Lignin-based nano-adsorbent for superfast and highly selective removal of phosphate

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The main equations used in this study are as follows:

$$\log\left(q_e - q_t\right) = logq_e - \frac{k_1 t}{2.303} \quad (1)$$

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

Where q_t (mg g^{-1}) and q_e are the adsorbed capacities (mg g^{-1}) at time t (min) and equilibrium, respectively, respectively; k_1 (min^{-1}) and k_2 (g mg^{-1} min^{-1}) are the related reaction rate constants.

$$q_t = k_{di}\sqrt{t} + C \quad (3)$$

Where k_i (mg P g^{-1} $min^{-1/2}$) is the diffusion rate constant whereas the C is the intercept for the intraparticle diffusion model. Values of k_i and C are calculated from the slope of the linear plot of q_t against $t^{1/2}$.

$$\frac{1}{q_e} = \frac{1}{q_m b C_e} + \frac{1}{q_m} \quad (4)$$

$$lnq_e = lnK_f + \frac{1}{n} lnC_e \quad (5)$$

Where q_e and q_m represent the amount of adsorbing phosphate per unit weight of adsorbent at equilibrium and the maximum adsorption capacity (mg g^{-1}), respectively. C_e (mg L^{-1}), b (L mg^{-1}), K_f, and $1/n$ respectively refer to the equilibrium solution concentration, the Langmuir model constant, a rough indicator of adsorption capacity, and the heterogeneity factor.

$$R_L = \frac{1}{1 + bC_0} \quad (6)$$

Where C_o is the highest initial phosphate concentration (mg L^{-1}), and the value of R_L can indicate whether the adsorption is irreversible ($R_L = 0$), favorable ($0 < R_L < 1$), linear ($R_L = 1$), or unfavorable ($R_L > 1$).

$$\Delta G^0 = -RT\, lnK_d \quad (7)$$

$$\Delta G^0 = \Delta H^0 - T\Delta S^0 \quad (8)$$

$$lnK_d = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \quad (9)$$

Where K_d is the adsorption distribution coefficient at different temperatures, and the value is computed by the ratio of the equilibrium (q_e) to equilibrium (C_e)

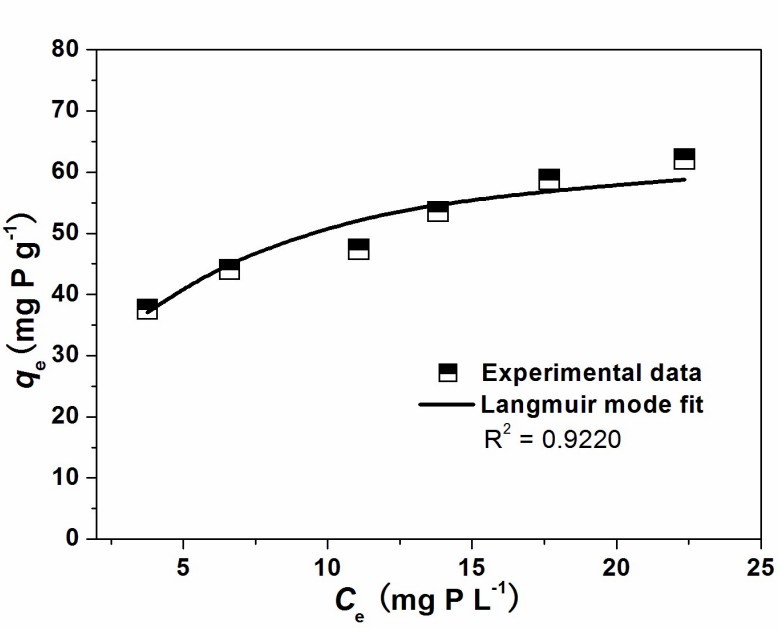

Fig. S1. Phosphate adsorption isotherm of AL-PEI-La in the ice-water bath at 273 K

