

Removal of Copper(II) Ion from Aqueous Solution by Adsorption on Iron Oxide and Kaolin

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Abstract: The effect of various physiochemical parameters on kinetics and equilibrium adsorption of Cu(II) metal ion from its aqueous solution by iron oxide and kaolin have been investigated using batch adsorption experiment. The results show that the amount of adsorption of Cu(II) metal ion increases with initial metal ion concentration, contact time, solution pH but decreases with the amount of adsorbent. The kinetic experimental results show that the adsorption of Cu(II) on oxide as well as on kaolin is a two-step process: a rapid adsorption of metal ions to the external surface is followed by possible slow intraparticle diffusion in the interior of the particles which has been confirmed by intra-particle diffusion model. Higher linear regression correlation coefficients (R^2) among fitted pseudo-first-order, pseudo-second-order and intra-particle diffusion model suggest that adsorption of copper metal ion on iron oxide as well as on kaolin follow pseudo-second-order kinetics and various kinetic parameters have been calculated. Langmuir and Freundlich models are used to describe the adsorption of copper metal ion on iron oxide and kaolin within specified metal ion concentration range. The value of separation factor, R_L from Langmuir equation and rate of biosorption, ' n ' from Freundlich model also gives an indication of favourable adsorption.

Key words: Metal ion adsorption, kinetics, isotherms.

Introduction

Heavy metals are considered as hazardous pollutants due to their toxicity even at low concentration and non-biodegradable properties. Copper is known to be one of the heavy metals most toxic to living organisms and it is one of the more widespread heavy metal contaminants of the environment (Ozer et al., 2004). The potential sources of copper in industrial effluents include metal cleaning and plating baths, pulp, paper board mills, wood pulp production, fertilizer industry, paints and pigments, municipal and storm water run-off, etc. (Ozer et al., 2004; Benaissa and Elouchdi, 2007). Intake of excessively large doses by man leads to severe mucosal irritation and corrosion, widespread capillary damage, hepatic and renal damage and central nervous system irritation followed by depression (Ajmal et al., 1998). Many technologies have been developed to remove heavy

metals from contaminated waters, such as chemical precipitation, ion exchange, filtration, solvent extraction and membrane technology and adsorption (Arias and Sen, 2009). Some of these methods have disadvantages and limitations. Precipitation, for example, produces large amount of sludge in solution (Sen and Ling, 2009) but membrane filtration, ion exchange, electro-deposition and filtration are costly (Sen and Ling, 2009). Alternatively, adsorption can remove these metals efficiently at low cost and also very simple in operation. Several solid materials can be employed as adsorbents.

Adsorption on activated carbon is the conventional method for the removal of heavy metal ions from aqueous solutions but its high cost limits its use (Arias and Sen, 2009). Therefore, the adsorption using inexpensive and easily available adsorbent would make the removal of heavy metals from wastewater an economically viable alternative. Clay is one of the potential good adsorbent

Nomenclature

C_0 = Initial dye concentration in solution, mg/L
 C_e = Equilibrium dye concentration, mg/L
 K_1 = Pseudo-1st order rate constant, min⁻¹
 K_2 = Pseudo-2nd order rate constant, g/mg-min
 K_f = Freundlich isotherm constant
 K_a = Langmuir constant
 m = Amount of adsorbent, g
 q_t = Adsorption density, mg/g
 q_e = Equilibrium adsorption density, mg/g
 V = Volume of reaction mixture, L

alternatives to activated carbon because of its large surface area, high cation exchange capacity, chemical and mechanical stability and layered structure. Aluminium oxides, iron oxides and clay minerals such as kaolin, are the most widespread minerals of the earth crust which are known to be good adsorbents/sorbents of various metal ions, inorganic anions and organic ligands (Arias and Sen, 2009; Sen and Ling, 2009). These oxides and clay minerals are important tropical soil secondary minerals, responsible for the low mobility and bioavailability of heavy metals (Mellis et al., 2004). Therefore, it is essential to understand the mechanism and kinetics of adsorption, because the studies of adsorption kinetics and mechanism are ultimately a prerequisite for designing an adsorption column (Sen and Sarzali, 2008).

There are various studies on the removal of copper(II) ions from its aqueous solutions by clay/oxides (Sen et al., 2002; Cornel and Schwartzman, 1998; Mishra, 2009). Removal of copper(II) by various biosorbents or by agricultural waste is also reported by Vicentius et al. (2008), Benaissa and Elouchdi (2007) and Khormaei et al. (2007). However, systematic studies on Cu(II) adsorption characteristics on kaolin and iron oxide under various physicochemical parameters are limited and also are very scarce. For this reason, a detailed study was conducted in order to determine the influence of initial solution pH, initial metal ion concentration, and adsorbent doses changes on adsorption characteristics of natural kaolin and iron oxide respectively. Another reason for this study is the importance of adsorption on solid surfaces in many industrial applications in order to improve efficiency and economy.

