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Adsorption characteristics of Cu(II) onto ion exchange resins 252H and 1500H: Kinetics, isotherms and error analysis

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Abstract

The adsorption of Copper(II) onto Amberjet 1500H and Ambersep 252H synthetic ion exchange resins have been studied. All the studies were conducted by a batch method to determine equilibrium and kinetic studies at the solution pH of 5.8 in the concentration ranges from 10 to 20 mg/L. The experimental isotherm data were analyzed using the Freundlich, Langmuir, Redlich Perterson, Temkin, Dubinin-Radushkevich equations. Correlation co-efficient was determined for each isotherm analysis. Error functions have been used to determine the alternative single component parameters by non-linear regression due to the bias in using the correlation coefficient resulting from linearisation. From the error analysis the EABS error function provides the best parameters for the isotherm equation in this system. Adsorption kinetics data were tested using pseudo-first-order, pseudo-second-order and intraparticle diffusion models. Kinetic studies showed that the adsorption followed a pseudo-second-order reaction. The initial sorption rate, pseudo-first-order, pseudo-second-order and intraparticle diffusion rate constants for different initial concentrations were evaluated and discussed.

Keywords: Adsorption; Ion exchange resins; Copper(II); Isotherms; Error analysis; Diffusion and kinetics

1. Introduction

The problem of removing pollutants from water and wastewater is an important process and is becoming more important with the increasing of industrial activities. In order to solve heavy metal pollution in ecosystem, it is important to bring applicable solutions to the subject. It is possible to clean polluted environment only with long study requiring expensive and complex plants. Therefore, it is important to take effective precautions to prevent water, soil and air pollutions. Copper is present in the wastewater of several industries, such as metal cleaning and plating baths, refineries, paper and pulp, fertilizer, and wood preservatives and it is highly toxic [1]. The excessive intake of copper by man leads to severe mucosal irritation, widespread capillary damage, hepatic and renal damage, central nervous problems followed by depression, gastrointestinal irritation, and possible necrotic changes in the liver and kidney [1]. The World Health Organization (WHO) recommended a maximum acceptable concentration of Cu(II) in drinking water of 1.5 mg/L [2]. Table 1 summarizes copper standards in current EPA regulations [3]. Therefore it is essential that potable waters be given some treatment to remove copper before domestic supply. There are many different methods for treating wastewaters. Current methods for wastewater treatment include precipitation, coagulation/flotation, sedimentation, flotation, filtration, membrane processes, electrochemical techniques, biological process, chemical reactions, adsorption and ion exchange. But the selection of the wastewater treatment method is based on the concentration of waste and the cost of treatment. Adsorption with ion exchange resin is one of the popular methods for the removal of heavy metals from the water and wastewater [4,5].

Ion exchange resins have been developed as a major option for treating wastewaters over the past few decades [6–8]. Selective resins reduce the residual concentration of heavy metal to below the maximum limits [9–12]. The influence of complex

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Nomenclature

a_R	constant of Redlich–Peterson isotherm (L/mg)
A	Temkin isotherm constant related to adsorbate/adsorbate interaction (L/g)
b	Langmuir constant (L/mg)
B	Temkin isotherm constant
C_e	equilibrium adsorbate concentration (mg/L)
C_t	solution phase adsorbate concentration at time t (mg/L)
C_0	initial concentration of adsorbate (mg/L)
E	Dubinin–Radushkevich isotherm constant
k_1	rate constant of pseudo-first-order adsorption model (h^{-1})
k_2	rate constant of pseudo-second-order adsorption model (g/mg h)
K_F	Freundlich constant (mg/g)
k_{id}	intraparticle diffusion rate constant (mg/g $h^{1/2}$)
K_R	constant in Redlich–Peterson isotherm (L/g)
M	mass of the adsorbent (g)
n	Freundlich isotherm constant related to adsorption intensity
N	number of data points
q_e	equilibrium adsorption uptake concentration (mg/g)
$q_{e,cal}$	calculated value of adsorbate concentration at equilibrium (mg/g)
$q_{e,exp}$	experimental value of adsorbate concentration at equilibrium (mg/g)
q_{max}	maximum adsorption capacity of adsorbent (mg/g)
q_s	Dubinin–Radushkevich isotherm constant related to adsorption capacity (mg/g)
q_t	amount of adsorbate adsorbed by adsorbent at time t (mg/g)
Q^0	Langmuir constant (mg/g)
R	universal gas constant (8.314 J/mol K)
R^2	correlation coefficient
T	absolute temperature (K)
t	time (h)
V	volume of the solution (L)

Greek letter

β	constant of Redlich–Peterson isotherm ($0 < \beta < 1$)

formation on ion exchange sorption equilibrium and on the distribution of metal ions between the liquid and resin phase has been extensively studied [13–16]. Many studies on the adsorption of metal ions on ion exchange resins such as IR-120, Dowex A-1, Duolite GT-73 [17], IRN77 [18], and NKA-9 [5] have been reported.

The present work is aimed at evaluating the kinetics, isotherm, error analysis and diffusion parameters for the adsorption of Cu(II) onto 252H and 1500H ion exchange resins for the adsorption process. The effect of various system parameters such as initial concentration, time, pH and resin dosage are studied and the results obtained are discussed.

Table 1
EPA copper discharge limits

EPA regulation	Limit
Toxic Release Inventory (TRI)	1 mg/L
Clean Water Act (CWA) (daily)	3.39 mg/L
Clean Water Act (CWA) (30-day average)	2.07 mg/L
Safe Drinking Water Act (SDWA)	1.3 mg/L
Superfund Amendments and Reauthorization Act (SARA)	4.5 kg/year

2. Experimental

2.1. Adsorbate

All the reagents used were analytical grade chemicals. A stock solution of copper ions (1000 mg/L) was prepared by dissolving appropriate amount of $CuCl_2 \cdot 2H_2O$ (Aldrich Chemical Company, USA) in double distilled water.

2.2. Adsorbent

The cation exchange resins 1500H and 252H (Rohm and Hass Korea Co., Ltd) used in this study are generally used for the removal of heavy metals from water and wastewater. The Physico-chemical properties and specifications of ion exchange resins are presented in Table 2.

Table 2
Characteristic properties of the ion exchange resins used[a]

AMBERJET 1500H	
Matrix	Styrene divinylbenzene copolymer
Functional groups	Sulphonates
Physical form	Dark amber beads
Ionic form as shipped	H^+
Total exchange capacity	≥2.0 equiv./L (H^+ form)
Moisture holding capacity	45–51% (H^+ form)
Specific gravity	1.28–1.32 (Na^+ form)
Shipping weight	820 g/L
Particle size Uniformity coefficient	≤1.20
Harmonic mean size	650 ± 50 μm
Fine contents	<0.425 mm: 0.5% max
Maximum reversible swelling	$Na^+ \rightarrow H^+$: 10%
AMBERSEP 252H	
Matrix	Styrene divinylbenzene copolymer
Functional groups	$-SO_3-$
Physical form	Light grey beads
Ionic form as shipped	H^+
Total exchange capacity	≥1.65 equiv./L (H^+ form)
Moisture holding capacity	52–58% (H^+ form)
Specific gravity	1.18–1.22 (H^+ form)
Shipping weight	755 g/L
Particle size harmonic mean size	0.90–1.10 mm
Uniformity coefficient	≤1.4
Fine contents	<0.600 mm: 1.0% max
Maximum reversible swelling	$Na^+ \rightarrow H^+$: 7%

[a] Manufacturer supplied.