CuO nanopowder for removal of Pb(II) and Zn(II)

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Metal oxide nanopowder, namely copper oxide nanopowder, was prepared. The produced metal oxide was characterised and used as a potential adsorbent for removal of lead(II) and zinc(II) from an aqueous solution. The rate of uptake of lead(II) and zinc(II) was found to be rapid in the first 10 min, and after 150 min, the amount of lead(II) and zinc(II) adsorbed was almost constant. The time of equilibrium is independent of initial concentration. The results showed that the removal of lead(II) increased significantly as the pH increased from 2.0 to 6.0 and approached a plateau at a pH range of 6.0–9.0, whereas the removal of zinc(II) increased significantly as the pH increased from 2.0 to 9.0. The adsorption of lead(II) and zinc(II) onto copper oxide followed the Langmuir isotherm. The pseudo-second-order kinetic model provided good correlation for the adsorption of both lead(II) and zinc(II).

Notation

b	Langmuir constant (L/mg)
C_e	concentration of heavy metal at equilibrium (mg/L)
C_i	initial heavy metal concentration (mg/L)
K	Dubinin–Radushkevich isotherm constant (mol^2/kJ^2) related to the adsorption energy
K_F and $1/n$	Freundlich constants related to adsorption capacity and intensity of adsorption, respectively
K_1	rate constant for pseudo-first-order reaction (min^{-1})
K_2	rate constant for pseudo-second-order reaction (g/mg min)
Q^0	maximum metal ion uptake per unit mass of adsorbent (mg/g)
q_e	amount of metal adsorbed per gram of the adsorbent at equilibrium (mg/g)
q_m	theoretical isotherm saturation capacity (mg/g)
q_t	amount of metal adsorbed per gram of the adsorbent at time t (mg/g)
R_L	separation factor
t	time (min)
V	solution volume (L)
Wt	adsorbent dosage (g)
ε	Polanyi potential

Introduction

The removal of hazardous heavy metals from wastewater has received much attention in recent years. Heavy metals are toxic and non-degradable and tend to accumulate in living organisms, causing various diseases and disorders (Jang *et al.*, 2008). Many industries such as metal finishing, electroplating, plastics, pigments and mining contain several heavy metals. Lead(II) and zinc(II) are among the most common heavy metals in these industries. Lead(II) is classified as one of the most toxic and carcinogenic

heavy metals and has been recorded by the US Environmental Protection Agency (EPA) as a priority issue (Perez-Quintanilla *et al.*, 2006). Zinc(II) has given rise to serious poisoning cases, and it therefore appears on the list of priority pollutants proposed by the EPA. The main symptoms of zinc(II) poisoning are dehydration, electrolyte imbalance, stomach ache, nausea, dizziness and lack of coordination in muscles (Jain *et al.*, 2004). Several techniques have been used to remove lead(II) and zinc(II) from wastewater, including precipitation (Kavak, 2013; Ku and Chen, 1990), ion exchange (Abdelwahab *et al.*, 2013; Ngah and Fatinathan, 2010), membrane filtration (Borbély and Nagy, 2009; Liu *et al.*, 2013) and bio-friendly polymer-based adsorption strategy (Alluri *et al.*, 2007). Several inorganic and organic adsorbents have been proposed for the adsorption of lead and zinc, including zeolites (Perić *et al.*, 2004), clay minerals (Ni *et al.*, 2009), calcium phosphates (Lyczko *et al.*, 2014) and activated carbon (Cetin and Pehlivan, 2007). Recently, increasing attention has been focused on the synthesis, characterisation and application of the uniform meso-porous materials exemplified by metal oxides as adsorbents, such as iron oxide (Dixit and Hering, 2003; Raven *et al.*, 1998; Van Benschoten *et al.*, 1994), aluminium oxide (Coston *et al.*, 1995; Lin and Wu, 2001; Patra *et al.*, 2012), titanium oxide (Jegadeesan *et al.*, 2010; Pena *et al.*, 2005; Xu *et al.*, 2010), manganese oxide (Agrawal and Sahu, 2006; Lafferty *et al.*, 2010), zirconium oxide (Hang *et al.*, 2012; Hristovski *et al.*, 2008) and copper oxide (Kumar *et al.*, 2014). In fact, hierarchical porous metal oxides such as copper oxide, iron oxide, aluminium oxide, titanium dioxide and others have attracted attention in adsorption applications pertaining to the uptake of toxic and heavy metals. This interest in metal oxides may often be attributed to their regular pore structures, enhanced surface areas and controlled organisation of primary building units of various dimensions