In this present work, adsorption characteristics of Cu(II) on iron oxide (Fe₂O₃) and on kaolin with respect to the contact time, initial metal ion concentration, initial solution pH and adsorbent dose are presented. It has been

found that the amount of adsorption of copper metal ion increases with initial metal ion concentration, contact time, solution pH but decreases with increase in adsorbent concentration. The kinetic adsorption experimental results have been analysed using pseudo-first-order and pseudo-second-order kinetic models respectively. The Langmuir and Freundlich adsorption isotherm models are used to describe the experimental data. The value of separation factor, R_L from Langmuir equation and rate of biosorption, ' n ' from Freundlich model also gives an indication of favourable adsorption.

Materials and Methods

Adsorbent and Chemicals

All chemicals used were of analytical grade. Salts used in the preparation of synthetic contaminant bearing solution is Cu(NO₃)₂·6H₂O, obtained from S.D. Fine Chemicals, Mumbai (India). The pH of the system was adjusted using reagent grade NaOH and HNO₃ respectively. Adsorbent, kaolin (BET surface area = 33.50 m²/g, saunter mean diameter = 2.80 μm) was obtained from Sastick Chemicals, Mumbai. Crystalline iron oxide adsorbent of 30 mesh size was obtained from Aldrich and then was crushed in a centrifugal ball mill to obtain a powder (BET surface area = 191.6 m²/g, saunter mean diameter = 3.0 μm). This was used as such after drying at a temperature of 70 °C in a temperature controlled oven. All plastic sample bottles and glassware were cleaned, then rinsed with double distilled water and dried at 70 °C in a temperature controlled oven. The concentration of Cu(II) was measured using GBC double beam flame atomic absorption spectrophotometer. Sizes of particles were measured by Master Sizer X Ver 1.2, Malvern Instruments Ltd, U.K. The pH was measured using Orion pH meter.

Adsorption Procedure

Adsorption measurements were determined by batch experiments of known amount of the sample with 30 mL of aqueous Cu(II) solutions as per Arias and Sen (2009); Sen and Ling (2009) in a series of 60 ml plastic bottles. The mixtures were shaken in a constant temperature shaker at 120 rpm at 24 °C for a given time and then the suspensions were filtered through glass micro filter. The filtrates were analysed using flame atomic absorption spectrophotometer with air-acetylene flame. The experiments were carried out by varying concentration of initial Cu(II) solution, contact time, amount of adsorbent (iron oxide and kaolin separately)

and pH of initial suspension. Adsorption mechanisms were studied according to predefined procedure with Cu(II) concentration ranging from 8.0 to 30 mg/L. The Cu(II) concentration retained in the adsorbent phase was calculated according to

$$q_t = \frac{(C_0 - C_t)V}{m} \quad (1)$$

where C_0 (mg/L) and C_t (mg/L) are the concentration in the solution at time $t = 0$ and at time t , V is the volume of solution (L) and m is the amount of adsorbent (g) added.

The kinetics of adsorption of Cu(II) was carried out at low and high initial metal ion concentration and at different pH using same adsorption procedure started above. The only difference was that samples were collected and analysed at regular time interval during adsorption process.

The transient behaviour of the Cu(II) adsorption process was analysed using two adsorption kinetic models: pseudo first and pseudo-second-order rate models. The rate constant of adsorption was determined from pseudo-first-order rate model (Arias and Sen, 2009; Sen and Sarzali, 2008) as follows

$$\log(q_e - q_t) = \log q_e - \frac{K_1}{2.303} t \quad (2)$$

where q_t and q_e represent the amount of metal ion adsorbed (mg/g) at any time t and at equilibrium time respectively and K_1 represents the adsorption first-order rate constant (min^{-1}). Plot of $\log(q_e - q_t)$ versus t gives a straight line for pseudo first-order adsorption kinetics which allow computation of the rate constant K_1 .

The pseudo-second-order model (Sen and Ling, 2009; Arias and Sen, 2009; Sen and Sarzali, 2008) based on equilibrium adsorption is expressed as:

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{1}{q_e} t \quad (3)$$

A plot between t/q_t versus t gives the value of the constants K_2 (g/mg h) and also q_e (mg/g) can be calculated.

The constant K_2 is used to calculate the initial sorption rate h , at $t \rightarrow 0$, as follows

$$h = K_2 q_e^2 \quad (4)$$

Thus the rate constant K_2 , initial adsorption rate h and predicted q_e can be calculated from the plot of t/q versus time t using Eq. (3).

Results and Discussion

Kinetics of Cu(II) Metal Ion Adsorption

Effect of Contact Time

Figures 1 and 2 represent a plot of the amount of copper metal ion adsorbed (mg/g) versus contact time for Cu-iron oxide and Cu-kaolin systems at different initial metal ion concentration range. From these plots, it is found that the amount of adsorption i.e. mg of adsorbate per gram of adsorbent increases with increasing contact time at all initial metal ion concentrations and equilibrium is attained within 160 minutes for both the systems. Further it was observed that the amount of metal ion uptake, q_t (mg/g) is increased with increase in initial metal ion concentration. These kinetic experiments clearly indicate that the adsorption of Cu(II) on oxide as well as on kaolin is a two-step process: a rapid adsorption of metal ions to the external surface is followed by possible slow intraparticle diffusion in the interior of the particles (Sen and Sarzali, 2008; Davis and Leckie, 1978). In case of kaolin, intraparticle diffusion occurs through the space between the lattice layers, while in case of iron oxide, intraparticle diffusion occurs in the microspores of the oxide particles (Sen et al., 2002). This two-stage process is also due to presence of two different types of binding sites on the adsorbents as well (Sen et al., 2002).

