

Supporting Information**Comparative Study of Biochar Modified with Different Functional Groups for Efficient Removal of Pb(II) and Ni(II)**

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Figures

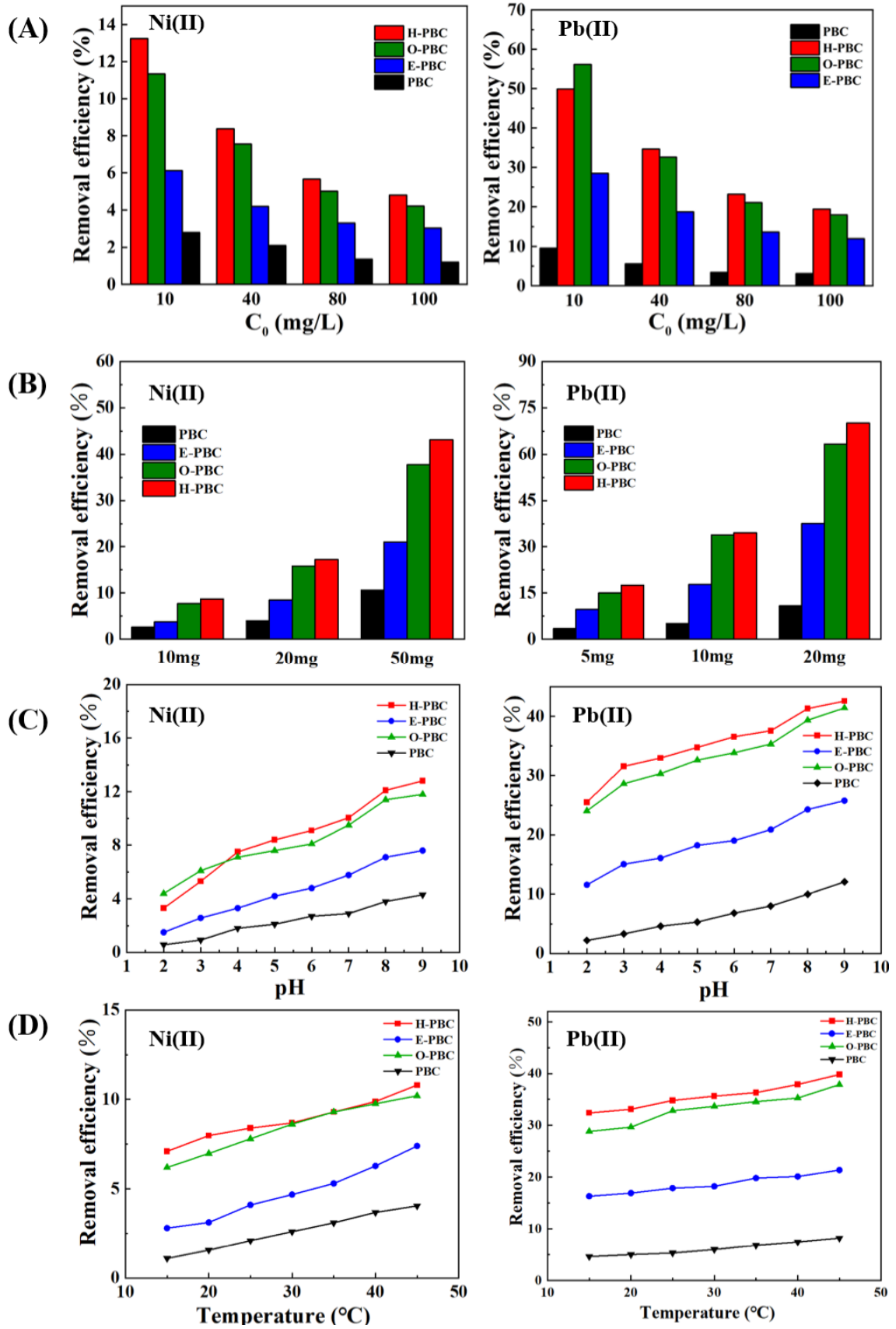


Figure S1. (A) Effect of initial concentration on Ni(II) and Pb(II) removal efficiency.

Experimental conditions: adsorbent dosage = 10 mg; pH = 5.0; temperature = 298.15 K;

adsorption time = 9 h. **(B)** Effect of adsorbent dosage on Ni(II) and Pb(II) removal efficiency.

Experimental conditions: [Ni(II)] and [Pb(II)] = 40 mg/L; pH = 5.0; temperature = 298.15 K;

adsorption time = 9 h. **(C)** Effect of pH on Ni(II) and Pb(II) removal efficiency. Experimental

conditions: adsorbent dosage = 10 mg; [Ni(II)] and [Pb(II)] = 40 mg/L; temperature = 298.15

K. **(D)** Effect of temperature on Ni(II) and Pb(II) removal. Experimental conditions:

adsorbent dosage = 10 mg; [Ni(II)] and [Pb(II)] = 40 mg/L; pH = 5.0; adsorption time = 9 h.