into ordered nanostructures and super-structures (El-Sayed, 2001; Henglein, 1989). In this regard, copper oxide nanopowder appears an interesting and promising transition metal oxide adsorbent, ostensibly due to its extensive applications in catalysis (Wei *et al.*, 1996), lithium-ion batteries (Pang *et al.*, 2012), super capacitors (Patake *et al.*, 2009) and gas sensors (Rydosz, 2013). Besides metal oxide nanopowder adsorbents, carbon-based materials have attracted attention because of their inertness to the surrounding environment, mechanical stability and highly porous structure with specific surface chemical properties (Ademiluyi and David-West, 2012). However, some of these carbon-based materials have manifested limited efficiency as an adsorbent for specific applications such as the uptake of toxic and heavy metals due to their irregular and micron-size morphology. On a related note, several chelating agents such as ethylene diamine tetraacetate and oxine (8-hydroxy quinoline) have been immobilised on activated carbon for efficient uptake of heavy metals from aqueous phases even at trace concentration levels (Ravindran *et al.*, 1999). The overall heterostructures of the metal oxides can be superior to carbon-based materials as adsorbents for toxic heavy metals since they provide desirable mechanical properties, such as robustness, facile transportation and easy recovery and regeneration, resulting in excellent adsorption capacities for heavy metal removal from contaminated water (Hu *et al.*, 2008).

The objective of this study was to investigate the feasibility of lead(II) and zinc(II) removal from aqueous solution by copper oxide nanopowder prepared from copper nitrate trihydrate by reduction with potassium hydroxide. The kinetics of the process were determined, especially in relation to the effects of various factors on the removal. The factors investigated included different lead(II) and zinc(II) concentrations, contact time, adsorbent dosage and initial pH of the solution.

Material and methods

Materials

All chemicals used in the experiment are of analytic reagent grade. Copper nitrate trihydrate, di-ethylene glycol, potassium hydroxide, lead nitrate, $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ and distilled water were used throughout the experiment.

Preparation of copper oxide

Copper nitrate trihydrate (0.1 M, 3.6 g) was dissolved in 300 mL deionised water in a round-bottom flask, and then 30 mL of di-ethylene glycol was poured into the solution. After di-ethylene glycol uniformly dispersed in the solution, potassium hydroxide (0.2 M) was added. The solution was vigorously stirred for 3 h, then the mixture was placed in the microwave reflux system and the reaction was carried out under ambient air for 15 min. After the reaction was completed, a great amount of dark brown precipitate occurred. After cooling to room temperature, all precipitate was filtered and repeatedly washed with deionised water and ethanol and finally dried at 80°C for 10 h.

Batch experiments

A stock solution of lead nitrate (1000 mg/L) was prepared by dissolving 1.6 g of 99% lead nitrate in 1 L of distilled water, whereas 1000 mg/L of zinc sulfate stock solution was prepared by dissolving 4.397 g of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ in 1-L distilled water.

Equilibrium isotherms for lead and zinc were obtained by performing batch adsorption studies. Solutions of 250 mg/L concentration were adjusted to optimum pH values, and adsorbent amounts ranging between 0.1 and 1 g were added to the solutions.

The adsorbed heavy metal amount (q) per unit adsorbent mass was calculated as follows:

$$1. \quad q = \frac{(C_i - C_e)}{Wt} V$$

where C_i is the initial heavy metal concentration (mg/L), C_e is the concentration of heavy metal at equilibrium (mg/L), Wt is the adsorbent dosage (g) and V is the solution volume (L).

Characterisation of adsorbents

Measurement of nanoparticle size

The method depends on measuring the rate of fluctuations in laser light intensity scattered by particles that they diffuse through a fluid (Kaszuba *et al.*, 2008). The powder sample was put in water and was then ultrasonicated for 15 min until good dispersion was produced, and then the sample was measured by a submicron particle size analyser (Beckman Coulter, Miami, USA).

Scanning electron microscopic examination for nanoparticles

In order to know the structure of the adsorbent, scanning electron microscopy (SEM) was employed to visualise sample morphology using a JEOL JSM-5300 scanning electron microscope operated between 15 and 20 keV.