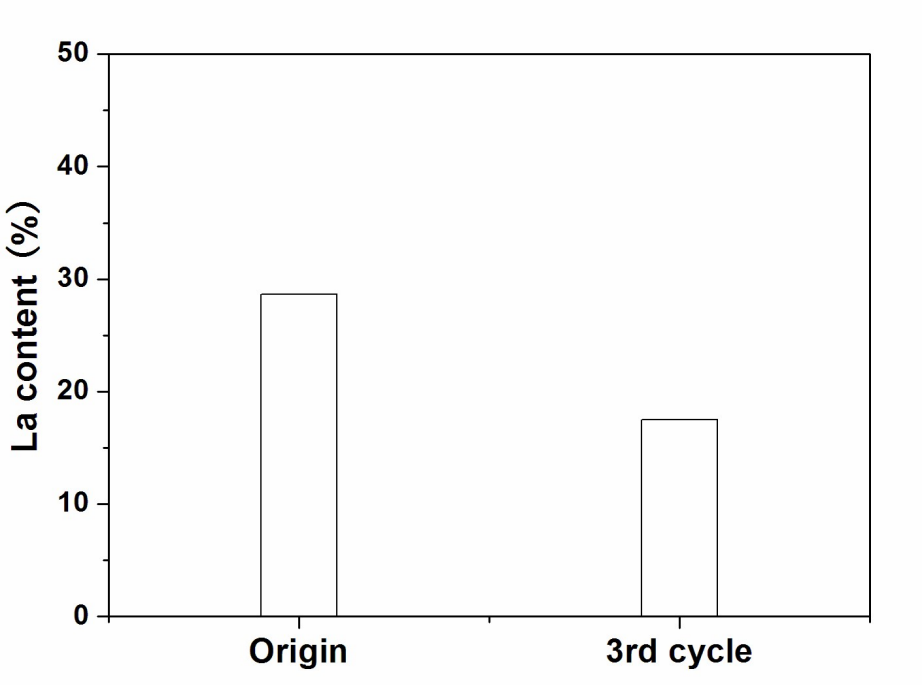

Fig. S2. The lanthanum content of AL-PEI-La origin AL-PEI-La and AL-PEI-LA after 3 cycles

Table S1. Adsorption kinetics fitting results for phosphate on AL-PEI-La by pseudo-first-order, pseudo-second-order, and intraparticle diffusion models.

C_o (mg P L^{-1})	($q_{e,exp}$)	Pseudo-first-order kinetics			Pseudo-second-order kinetics		
		($q_{e,cal}$) (mg P g^{-1})	k_1 (g mg^{-1} min^{-1})	R^2	($q_{e,cal}$) (mg P g^{-1})	k_2 (g mg^{-1} min^{-1})	R^2
50	37.27	5.00	0.011	0.8830	37.59	0.07	1.0000

	Intra-particle diffusion model					
	C_1 (mg P g^{-1})	k_{d1} (mg P g^{-1} $min^{-1/2}$)	R_1^2	C_2 (mg P g^{-1})	k_{d2} (mg P g^{-1} $min^{-1/2}$)	R_2^2
50	0	27.43	1.000	26.29	2.171	0.913

Table S2. Equilibrium parameters of Langmuir and Freundlich models

	Temperature (K)	Langmiur isotherm constans			Freundlich isotherm constans		
		b (L mg^{-1})	q_m (mg g^{-1})	R^2	K_f	n	R^2
AL-PEI-La	298	4.47	65.79	0.9700	52.25	12.74	0.8796
	308	4.32	74.60	0.9249	51.46	8.12	0.7564
	318	0.57	85.47	0.9213	56.39	9.46	0.8612

Table S3. Thermodynamic parameters of phosphate adsorption on AL-PEI-La at 298 K, 308 K, and 318 K, respectively.

Temperature	Thermodynamic parameters		
(K)	ΔG^0 (kJ mol^{-1})	ΔH^0 (kJ mol^{-1})	ΔS^0 (J mol^{-1} K^{-1})
298	-4.43	21.23	85.97
308	-5.21	21.23	85.97
318	-6.15	21.23	85.97