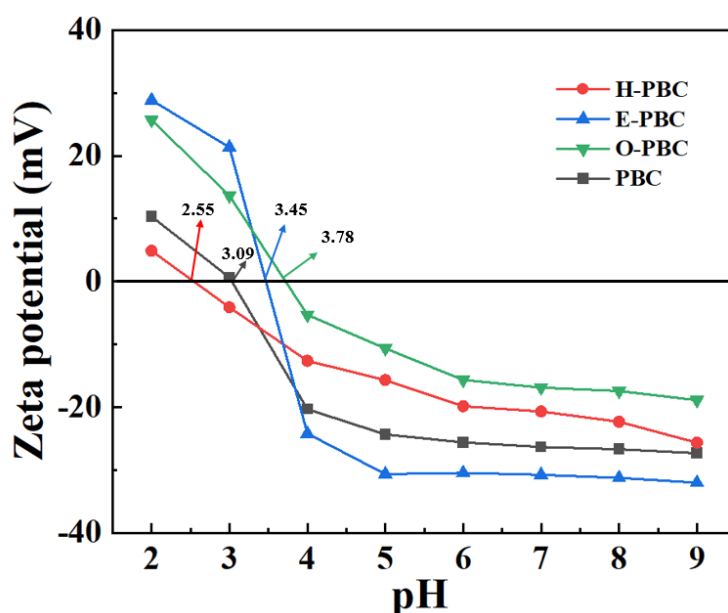


Figure S2. Zeta potential measurements

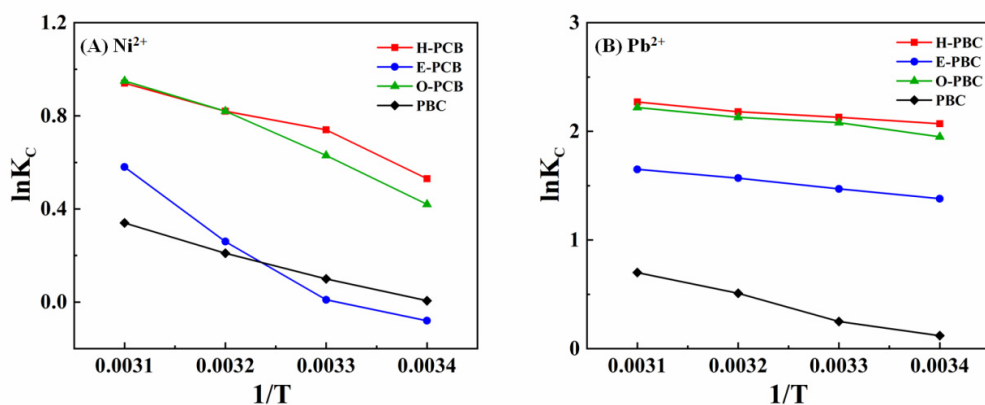


Figure S3. Plots of $\ln K_c$ versus $1/T$ for the adsorption of (A) Ni(II) and (B) Pb(II) by PBC, H-PBC, E-PBC, and O-PBC.

Tables

Table S1. Main textural properties for PBC, H-PBC, O-PBC, and E-PBC.

Sample	BET surface area (m ² /g)	Pore volume (cm ³ /g)	Pore size (Å)
PBC	360.41	0.213	25.8
H-PBC	344.17	0.234	26.9
O-PBC	3.66	0.002	91.5
E-PBC	1.64	0.005	122.7

Table S2. Thermodynamic parameters for the adsorption of Ni²⁺ by PBC, H-PBC, E-PBC, and O-PBC at different temperatures.

Adsorbate adsorbent		ΔH (kJ mol ⁻¹)	ΔS (J mol ⁻¹ K ⁻¹)	ΔG (kJ mol ⁻¹)			
				288.15 K	298.15K	308.15 K	318.1K
Ni (II)	PBC	6.79	23.6	−0.02	−0.25	−0.48	−0.72
	H-PBC	15.15	57.00	−1.27	−1.84	−2.41	−2.98
	E-PBC	15.98	56.00	−0.16	−0.72	−1.27	−1.83
	O-PBC	12.23	46.00	−1.02	−1.48	−1.94	−2.40

Table S3. Thermodynamic parameters for the adsorption of Pb^{2+} by PBC, H-PCB, E-PBC, and O-PBC at different temperatures.