Fourier transform infrared (FTIR) spectroscopy analysis

The surface functional groups and structure were studied by FTIR spectroscopy. The FTIR spectra of the adsorbent were recorded between 500 and 4000 cm^{-1} in FTIR-8,400 S Shimadzu.

Results and discussion

Characterisation of adsorbent

Morphology and particle size

In order to understand the morphology of the adsorbent, SEM analyses of copper oxide nanopowder were carried out. An SEM image with a magnification factor 3500 is presented in Figure 1, which shows the rectangular morphology with high surface roughness of the particles. All the particles are regularly arranged and form a flake-like structure. The increase in surface roughness leads to an increase in the surface area of the adsorbent. The particle

Figure 1. SEM for copper oxide nanopowder

size distribution for nanoparticles is found to be 33–160 nm and the surface area is 220 m²/g.

FTIR for copper oxide nanopowder

The FTIR analysis permits spectrophotometric observation of copper oxide nanopowder in the range 400–4000 cm⁻¹ and serves as a direct means for the identification of the functional groups on the surface. Figure 2 shows the FTIR of copper oxide nanopowders at room temperature. The characteristic peaks of copper oxide were positioned from 984 to 426 cm⁻¹. The peaks at 521 and 603 cm⁻¹ indicated the formation of copper oxide nanostructure and the vibration and stretching of copper–oxygen along the [202] direction (Dar *et al.*, 2010), respectively. The bands at 803 and 1021 cm⁻¹ are due to the Cu–OH deformation. The peak at 1458 cm⁻¹ is evidence of (N–O) tremble. The band at 1639 cm⁻¹ represents the H–O–H bending. The IR peak at 3436 cm⁻¹ represents the OH stretching band of water.

Effect of contact time

The contact time affected the extent of adsorption of lead(II) and zinc(II) on copper oxide nanopowder as adsorbents. The effect of contact time on the adsorption of lead(II) and zinc(II) is presented in Figures 3 and 4, respectively. Uptake of lead(II) and zinc(II) was found to be rapid in the first 10 min, and after 120 min, the amount of lead(II) and zinc(II) adsorbed was almost constant. The initial rapid phase may be due to the increased number of vacant sites available at the initial stage. Later, the process becomes relatively slower, and equilibrium conditions are reached within 120 to 150 min.

Figures 3 and 4 showed that zinc(II) had a significantly higher affinity to copper oxide nanopowder than lead(II) ion. The effect of concentration on the equilibration time was also investigated as a function of initial lead(II) and zinc(II) concentrations. It was found that the time required to achieve a definite fraction of equilibrium adsorption is independent of the initial concentration.

Figure 2. FTIR for copper oxide nanopowder

Figure 3. The effect of contact time on the adsorption capacity of copper oxide nanopowder for lead(II) at different concentrations; pH is 5, adsorbent dosage is 2 g/L and temperature is 25°C

Figure 4. The effect of contact time on the adsorption capacity of copper oxide nanopowder of zinc(II) at different concentrations; pH is 5, adsorbent dosage is 2 g/L and temperature is 25°C

Effect of pH

The pH of the solution is one of the most important parameters controlling the uptake of heavy metals from aqueous solutions. Figure 5 shows that the removal of lead(II) increased significantly as the pH increased from 2.0 to 6.0 and approached a plateau at a pH range of 6.0–8.0. The removal percentage reached 55% of lead(II) on copper oxide nanopowder at pH 6.0. To avoid precipitation, studies were not performed at pH > 8. On the other hand, the removal of zinc(II) increased significantly as the pH increased from 2.0 to 7.0, and then decreased while the pH reached 8. At a low-pH region, the low lead(II) and zinc(II) uptake is due to reduced availability of free lead(II) and zinc(II) ions, whereas the slight reduction at high pH may result from competitive interaction with hydroxyl ions and electrostatic repulsion between some active sites and lead(II) or zinc(II) (Kumar *et al.*, 2014).

