

## Supplementary materials

# Facile and green preparation of solid carbon nanoions via catalytic co-pyrolysis of lignin and polyethylene and their adsorption capability towards Cu(II)

### Adsorption isotherm

Two typical adsorption isotherm models, i.e., Langmuir model (Eq.1) and Freundlich model (Eq. 2) are employed to describe the adsorption process. Particularly, Langmuir model reveals the assumption of monolayer adsorption of adsorbate molecular onto a homogeneous adsorbent surface with no interactions between the adsorbed molecules while Freundlich model assumes that the adsorption enthalpy on the sorbent surface is heterogeneously distributed and increased with a surface coverage of adsorbent.

$$q_e = \frac{Q_m K_l C_e}{1 + K_l C_e} \quad \text{Eq. 1}$$

$$q_e = K_f C_e^n \quad \text{Eq. 2}$$

where  $q_e$  is the equilibrium Cu(II) adsorption capacity (mg/g),  $Q_m$  is the maximum capacity (mg/g),  $K_l$  is the Langmuir binding term related to interaction energies (L/mg),  $C_e$  is the equilibrium concentration of Cu(II) (mg/L),  $n$  is the Freundlich linearity constant,  $K_f$  represents the Freundlich affinity coefficient ( $\text{mg}^{(1-n)} \text{L}^n/\text{g}$ ).

## Adsorption kinetics

Two typical kinetics models, i.e., Pseudo-first-order (Eq. 3) and Pseudo-second-order (Eq. 4) models, are employed to fit the adsorption process. Pseudo-first-order model is related to a reversible adsorption reaction and a chemisorption-related process can be inferred according to Pseudo-second-order model.

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad \text{Eq. 3}$$

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad \text{Eq. 4}$$

Where  $q_e$  and  $q_t$  represent the amount of Cu(II) adsorbed at equilibrium and at time  $t$ , respectively (mg/g),  $t$  is the contact time (h),  $k_1$  and  $k_2$  are adsorption rate constants of the Pseudo-first-order (1/h) and Pseudo-second-order (g/(mg h)) models, respectively.

## Thermodynamic analysis

The relationship between ambient temperature and Cu(II) adsorption can be revealed using Gibbs free energy ( $\Delta G^0$ ), enthalpy ( $\Delta H^0$ ) and entropy ( $\Delta S^0$ ), which can be calculated from several equations (Eq. 5-7).  $\Delta G^0$  is an indication of the spontaneity of a chemical reaction ( $\Delta G^0 < 0$  indicates a spontaneous reaction,  $\Delta G^0 > 0$  indicates an unspontaneous reaction).  $\Delta H^0$  and  $\Delta S^0$  represent the energy change of system and the randomness state of the adsorption, respectively.

$$\Delta G^0 = -RT \ln K_e \quad \text{Eq. 5}$$

$$K_e = \frac{q_e}{C_e} \quad \text{Eq. 6}$$

$$\ln K_e = -\frac{\Delta H^0}{RT} + \frac{\Delta S^0}{R} \quad \text{Eq. 7}$$

where  $R$  is gas constant (8.314 J/(mol K)),  $T$  is the absolute temperature (K),  $q_e$  is Cu(II) concentration on the CNOs at equilibrium (mg/g),  $C_e$  is the remaining Cu(II) concentration in the solution at equilibrium (mg/L),  $\Delta G^0$  (kJ/mol),  $\Delta H^0$  (kJ/mol) and  $\Delta S^0$  (J/(mol K)) can be obtained from the slope and intercept of the plot of  $\Delta G^0$  versus  $T$ .