

Supporting Information

Mesocarbon Microbead Carbon Supported Magnesium Hydroxide

Nanoparticles: Turning Spent Li-ion Battery Anode into a Highly Efficient

Phosphate Adsorbent for Wastewater Treatment

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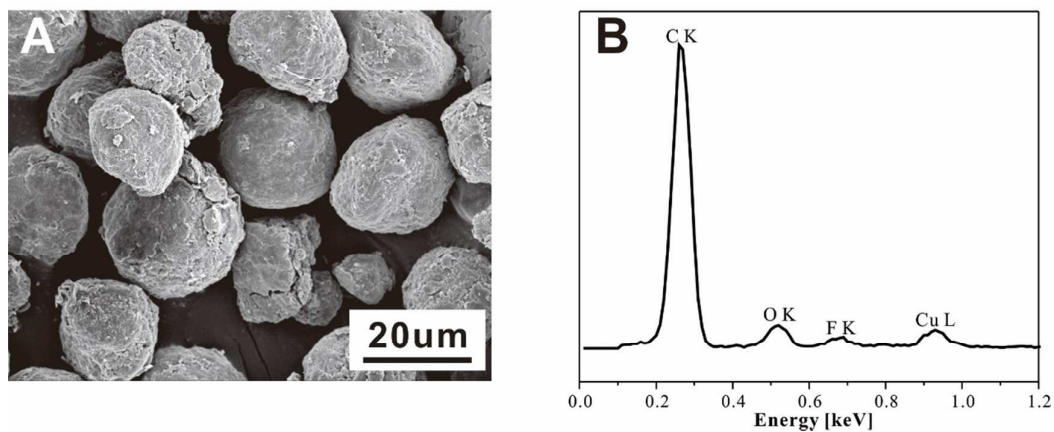


Figure S1. SEM images and corresponding EDX spectra of the MCMB.

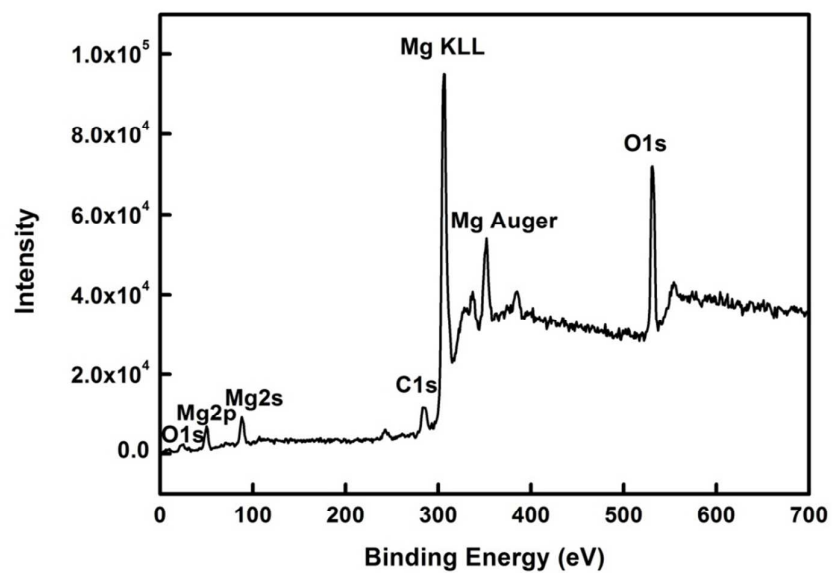


Figure S2. XPS spectra for the Mg-MCMB.