Effect of Initial Solution pH on Metal Ion Adsorption Kinetics

The pH of the adsorbate solutions is an important

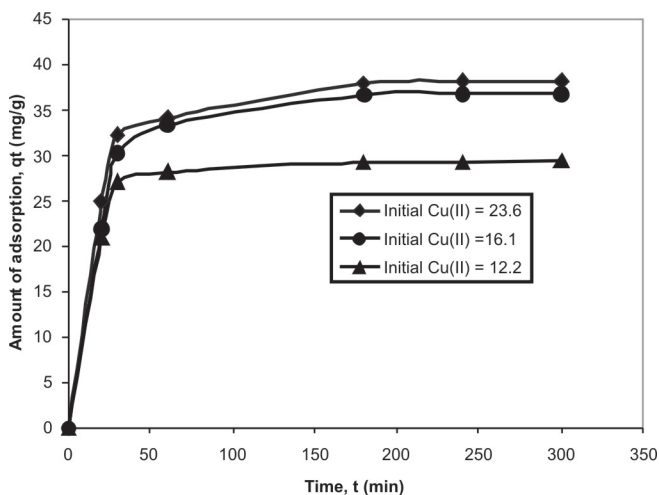


Figure 1: Effect of contact time on Cu(II) metal ion adsorption by iron-oxide with different initial metal ion concentrations. Initial solution pH = 4.5, amount of adsorbent = 8 mg, total reaction volume = 0.03 L, temperature = 28°C and shaker speed = 120 rpm.

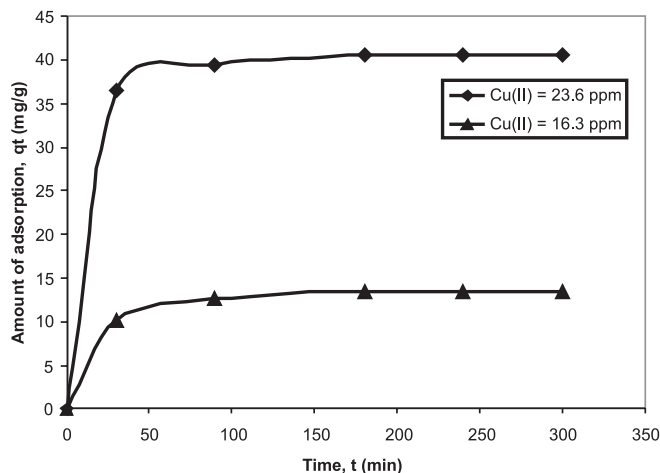


Figure 2: Effect of contact time on Cu(II) metal ion adsorption by kaolin with different initial metal ion concentrations. Initial solution pH = 7.5, amount of adsorbent = 8 mg, total reaction volume = 0.03 L, temperature = 28°C and shaker speed = 120 rpm.

parameter governing adsorption on different adsorbents (Arias and Sen, 2009; Benaissa and Elouchdi, 2007; Sen and Khilar, 2006). In principle, the dependence of metal uptake on pH can be associated with both the surface functional groups on the adsorbent as well as the metal chemistry of the solution (Sen and Khilar, 2006). The effect of initial solution pH on the amount of adsorption of Cu(II) ions i.e. mg of copper metal ion per gram of iron oxide or kaolin, q_t (mg/g) is shown in Figures 3 and 4 respectively. It has been found that amount of adsorption increases with solution pH and also with time for both the systems respectively. At the beginning the adsorption was very fast and maximum adsorption at a particular pH takes place within 20 min and ultimately reached equilibrium within 160 min. Such increase in adsorption with pH can be attributed to the favourable change in surface charge and to the extent of hydrolysis of the adsorbing metal ion change with varying pH (Meillis et al., 2004; Sen et al., 2008; Cornel and Schwartzman, 1998). The fast adsorption at the initial stage is probably due to the increased concentration gradient between the adsorbate in solution and adsorbate in adsorbent as there must be increased number of available surface sites in the beginning (Arias and Sen, 2009). Adsorption of heavy metals onto various clay minerals/oxides occurs in two or more stages (Angove et al., 1997; Spark et al., 1993). Figures 3 and 4 also show that copper metal ion adsorption on iron oxide and kaolin occurs more or less in two stages: a very rapid fast reaction followed by decreasing equilibrium plateau. The oxygen atoms present on the oxide/clay surface

