



# Chitosan/Phosphate Rock-Derived Natural Polymeric Composite to Sequester Divalent Copper Ions from Water

Rachid El Kaim Billah <sup>1</sup>, Moonis Ali Khan <sup>2,\*</sup>, Saikh Mohammad Wabaidur <sup>2</sup>, Byong-Hun Jeon <sup>3</sup>, Amira AM <sup>4</sup>, Hicham Majdoubi <sup>4</sup>, Younesse Haddaji <sup>5</sup>, Mahfoud Agunaou <sup>1</sup> and Abdessadik Soufiane <sup>1</sup>

<sup>1</sup> Laboratory of Coordination and Analytical Chemistry, Department of Chemistry, Faculty of Sciences, University of Chouaib Doukkali, El Jadida 24000, Morocco; rachidelkaimbillah@gmail.com (R.E.K.B.); m.agunaou@gmail.com (M.A.); abdessadiksoufiane@gmail.com (A.S.)

<sup>2</sup> Chemistry Department, College of Science, King Saud University, Riyadh 11451, Saudi Arabia; swabaidur@ksu.edu.sa

<sup>3</sup> Department of Earth Resources and Environmental Engineering, Hanyang University, Seoul 04763, Korea; bhjeon@hanyang.ac.kr

<sup>4</sup> Laboratory of Analytical Chemistry and Physico-Chemistry of Materials, Department of Chemistry, Faculty of Sciences Ben M'Sik, University of Hassan II-Casablanca, Casablanca 21100, Morocco; Amamira6@gmail.com (A.A.); hichammajdoubi.hm@gmail.com (H.M.)

<sup>5</sup> Laboratory of Engineering and Materials, Department of Chemistry, Faculty of Sciences Ben M'Sik, University of Hassan II-Casablanca, Casablanca 21100, Morocco; ys.haddaji@gmail.com

\* Correspondence: mokhan@ksu.edu.sa

## Text S1. Isotherm models

Langmuir isotherm model assumes formation of monomolecular layer over adsorbent surface without interaction between the adsorbed molecules. Langmuir isotherm model [1] in linearized form is expressed as:

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{q_m K_L} \times \frac{1}{C_e} \quad (S1)$$

where  $q_m$  (mg/g) and  $K_L$  (L/mg) are the constants for maximum monolayer adsorption capacity and a constant related to the heat of adsorption, respectively.

Freundlich isotherm [2] in linearized form is expressed as:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \quad (S2)$$

where  $K_F$  ((mg/g) (L/mg)<sup>(1/n)</sup>) and  $n$  are the Freundlich constants related to bonding energy and deviation in adsorption from linearity, respectively.

## Text S2. Adsorption kinetic models

The pseudo-first-order [3], and pseudo-second-order [4] kinetic models in linearized forms are expressed as:

$$\log(q_{e1} - q_t) = \log q_e - \frac{k_1}{2.303} \times t \quad (S3)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} \times t \quad (S4)$$

where  $q_{e1}$ ,  $q_{e2}$  and  $q_t$  are the adsorption capacities for pseudo-first order model, pseudo-second order model at equilibriums, and at time  $t$ , respectively,  $k_1$  (1/min) and  $k_2$  (g/mg-min) are the pseudo-first-order and pseudo-second-order rate constants, respectively.

**Text S3. Thermodynamic parameters**

Thermodynamic parameters viz. standard Gibb's free energy change ( $\Delta G^\circ$ ), entropy change ( $\Delta S^\circ$ ), and enthalpy change ( $\Delta H^\circ$ ) were calculated as:

$$\Delta G^\circ = -RT \ln K_c \quad (\text{S5})$$

$$\ln K_c = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{R} \times \frac{1}{T} \quad (\text{S6})$$

where  $R$  is the universal gas constant (8.314 J/mol-K),  $T$  is the absolute temperature (K), and  $K_c$  is a separation factor.  $\Delta S^\circ$  and  $\Delta H^\circ$  were calculated from the intercept and slope of the plot of  $\ln K_c$  versus  $1/T$ .

**References**

1. Langmuir, I. The adsorption of gases on plane surface of glass, mica and platinum. *J. Am. Chem. Soc.* **1916**, *40*, 1361–1403.
2. Freundlich, H.M.F. Over the adsorption in solution. *J. Phys. Chem.* **1906**, *57*, 385–470.
3. Lagergren, S.K. About the theory of so-called adsorption of soluble substances. *Sven. Vetenskapsakad. Handl.* **1989**, *24*, 1–39.
4. Ho, Y.S.; McKay, G. The kinetics of sorption of divalent metal ions onto sphagnum moss peat. *Water Res.* **2000**, *34*, 735–742.