Figure 5. Effect of pH on % removal of lead(II) and zinc(II) using copper oxide nanopowder as an adsorbent (initial concentration of 100 mg/L, adsorbent dosage 2 g/L and temperature 25°C at 1 h)

Effect of weight of adsorbent

The results of the experiments with varying adsorbent dosage are presented in Figure 6. The results reveal that with an increase in the adsorbent dosage from 0.8 to 4.5 g/L, the removal of lead(II) increased from 60% to 90%, whereas the removal of zinc(II) increased from 35% to 90%. This can be explained by the fact that the greater the available mass, the greater the contact surface that is offered to the adsorption. These results are qualitatively in good agreement with those found in the literature (El-Sayed *et al.*, 2011).

Equilibrium study

Langmuir's isotherm model

The well-known Langmuir's isotherm model (Langmuir, 1918) suggests that the uptake occurs on a homogeneous surface by monolayer sorption without interaction between adsorbed ions and

Figure 6. Effect of adsorbent dosage on % removal of lead(II) and zinc(II) using copper oxide nanopowder as an adsorbent (initial concentration of 100 mg/L, pH = 6 and temperature is 25°C at 1 h)

assumes that no further adsorption occurs. The linear form of the Langmuir isotherm equation is represented by

$$2. \quad \frac{C_e}{q_e} = \frac{1}{Q^0 b} + \frac{1}{Q^0} C_e$$

where Q^0 is the maximum metal ion uptake per unit mass of adsorbent (mg/g) related to adsorption capacity, b is the Langmuir constant (L/mg) related to energy of sorption, C_e is the equilibrium concentration of adsorbate (mg/L) and q_e is the amount of metal adsorbed per gram of the adsorbent at equilibrium (mg/g). A plot of C_e/q_e against C_e gives a straight line of slope $1/Q^0$ and intercept $1/(Q^0 b)$. The essential features of the Langmuir isotherm may be expressed in terms of the equilibrium parameter R_L , which is a dimensionless constant referred to as the separation factor or the equilibrium parameter (Webber and Chakravarti, 1974):

$$3. \quad R_L = \frac{1}{(1 + bC_i)}$$

where C_i is the initial concentration (mg/L), and b is the constant related to the energy of adsorption (Langmuir constant). The R_L value indicates the adsorption nature to be either unfavourable if $R_L > 1$, linear if $R_L = 1$, favourable if $0 < R_L < 1$ or irreversible if $R_L = 0$. From the data calculated in Table 1, R_L is greater than 0 but less than 1 for both lead and zinc adsorption indicating that the Langmuir isotherm is favourable. From this research work, the maximum monolayer coverage capacity (Q_0) from the Langmuir isotherm model was determined to be 14.859 mg/g, b (Langmuir isotherm constant) was 0.131 L/mg and R_L (the separation factor) was 0.071 for lead, whereas the maximum monolayer coverage capacity (Q_0) from the Langmuir isotherm model was determined to be 44.248 mg/g, b (Langmuir isotherm constant) was 0.059 L/mg and R_L (the separation factor) was 0.145 for zinc. The results indicate that the equilibrium sorption was favourable and the R^2 value is 0.99 proving that the sorption data fitted well to the Langmuir isotherm model.

Freundlich's isotherm model

The Freundlich isotherm describes the adsorption equation for non-ideal adsorption that involves heterogeneous adsorption. The expression for the Freundlich isotherm model was given as (Freundlich, 1907):

$$4. \quad q_e = K_F C_e^{1/n}$$

The equation is conveniently used in the linear form by taking the logarithm of both sides as

$$5. \quad \log q_e = \log K_F + \frac{1}{n} \log C_e$$

Isotherm model	Removal of lead(II)	Removal of zinc(II)
Langmuir		
q_m : mg/g	14.859	44.248
b : L/mg	0.131	0.059
R_L	0.071	0.145
No. of parameters	4	2
Data point available	0.995	4
R^2		0.998
Freundlich		
$1/n$	0.163	0.291
K_F : mg/g	6.565	9.884
No. of parameters	2	2
Data point available	4	4
R^2	0.9731	0.993
Dubinin–Radushkevich		
q_m : mg/g	36.613	12.89
K : mol ² /KJ ²	2×10^{-3}	4×10^{-3}
E	15.8	11.18
No. of parameters	2	2
Data point available	4	4
R^2	0.955	0.759

Table 1. Langmuir, Freundlich and Dubinin–Radushkevich models for the removal of lead(II) and zinc(II) onto copper oxide nanopowder

where the Freundlich constants, K_F and $1/n$, are related to adsorption capacity and intensity of adsorption, respectively. The values of n and K_F can be calculated from the slope and intercept of the plot of $\log q_e$ against $\log C_e$ derived from Equation 5. If the value of $1/n$ is below 1, it indicates a normal adsorption. On the other hand, a value above 1 for $1/n$ indicates co-operative adsorption (Mohan and Karthikeyan, 1997). From the data in Table 1, $1/n = 0.163$ for lead and 0.291 for zinc. The results indicate that the sorption of lead and zinc onto copper oxide is favourable, and the R^2 value is 0.97 for lead adsorption and 0.99 for zinc adsorption.