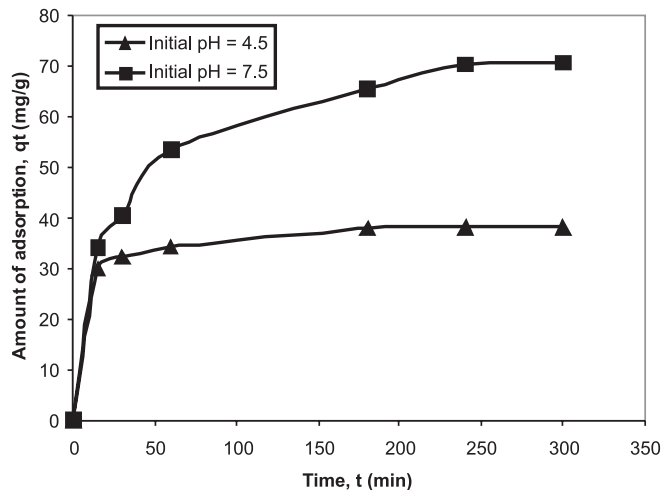


Figure 3: Effect of initial solution pH on Cu(II) adsorption. Initial Cu(II) = 23.6 ppm, amount of iron oxide added = 8 mg, temperature = 28°C, shaker speed = 120 rpm.

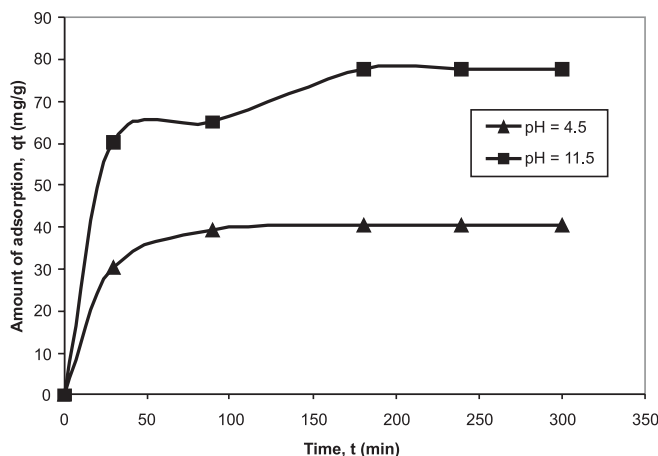
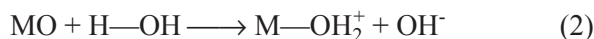
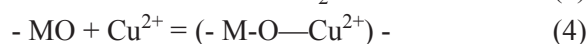
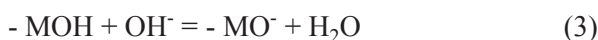


Figure 4: Effect of initial solution pH on Cu(II) adsorption. Initial Cu(II) = 23.6 ppm, amount of kaolin added = 8 mg, temperature = 28°C, shaker speed = 120 rpm.

interact with water in an acidic medium forming some aqua complexes (Sengupta and Bhattacharyya, 2006) which result in positive charge formation as follows:



The surface charge is responsible for preventing Cu(II) ions from approaching the surface and explains the smaller extent of adsorption at low pH (Sengupta and Bhattacharyya, 2006). Basically, at low pH, due to high positive charge density, electrostatic repulsion will be high during uptake of metal ions resulting in lower adsorption. In an alkaline medium, the clay/oxide surface becomes negatively charged favouring Zn^{2+} uptake as per the following:



The above fact is related to the effect of pH on adsorption also supported by many earlier workers (Arias and Sen, 2009; Sengupta and Bhattacharyya, 2006; Sen et al., 2002). Specific adsorption is believed to occur in iron oxide whereas the adsorption on kaolin occurs predominantly on the permanent negatively charged siloxanol sites and less on the variable-charged aluminol sites which are strongly affected by the solution pH (Sen and Ling, 2009).

Effect of Adsorbent Dosage on Metal Ion Kinetics Adsorption

The results of the kinetic experiments with varying adsorbent concentrations for both the systems are presented in Figures 5 and 6 respectively. It has been found that the amount of Cu(II) adsorbed per unit mass

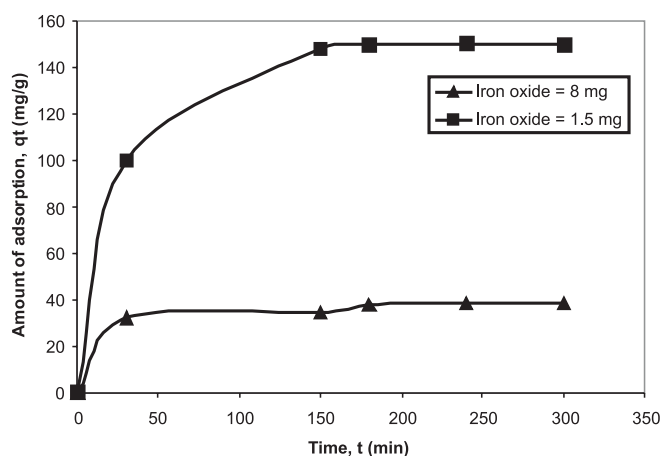


Figure 5: Effect of amount of iron oxide on Cu(II) adsorption. Initial Cu(II) = 23.6 ppm, initial solution pH = 4.5, temperature = 28°C, shaker speed = 120 rpm.