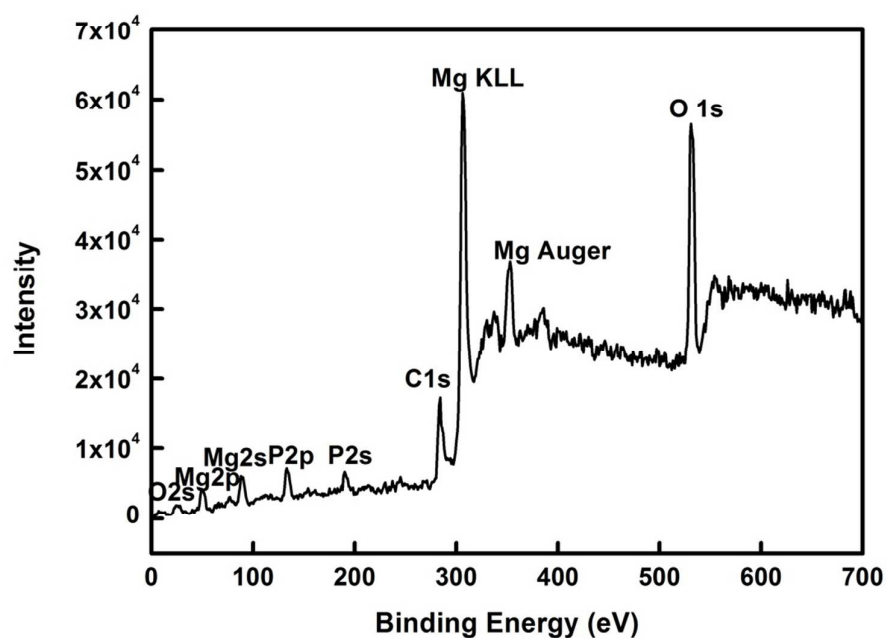


Figure S3. XPS spectra for the post-sorption Mg-MCMB.

Table S1. Elemental compositions of post-sorption solution.

Solution	Concentration (mg/L)													
	K	Na	Ca	Mg	Fe	Zn	Mn	Co	Ni	Cu	Li	Pb	Cd	Cr
Post-sorption	578.55	-	-	13.37	-	-	-	-	-	0.05	-	-	-	-

SM 1. Adsorption kinetic models

Pseudo first-order, pseudo second-order model, Ritchie N_{th}-order, Elovich, Intraparticle diffusion were used to fit the adsorption kinetic data¹.

The first-order describe the kinetics of the solid-solution system based on mononuclear adsorption.

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (1), \text{ first-order}$$

where $(1/h)$ is the rate constant of the pseudo first-order model of adsorption; $t(h)$ is the adsorption time, q_e (mg/g) and q_t (mg/g) is the absorbed amount of phosphate at equilibrium and at different time, respectively.

The second-order describe the kinetics of the solid-solution system based on binuclear adsorption, and the rate-limiting step may be chemical sorption or chemisorption involving valence forces.

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \quad (2), \text{ second-order}$$

where k_2 (g/(mg·h)) is the rate constant of the pseudo first-order model of adsorption, while q_e and q_t are defined the same as the parameters in the pseudo first-order model.

Ritchie N_{th}-order models describe the kinetics of the solid-solution system based on N-nuclear adsorption.

$$\frac{dq_t}{dt} = k_n(q_e - q_t)^n \quad (3), \text{ Ritchie N}_{th}\text{-order}$$

where k_n (gⁿ⁻¹/(mgⁿ⁻¹ h)) is the rate constant of the Ritchie N_{th}-order model of adsorption; while q_e and q_t are defined the same as the parameters in the pseudo first-order model.

The Elovich model is an empirical equation considering the contribution of desorption.

$$\frac{dq_t}{dt} = \alpha \exp(-\beta q_t) \quad (4), \text{ Elovich}$$

where α (mg/(g h)) is the initial adsorption rate; and β (g/mg) is the desorption constant of the Elovich model. while q_t are defined the same as the parameters in the pseudo first-order model.

