorbate reactions. Equilibrium data provides the necessary drive for the transportation or diffusion of the solute (adsorbate) ions from solution to the solid adsorbent surface.

Attempts are made in order to arrive at a suitable kinetic model for adsorption reactions between

metal ions, adsorbate, and MFLP adsorbent. The diffusion rates of ions from solution to the surface of adsorbent are probably monitored or controlled by a boundary. The rate kinetics in most of such instances follow the **pseudo-first-order rate equation** of Lagergren given below (eq. 2).

$$\frac{\mathrm{d}\mathbf{q}_{t}}{\mathrm{d}t} = \mathbf{k}_{ad} \left(\mathbf{q}_{e} - \mathbf{q}_{t} \right) \tag{2}$$



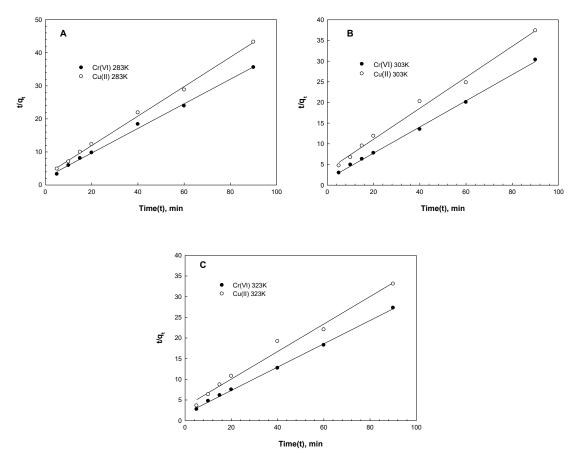


Fig. 14 Pseudo second-order kinetics for binary (Cr-Cu) system

Where q_e and q_t are amounts adsorbed at t (min) and equilibrium,

 K_{ad} is the rate constant of the **pseudo-first-order adsorption process**.

The above equation can be written as (eq. 3):

$$\log(\mathbf{q}_{e} - \mathbf{q}_{t}) = \log \mathbf{q}_{e} - \left(\frac{\mathbf{k}_{1}}{2.303}\right) \mathbf{t}$$
(3)

The plot of 'log $(q_e - q_t)$ ' vs. 't' gives a straight line for the first-order kinetics, making possible the calculation of first-order rate constant (K_{ad}) for the adsorption process.

The above equation may not represent the experimental data due to the following two reasons:

- K_{ad} $(q_e q_t)$ doesn't signify several accessible adsorption sites.
- Log q_e is not equivalent to intercept.

Pseudo-second-order model

The pseudo-first-order kinetic equation failed to represent the kinetic adsorption data on Cr(VI)

(adsorbate) – MFLP (adsorbent) and Cu(II) (adsorbate) - MFLP (adsorbent) systems; therefore, the pseudo-second kinetic model has been adopted in order to explain the adsorption kinetic data of Cr(VI) and Cu(II). The regression data showed the best fit of the pseudo-second-order kinetic equation to the adsorption data of only one sorbate (single metal) is present in the solution. Accordingly, an attempt has been made to fit the present data on the binary (two metal sorbate) system using the pseudo-second-order kinetic model.

$$\frac{\mathrm{d}\mathbf{q}_{t}}{\mathrm{d}t} = \mathbf{K}_{ad} \left(\mathbf{q}_{e} - \mathbf{q}_{t}\right)^{2} \tag{4}$$

Where 'K' is the second-order rate constant. The above equation could be presented as (eq. 5)

$$\frac{\mathbf{t}}{\mathbf{q}_{t}} = \frac{1}{\mathbf{K}_{ad}\mathbf{q}_{e}^{2}} + \frac{1}{\mathbf{q}_{e}}\mathbf{t}$$
 (5)

For the pseudo-second-order kinetics, the plot of (t/qt) versus t shown in Fig. 14 gives a linear equation (eq. 6) facilitating the

Kinetics	Parameters at pH= 2	Model equation	qe cal, mg/g	qe exp, mg/g	\mathbb{R}^2	Rate constant, k ₂ , g/mg.min
	283K, Cr[Cr-Cu] system	$\frac{t}{q} = 0.3722t + 2.219$	2.686	2.51	0.996	0.06243
	283K, Cu[Cr-Cu] system	$\frac{t}{q} = 0.316t + 1.399$	3.159	2.08	0.998	0.071577
2 nd order	303K, Cr[Cr-Cu]system	$\frac{t}{q} = 0.2819t + 1.669$	3.547	2.99	0.998	0.047614
2 order	303K, Cu[Cr-Cu]system	$\frac{t}{q} = 0.445t + 3.008$	2.247	2.41	0.9977	0.065833
	323K, Cr[Cr-Cu]system	$\frac{t}{q} = 0.3748t + 3.605$	2.668	3.28	0.9926	0.038967
	323K, Cu[Cr-Cu]system	$\frac{\dot{t}}{a} = 0.332t + 3.4073$	3.012	2.72	0.9833	0.032349

Table 4. Pseudo second-order kinetics constants and regression coefficients

computation of qe and K (Table 4).

$$\frac{t}{q} = 0.189t + 0.132\tag{6}$$

CONCLUSIONS

The adsorption rates of both Chromium and Copper are lowered by 3.4% and 48.4% respectively in contrast to those obtained when only one metal is present in the solution. The presence of Copper along with Chromium has not much affected the adsorption rates of Chromium. Higher adsorption rates of Chromium than Copper at different temperatures may be attributed to the valence level of hexavalent Chromium, which exhibits more affinity to the charged surface of the MFLP adsorbent when compared to divalent Copper. Competitive preferential metal adsorption between Chromium and Copper depends on the rates of attachment and detachment of both metal ions on vacant and occupied active sites simultaneously. As Cr (VI) has less ionic radii than Cu (II), more Cr (VI) ions are transported to the surface pores for adsorption in preference to Cu (II) ions at higher temperatures. The time of contact influences the transportation of the metal ion towards the active sites at the inner pores. Metal uptake is controlled by the surface diffusion initially, up to 40 min of contact time. After 40 mins, the adsorption process is under the control of pore diffusion so that the system approaches equilibrium between the adsorption and desorption phenomena. The effect of initial concentration on the recovery of Cu(II) from loaded adsorbent decreases up to 60 mg/l where about 68% recovery was found. As the initial concentration of Cu(II) increases, the retention of metal on MFLP also increases. The paper shows

that MFLP can be used as an efficient adsorbent for studying the simultaneous removal of Chromium and Copper.

CONFLICT OF INTEREST

Author declares no conflict of interest.

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