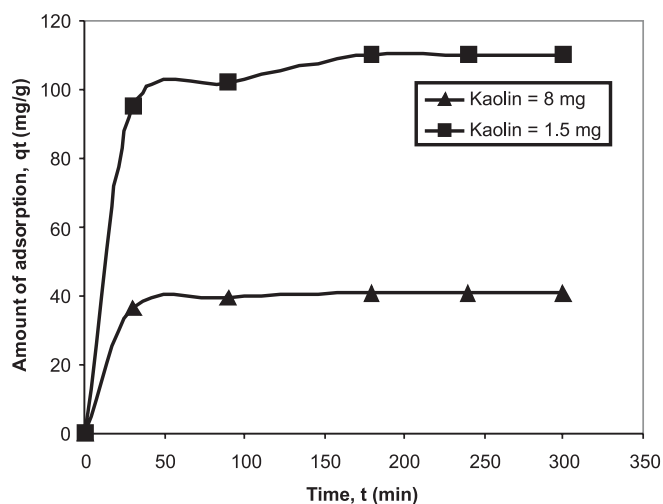


Figure 6: Effect of amount of kaolin on Cu(II) adsorption. Initial Cu(II) = 23.6 ppm, initial solution pH = 4.5, temperature = 28°C, shaker speed = 120 rpm.

of adsorbent decreases as the adsorbent mass increase for both the Cu-iron oxide and Cu-kaolin systems. Several other investigators have also reported the same trend of adsorbent concentration effect on metal ion adsorption which has been mentioned in Arias and Sen (2009) and Sen and Ling (2009) respectively. Although the number of adsorption sites per unit mass of an adsorbent should remain constant, independent of the total adsorbent mass, increasing the adsorbent amount in a fixed volume reduces the number of available sites as the effective surface area is likely to decrease.

Adsorption Kinetic Model

In this study, two most widely used kinetic models—pseudo-first-order and pseudo-second-order—were employed which are described in earlier section. In the pseudo-first-order model, the rate constant k_1 and linear correlation coefficient, R^2 , were determined by plotting $\log(q_e - q_t)$ against time, t which is not shown here with very poor regression coefficient, R^2 of 0.74. Moreover, pseudo-first-order kinetic model predicts a much lower value of the equilibrium adsorption capacity than the experimental value for both systems and hence it gives the inapplicability of this model. Figures 7-10 represent the pseudo-second-order kinetic plots between $1/q_t$ versus time t for copper metal ion adsorption at different initial metal concentrations and also at different solution pH for both the systems respectively but pseudo-second-order plots at different amount of adsorbents are not presented here. It is clearly indicated that the pseudo-second-order kinetic model is fitted very well with very high linear regression coefficient (R^2) for both Cu-iron oxide and Cu-kaolin systems.

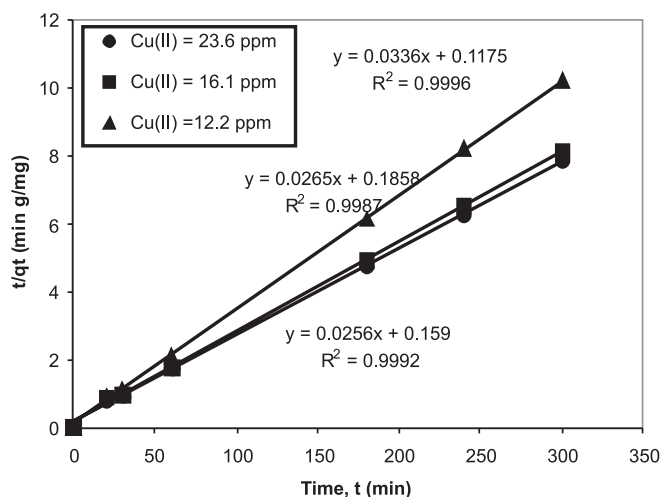


Figure 7: Pseudo-second-order kinetic model for Cu(II) adsorption on iron oxide at different metal ion concentration.

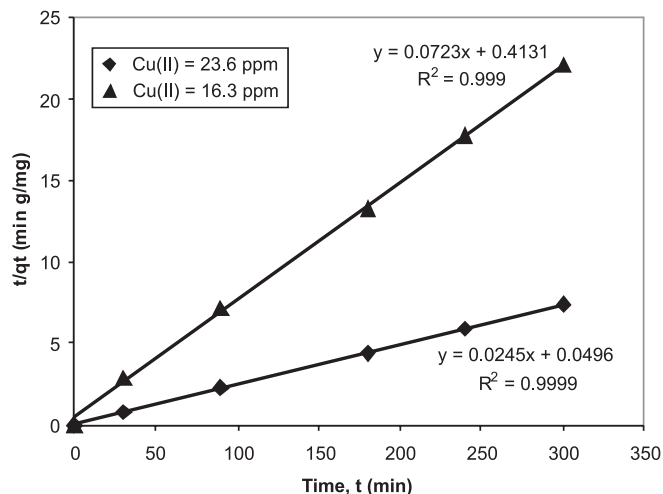


Figure 8: Pseudo-second-order kinetic model for Cu(II) adsorption on kaolin at different metal ion concentration.