Intraparticle diffusion model assume that the adsorption process is controlled by the pore diffusion as well as the external mass transfer in the sorbent².

$$q_t = k_i t^{1/2} + C_i \quad (5), \text{ intraparticle diffusion}$$

where k_i (mg g⁻¹ h^{-1/2}) is the intraparticle diffusion rate constant; C_i (mg/g) is a constant in the intraparticle diffusion equation, corresponding to the thickness of boundary layer. While q_t is defined the same as the parameter in the pseudo first-order model.

SM 2. adsorption isotherms models

For phosphate, Langmuir, Freundlich, Langmuir-Freundlich, Toth, dual-mode and BET models were used to fit the adsorption data^{3, 4}.

Langmuir equation (Langmuir, 1916; Weber, 1972) is applicable for single-layer adsorption and provides information on maximum uptake capabilities⁵.

$$q_e = \frac{KQ C_e}{1 + K C_e} \quad (6), \text{ Langmuir}$$

where K (L/mg) represent the Langmuir models' coefficients; Q (mg/g) is the maximum adsorption capacity of phosphate (mg/g); q_e is the equilibrium phosphate uptake (mg/g), C_e is the aqueous phosphate concentration (mg/L).

The Freundlich equation (Freundlich, 1906; Weber, 1972) does not indicate an equilibrium uptake capacity of the adsorbent and is suited for heterogeneous

adsorption. Therefore, it can only reasonably be applied in the low to intermediate concentration range⁵.

$$q_e = K_f C_e^n \quad (7), \text{ Freundlich}$$

where $K_f (\text{mg}^{1-n} \text{ L}^n / \text{g})$ is the Freundlich affinity coefficient, n is the exponential coefficient, while q_e and C_e are defined the same as the parameters in the Langmuir model.

The Langmuir-Freundlich equation (Sips, 1948) is a combined form of Langmuir and Freundlich models derived for predicting the heterogeneous adsorption systems (Foo and Hameed, 2010). At low concentrations, this equation effectively reduces to a Freundlich isotherm and thus, does not obey Henry's law. At high adsorbate concentrations, it predicts a monolayer sorption capacity characteristic of Langmuir isotherm.⁵

$$q_e = \frac{K_{if} Q C_e^n}{1 + K_{if} C_e^n} \quad (8), \text{ Langmuir-Freundlich}$$

where $K_{if} (\text{L}^n / \text{mg}^n)$ is the constants for Langmuir-Freundlich isotherm models, n is the exponential coefficient. While q_e and C_e are defined the same as the parameters in the Langmuir model.

The Toth isotherm model (Toth, 1971) is an improved Langmuir isotherm model useful in describing heterogeneous adsorption systems satisfying both low and high-end boundary of the concentration (Foo and Hameed, 2010)^{5, 6}.

$$q_e = \frac{K_T C_e}{(1 + B_T C_e^n)^{1/n}} \quad (9), \text{ Toth}$$

where $K_T (\text{L/g})$, $B_T (\text{L}^n / \text{mg}^n)$ and n are the Toth constants. While q_e and C_e are defined the same as the parameters in the Langmuir model.

Dual-mode model that incorporates precipitation and adsorption (ion exchange and surface complexation)^{7, 8}.

$$q_e = \frac{bQ C_e}{1+bC_e} + K_D C_e \quad (10), \text{ Dual-mode}$$

where K_D (L/mg) is the partitioning coefficient, and b (L/g) and Q (mg/g) are the Langmuir affinity constant and maximum sorption capacity, respectively. While q_e and C_e are defined the same as the parameters in the Langmuir model.

BET model⁹:

$$q_e = \frac{Q K_S C_e}{(1-K_B C_e) (1-K_B C_e + K_S C_e)} \quad (11), \text{ BET}$$

where Q (mg/g) is the maximum adsorption capacity of the adsorbents, K_S (L/mg) is the equilibrium constant of sorption for 1st layer in Langmuir and BET isotherms. K_B (L/mg) is the equilibrium constant of adsorption for upper layers in BET isotherm. While q_e and C_e are defined the same as the parameters in the Langmuir model.

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