Dubinin–Radushkevich isotherm

The Dubinin–Radushkevich isotherm is generally applied to sorption mechanisms with a Gaussian energy distribution onto a heterogeneous surface, and it distinguishes between physical and chemical sorption mechanisms. In order to understand the adsorption type, equilibrium data were tested with the Dubinin–Radushkevich isotherm (Dubinin, 1960).

The linearised D-R equation can be written as

$$6. \quad \ln q_e = \ln q_m - K\varepsilon^2$$

where q_e is the amount of adsorbate in the adsorbent at equilibrium (mg/g), q_m is the theoretical isotherm saturation capacity (mg/g), K is the Dubinin–Radushkevich isotherm constant (mol²/kJ²) related

to the adsorption energy and ε is the Polanyi potential calculated from

$$7. \quad \varepsilon = RT \ln \left(1 + \frac{1}{C_e} \right)$$

The slope of the plot of $\ln q_e$ vs. ε^2 gives K (mol^2/kJ^2) and the intercept yields the adsorption capacity q_m (mg/g). Radushkevich (1949) and Dubinin (1965) have reported that the characteristic sorption curve is related to the porous structure of the sorbent. The constant, B_D , is related to the mean free energy of sorption per mole of the sorbate as it is transferred to the surface of the solid from an infinite distance in the solution, and this energy can be computed using the following relationship (Hasany and Chaudhary, 1996):

$$8. \quad E = \frac{1}{\sqrt{2k}}$$

The magnitude of E is useful for estimating the mechanism of the adsorption reaction. In the case of $E < 8 \text{ kJ/mol}$, physical forces may affect the adsorption. If ε is in the range of 8–16 kJ/mol, adsorption is governed by ion exchange mechanism, while for the values of $E > 16 \text{ kJ/mol}$, adsorption may be dominated by particle diffusion (Gubbuk, 2011). From the data in Table 1, the mean free energy $E = 15.8$ and 11.18 kJ/mol for lead(II) and zinc(II), respectively, which suggests that the adsorption of lead(II) occurs through ion exchange mechanism.

Comparisons of maximum adsorption capacities for lead(II) and zinc(II) ions by different adsorbents are shown in Table 2. The results show that copper oxide nanopowder has high adsorption capacity for both zinc(II) and lead(II).

Kinetic models applied to the adsorption of lead(II) and zinc(II) onto copper oxide nanopowder

Pseudo-first-order equation

The adsorption kinetic data were described by the Lagergren pseudo-first-order model (Lagergren, 1898), which is the earliest

known equation describing the adsorption rate based on the adsorption capacity. The linear form equation is generally expressed as

$$9. \quad \log(q_e - q_t) = \log q_e - \frac{K_1}{2.303} t$$

In order to obtain the rate constants, the values of $\log(q_e - q_t)$ were linearly correlated with t by the plot of $\log(q_e - q_t)$ against t to give a linear relationship from which K_1 and predicted q_e can be determined from the slope and intercept of the plot, respectively.

The variation in rate should be proportional to the first power of concentration for strict surface adsorption. However, the relationship between initial solute concentration and rate of adsorption will not be linear when pore diffusion limits the adsorption process.