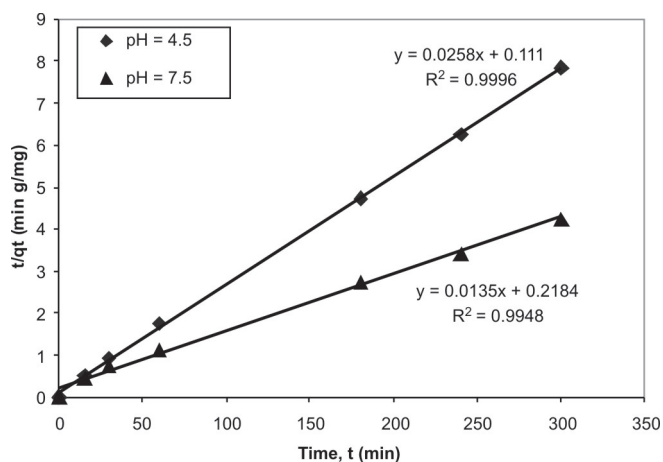


Figure 9: Pseudo-second-order kinetic model for Cu(II) adsorption on iron oxide at different solution pH.

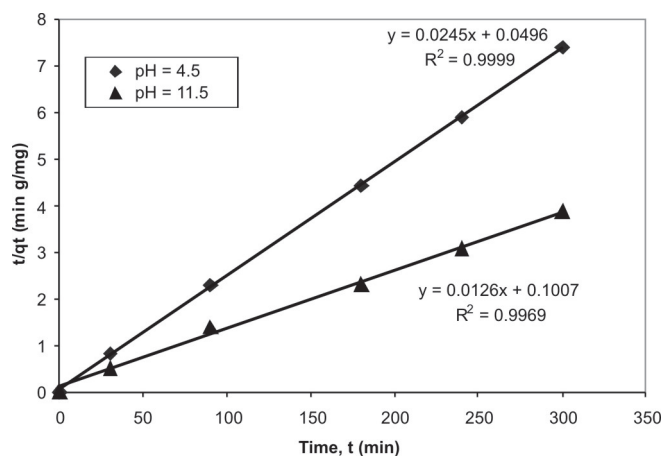


Figure 10: Pseudo-second-order kinetic models for Cu(II) adsorption on kaolin at different solution pH.

The pseudo-second-order rate constant, k_2 , equilibrium sorption capacity, q_e and initial rate constant, h were calculated for both systems from the fitted model equations which are tabulated in Table 1. Higher linear correlation coefficients (R^2) with respect to fitted pseudo-first-order model suggest that adsorption of copper metal ion on iron oxide as well as on kaolin follow pseudo-second-order kinetics. Moreover, all calculated q_e from model fitting are very close to the experimental q_e for all the cases. As for example, calculated q_e for Cu-Fe₂O₃ is 29.7 with initial Cu(II) concentration of 12.2 ppm, whereas experimental q_e value is 29.50 with the same condition. Similarly for Cu-kaolin system, calculated q_e is 13.8 with initial Cu(II) concentration of 16.3, whereas experimental q_e value is 13.54 with the same conditions. Also this suggests the assumption behind the pseudo-second-order model that the metal ion uptake process is due to chemisorptions (Arias and Sen, 2009; Sen and Sarzali, 2008) and more than one step may be involved in sorption processes. It has also been found from Table 1 that adsorption capacity increases with increase in metal ion concentration and within initial solution pH respectively but decreases with adsorbent doses.

Adsorption Equilibrium Isotherm

The adsorption equilibrium data were fitted for Langmuir-1 and Frenundlich isotherms within the metal ion concentration range of 10-30 ppm respectively. Linear regression was frequently used to determine the most fitted isotherm.

The Freundlich adsorption isotherm can be expressed as (Sen and Sarzali, 2008):

$$\ln q_e = \ln K_f + 1/n (\ln C_e) \quad (5)$$

where q_e is the amount of metal ion adsorbed at equilibrium time, and C_e is equilibrium concentration of nickel metal ion in solution. K_f and n are isotherm constants which indicate the capacity and the intensity of the adsorption respectively (Arias and Sen, 2009) and can be calculated from the intercept and slope between $\ln q_e$ and $\ln C_e$ which are shown in Table 2 for both the systems at two different system pH. The Freundlich plots at pH 4.5 are shown in Figure 11 for Cu-Fe₂O₃ and Figure 12 for Cu-kaolin respectively.