Adsorbate	adsorbent	ΔH (kJ mol ⁻¹)	ΔS (J mol ⁻¹ K ⁻¹)	ΔG (kJ mol ⁻¹)			
				288.15 K	298.15K	308.15 K	318.1K
Pb (II)	PBC	8.62	31.00	-0.31	-0.62	-0.93	-1.24
	H-PCB	4.27	32.00	-4.95	-5.27	-5.59	-5.91
	E-PBC	5.85	34.00	-3.94	-4.28	-4.62	-4.96
	O-PBC	4.68	33.00	-4.83	-5.16	-5.49	-5.82

Table S4. Kinetic parameters for pseudo-first order and pseudo-second order models of Ni(II) adsorption by PBC, H-PBC, E-PBC, and O-PBC.

Samples	Q_{exp} (mg/g)	Pseudo first-order			Pseudo second-order		
		q_{e1} (mg/g)	K_1 (h ⁻¹)	R^2	q_{e2} (mg/g)	K_2 (mg.(gh) ⁻¹)	R^2
PBC	8.39	7.95	2.91	0.967	8.40	0.57	0.994
H-PBC	33.52	31.79	4.54	0.960	33.44	0.24	0.995
E-PBC	16.75	15.80	4.95	0.871	16.56	0.54	0.993
O-PBC	30.21	29.08	6.36	0.812	30.21	0.42	0.983

Table S5. Kinetic parameters for pseudo-first order and pseudo-second order models of Pb(II) adsorption by PBC, H-PBC, E-PBC, and O-PBC.

Samples	$Q_{e,exp}$ (mg/g)	Pseudo first-order			Pseudo second-order		
		q_{e1} (mg/g)	K_1 (h ⁻¹)	R^2	q_{e2} (mg/g)	K_2 (mg.(gh) ⁻¹)	R^2
PBC	22.21	21.13	3.85	0.883	22.22	0.293	0.989
H-PBC	138.57	132.14	5.57	0.822	138.89	0.077	0.987
E-PBC	71.86	68.62	4.53	0.880	71.94	0.113	0.993
O-PBC	130.47	125.05	5.03	0.867	137.58	0.072	0.993

Table S6. Parameters fitted to Langmuir and Freundlich models of Ni(II) adsorption by PBC, H-PBC, E-PBC, and O-PBC.

	Langmuir			Freundlich		
	q_m (mg/g)	K_L (L.mg ⁻¹)	R^2	K_F	1/n	R^2
PBC	19.80	0.017	0.998	0.704	0.633	0.875
H-PBC	64.94	0.0295	0.996	4.225	0.548	0.885
E-PBC	47.17	0.0158	0.998	1.323	0.669	0.995
O-PBC	60.24	0.0262	0.999	3.493	0.563	0.978

Table S7. Parameters fitted to Langmuir and Freundlich models of Pb(II) adsorption by PBC, H-PBC, E-PBC, and O-PBC.

	Langmuir			Freundlich		
	q_m (mg/g)	K_L (L.mg ⁻¹)	R^2	K_F	$1/n$	R^2
PBC	38.31	0.037	0.999	3.368	0.491	0.981
H-PBC	243.90	0.0514	0.999	23.58	0.500	0.875
E-PBC	156.25	0.031	0.968	9.34	0.579	0.975
O-PBC	192.31	0.0935	0.997	31.907	0.403	0.939

Table S8. Comparison of various representative Ni²⁺ adsorbents.

Years	Biomass feedstock	Finishing materials	Maximum adsorption capacity (mg.g ⁻¹)	Reference
2017	Straw		25.06	[12]
	Rice husk		10.15	
2013	Figs	H ₃ PO ₄	18.78	[7]
2017	Sludge	Mercaptan	52.40	[9]
2017	Sawdust	KOH	94.49	[11]
		ZnCl ₂	19.36	
2020	Cactus	NaOH	44.35	[2]
2020	Rice bran	Al(NO ₃) ₃ 、Mg(NO ₃) ₂	201.62	[6]
		、FeSO ₄	19.80	
	Corn	H ₃ PO ₄	64.94	This study
		EDTA	47.17	
		NaOH	60.24	

Table S9. Comparison of various representative Pb²⁺ adsorbents.

Years	Biomass feedstock	Finishing materials	Maximum adsorption capacity (mg.g ⁻¹)	Reference
2014	Eggshell	ALG and PEI	344.8	[5]
2014	Bean shell		45.3	[3]
2014	Sawdust	H ₃ PO ₄	80.65	[4]
		Ammonium		
2017	Banana peel	sulfate	315.16	[14]
		persulfate		
2018	Straw		134.68	[1]
2019	Shell	EDTA	129.31	[10]
		H ₃ PO ₄	353.4	
2019	Peanut shells	PEI	214.0	[8]
2019	Lignin	PEI 和 CS ₂	79.9	[13]
			38.31	
	Corn	H ₃ PO ₄	243.90	This study
		EDTA	156.25	
		NaOH	192.31	

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