Pseudo-second-order equation

The adsorption kinetic may be described by the pseudo-second-order model. The linear equation is generally given as

$$10. \quad \frac{t}{q_t} = \frac{1}{K_2} \frac{1}{q_e^2} + \frac{1}{q_e} t$$

If the second-order kinetics are applicable, then the plot of t/q_t against t should show a linear relationship. Values of K_2 and equilibrium adsorption capacity q_e were calculated from the intercept and the slope of the plots of t/q_t against t . The correlation coefficients for the pseudo-second-order kinetic model are greater than 0.90 (Table 3), which suggests that the pseudo-second-order kinetic model provides good correlation for the adsorption of lead(II) and zinc(II) onto copper oxide nanopowder. A good agreement can be further supported by the almost similar calculated and experimental values of q_e . The consistency of the experimental data with the pseudo-second-order kinetic model indicates that

Adsorbents	Surface area: m ² /g	Concentration: ppm	q _{max} : mg/g		References
			Lead	Zinc	
Activated carbon	655.44	100	6.68	11.24	Misra and Patel, 2009
Kaolin	19.43	100	4.5	3.05	Misra and Patel, 2009
Bentonite	62.69	100	7.65	9.12	Misra and Patel, 2009
Blast furnace slag	0.70	100	5.52	3.25	Misra and Patel, 2009
Fly ash	0.75	100	4.89	5.82	Misra and Patel, 2009
Copper oxide nanopowder	220	100	14.859	44.248	Present work

Table 2. A comparison of maximum adsorption capacities for lead and zinc ions by different adsorbents

Kinetics models	Lead(II) on copper oxide	Zinc(II) on copper oxide
Pseudo-first-order kinetics		
$K_1: \text{min}^{-1}$	0.016	0.008
$q_1: \text{mg/g}$	23.71	5.633
R_1^2	0.854	0.201
Pseudo-second-order kinetics		
$K_2: \text{g/mg min}$	0.0009	0.0123
$q_2: \text{mg/g}$	42.523	11.198
R_2^2	0.924	0.962

Table 3. Kinetic parameters for the adsorption of zinc(II) and lead(II) onto copper oxide nanopowders

the adsorption of lead(II) onto copper oxide is controlled by chemical adsorption involving valence forces through sharing or exchange of electrons between sorbent and sorbate (Kumar *et al.*, 2014).

Since the adsorption step is very rapid, it is assumed that it does not influence the overall kinetics. The overall rate of the adsorption process therefore will be controlled by either surface diffusion or intraparticle diffusion.

The intraparticle diffusion model is expressed by

$$11. \quad q_t = k_{ip}t^{0.5} + C$$

where q_t is the adsorption capacity at any time (t), k_{ip} is the intraparticle diffusion rate constant ($\text{mg/g/min}^{1/2}$) and C (mg/g) is a constant proportional to the thickness of the boundary layer. Plotting q_t against $t^{0.5}$, a 'Weber–Morris plot' can give an indication of the dependency of adsorption on the intraparticle diffusion.

Figure 7. Weber–Morris plots for adsorption of lead(II) on copper oxide nanoparticle

Figure 8. Weber–Morris plots for adsorption of zinc(II) on copper oxide nanoparticle

Figures 7 and 8 show that all plots seem to be non-linear for the whole sorption period, suggesting that the intraparticle diffusion is not the rate-limiting step for the whole process. The data can be better represented by three linear steps with different slopes. The first sharper portion was attributed to the diffusion of lead(II) and zinc(II) through the solution to the external surface of the adsorbent. The second portion described the gradual adsorption stage, where intraparticle diffusion was rate limiting. The third portion was attributed to the final equilibrium stage for which the intraparticle diffusion started to slow down due to the extremely low concentration left in the solution.

Conclusion

Metal oxide nanopowder, namely copper oxide nanopowder, was prepared. The produced metal oxide was characterised and used as a potential adsorbent for the removal of lead and zinc from aqueous solution. The rate of uptake of lead(II) and zinc(II) is rapid in the beginning, and the time required for equilibrium adsorption is found to be 120 min. The results showed that copper oxide nanopowder has higher adsorption capacity for zinc(II) than for lead(II). The time of equilibrium was found to be independent of initial concentration. The removal of lead(II) was found to be increased significantly as the pH increased from 2.0 to 6.0 and approached a plateau at a pH range of 6.0–9.0. On the other hand, the removal of zinc(II) increased significantly as the pH increased from 2.0 to 8.0. The adsorption of lead(II) and zinc(II) onto copper oxide nanopowder followed the Langmuir isotherm. The pseudo-second-order kinetic model provided good correlation for the adsorption of lead(II) and zinc(II) onto copper oxide nanopowder. The intraparticle diffusion model suggested that the initial adsorption rate controlled by the film diffusion was followed by pore diffusion. The study revealed that copper oxide nanopowder can be a promising adsorbent for the removal of lead(II) and zinc(II) from wastewater.

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