Also Langmuir-1 isotherm equation was tested for both the system with this same metal ion concentration range. The linearized form of Langmuir-1 can be written

$$C_e/q_e = (1/K_a q_m) + C_e/q_m \quad (6)$$

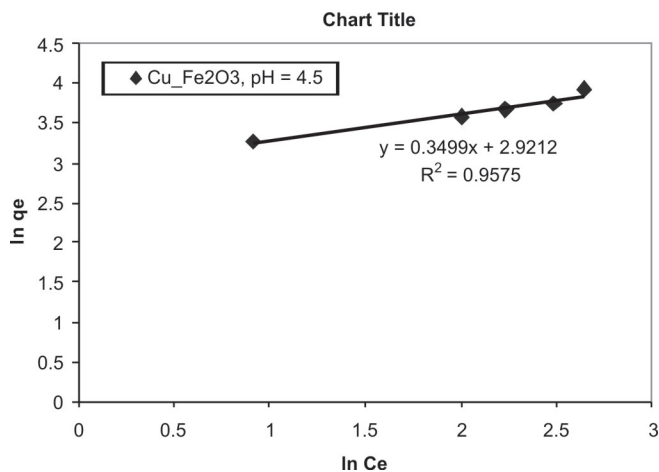
The Langmuir constants, q_m (maximum adsorption capacity) and K_a (values for Langmuir-1) can be obtained from plots between C_e/q_e versus C_e which are shown in Figures 13 and 14 respectively with fixed initial

Table 1: Pseudo-second-order kinetic parameters

| System | System parameters | k_2 (g/mg.min) | q_e (mg/g) | h (mg/ g.min) | R^2 |
|---------------|------------------------------|------------------|--------------|-----------------|-------|
| Cu-Iron oxide | Initial Ni(II) concentration | | | | |
| | 12.2 ppm | 0.0096 | 29.761 | 8.51012 | 0.999 |
| | 16.1 ppm | 0.003777 | 37.735 | 5.3789 | 0.998 |
| | 23.6 ppm | 0.00412 | 39.0625 | 6.2893 | 0.999 |
| | Initial solution pH | | | | |
| | 4.5 | 0.005996 | 38.759 | 9.009 | 0.999 |
| | 7.5 | 0.00083 | 74.074 | 4.5787 | 0.994 |
| | Adsorbent dose | | | | |
| Cu-Kaolin | 1.5 mg | 0.0009368 | 153.846 | 22.17290 | 0.998 |
| | 8 mg | 0.00467 | 38.61 | 6.9637 | 0.996 |
| | Initial Ni(II) concentration | | | | |
| | 16.3 ppm | 0.01265 | 13.8312 | 2.4206 | 0.999 |
| | 23.6 ppm | 0.0121 | 40.816 | 20.1612 | 0.999 |
| | Initial solution pH | | | | |
| | 4.5 | 0.0121 | 40.816 | 20.161 | 0.999 |
| | 7.5 | 0.00157 | 79.365 | 9.930 | 0.996 |
| | Adsorbent dose | | | | |
| | 1.5 mg | 0.00245 | 111.11 | 30.3024 | 0.999 |
| | 8.0 mg | 0.01202 | 40.816 | 20.04 | 0.999 |

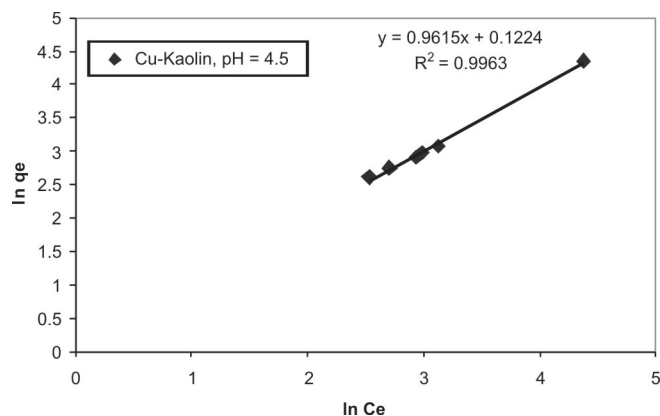
Table 2: Freundlich parameters obtained from Freundlich plots

| Adsorbent | Equation | KF | n | R^2 | System pH |
|--------------------------------|------------------------|--------|--------|--------|-----------|
| Fe ₂ O ₃ | $y = 0.3499x + 2.921$ | 18.563 | 2.8653 | 0.9575 | 4.5 |
| | $y = 0.5783 + 3.388$ | 29.606 | 1.729 | 0.964 | 11.5 |
| Kaolin | $y = 0.9615x + 0.1224$ | 1.1302 | 1.0400 | 0.996 | 4.5 |
| | $y = 0.4594x + 3.59$ | 36.234 | 2.176 | 0.8388 | 11.5 |

**Figure 11: Freundlich adsorption isotherm for Cu-Fe₂O₃ system.**

conditions and at a pH of 4.5. The Langmuir parameters at two different system pH for two different systems are presented in Table 3.

A further analysis of the Langmuir equation can be made on the basis of a dimensionless equilibrium

**Figure 12: Freundlich adsorption isotherm for Cu-kaolin system.**

parameter, R_L , also known as the separation factor, given by (Demiral et al., 2008)

$$R_L = \frac{1}{1 + K_a C_0} \quad (7)$$

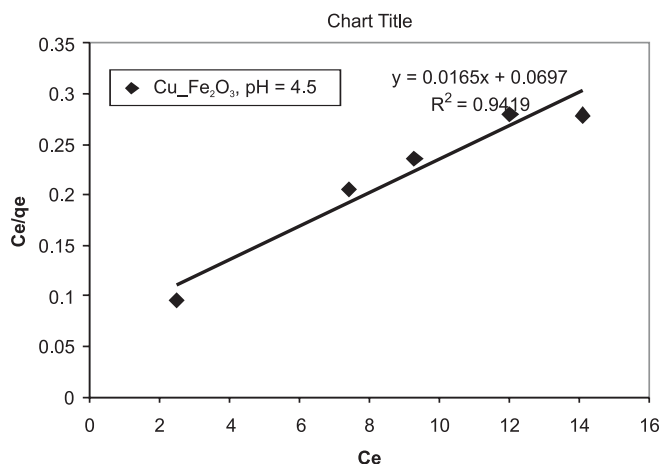


Figure 13: Langmuir adsorption isotherm for Cu-Fe₂O₃ system.

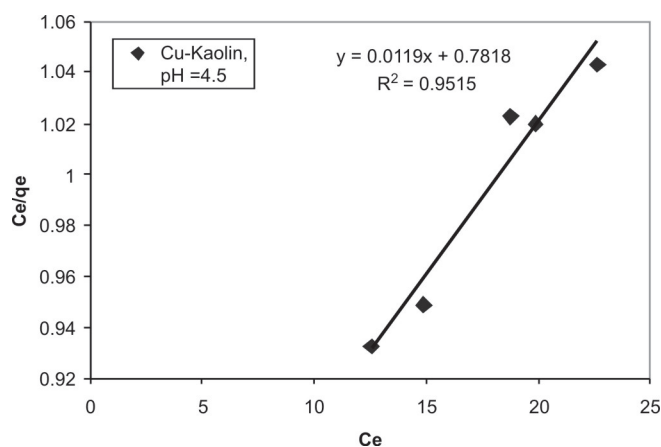


Figure 14: Langmuir adsorption isotherm for Cu-kaolin system.

Table 3: Langmuir adsorption isotherm parameters

| Adsorbent | pH | q_m (mg/g) | K_a | R^2 |
|--------------------------------|------|--------------|---------|-------|
| Fe ₂ O ₃ | 0.5 | 60.606 | 0.2367 | 0.941 |
| | 11.5 | 128.205 | 0.27464 | 0.938 |
| Kaolin | 4.5 | 84.0336 | 0.0152 | 0.951 |
| | 11.5 | 108.695 | 0.4554 | 0.962 |

where K_a is the Langmuir constant and C_0 is the initial metal ion concentration (mg/L). If the average of the R_L values for each of the different initial concentrations used is between 0 and 1, it indicates favourable adsorption (Demiral et al., 2008). Here the separation factor lies between 0 and 1 at all metal ion concentration range for both the systems respectively.

Conclusions

- The adsorption characteristics of copper metal ion Cu(II) are strongly affected by initial solution pH, initial metal ion concentration, amount and type of adsorbent respectively.
- Kinetic experiments clearly indicate that adsorption of copper metal ion on both iron-oxide and kaolin is a two steps processes: a rapid adsorption of metal ion followed by intraparticle diffusion. Overall the kinetics studies showed that the copper metal ion adsorption followed pseudo-second-order kinetics for both Cu-iron oxide and Cu-kaolin systems and the different kinetic parameters are determined at different initial metal ion concentration, pH, amount of adsorbent and type of adsorbent respectively.
- Langmuir and Freundlich equations both are applicable to describe the adsorption of Cu(II) by iron

oxide and kaolin within these small initial metal ion concentration range. The Langmuir equation and Freundlich model described the isotherm Cu(II) sorption with high linear correlation coefficient ($R^2 > 0.92$) for both the systems. The constant value, R_L (low separation factor) in Langmuir isotherm and “ n ” (rate of adsorption) of Freundlich isotherm give an indication of favourable adsorption at different pH for both the systems respectively.

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Asian Journal of Water, Environment and Pollution



Aims and Scope

Asia, as a whole region, faces severe stress on water availability, primarily due to high population density. Many regions of the continent face severe problems of water pollution on local as well as regional scale and these have to be tackled with a pan-Asian approach. However, the available literature on the subject is generally based on research done in Europe and North America. Therefore, there is an urgent and strong need for an Asian journal with its focus on the region and wherein the region specific problems are addressed in an intelligent manner. In Asia, besides water, there are several other issues related to environment, such as; global warming and its impact; intense land/use and shifting pattern of agriculture; issues related to fertilizer applications and pesticide residues in soil and water; and solid and liquid waste management particularly in industrial and urban areas.

Asia is also a region with intense mining activities whereby serious environmental problems related to land/use, loss of top soil, water pollution and acid mine drainage are faced by various communities.

Essentially, Asians are confronted with environmental problems on many fronts. Many pressing issues in the region interlink various aspects of environmental problems faced by population in this densely habited region in the world. Pollution is one such serious issue for many countries since there are many transnational water bodies that spread the pollutants across the entire region. Water, environment and pollution together constitute a three axial problem that all concerned people in the region would like to focus on.

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