

Fe₃O₄-loaded phosphoric acid-modified walnut shell biochar for uranium adsorption from simulated groundwater

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1. Experiment

1.1. Uranium standard curve

First, the stock uranyl nitrate solution (1000 mg/L) was diluted with an appropriate volume of deionized water to obtain the desired concentrations: 0.03, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, and 1.00 mg/L. Three replicate samples were prepared for each concentration. Subsequently, the absorbance corresponding to each uranium concentration was measured at 652 nm using a UV–Vis spectrophotometer with Arsenazo (III) as the chromogenic reagent.¹ Finally, a calibration curve was constructed based on the relationship between absorbance and uranium concentration. The resulting standard curve is given in Equation S1:

$$y = 0.2382x - 0.00668 \quad (\text{S1})$$

where x represents the uranium concentration (mg/L) and y is the absorbance. The calibration curve exhibits a strong linear correlation over the range of 0.03–1.00 mg/L, with a high correlation coefficient ($R^2=0.997$). If the uranium concentration in a sample exceeds this linear range, the solution should be appropriately diluted prior to measurement.

2. Figure

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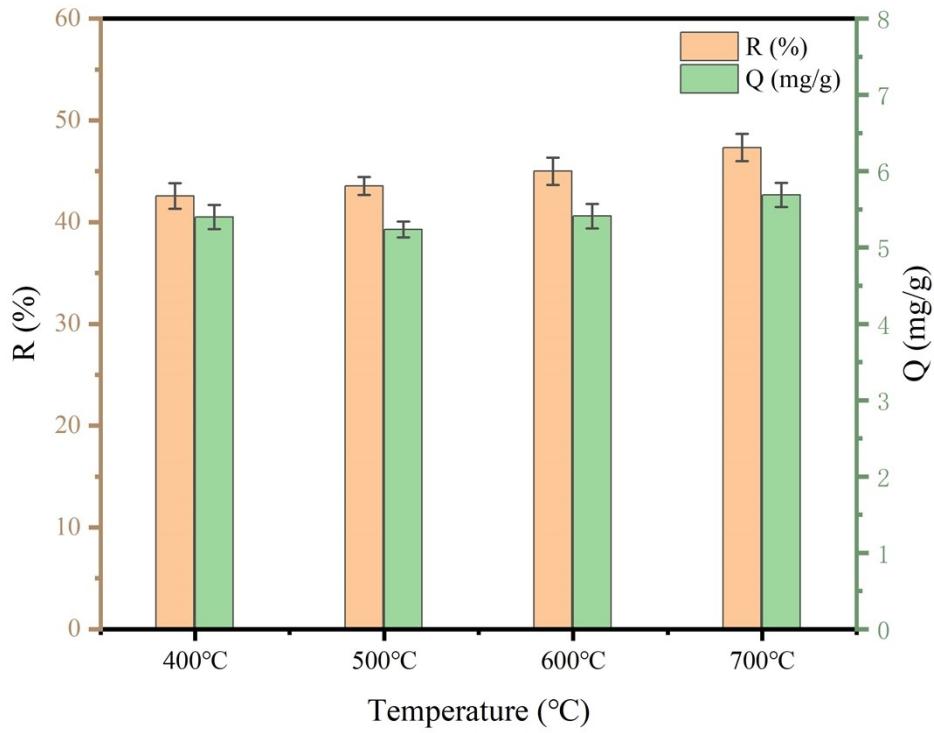


Fig. S1 Preliminary adsorption experiment results of original walnut shell biochar (WSBC) prepared under insulation conditions of 400°C and 700°C for uranium ($C_0 = 5 \text{ mg/L}$, $\text{pH} = 5.0$, dosage = 0.4 g/L, $t = 60\text{min}$, $T = 313 \text{ K}$).

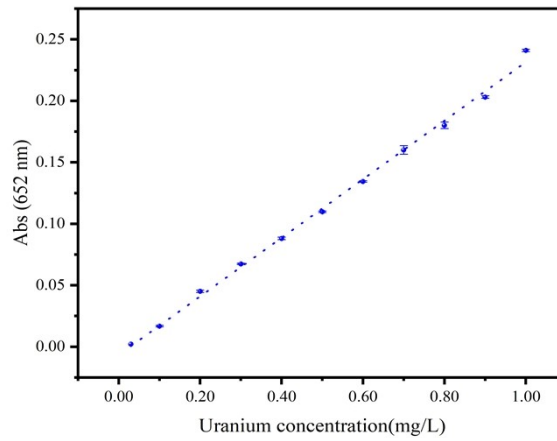


Fig. S2 Standard curve graph of uranium and absorbance.

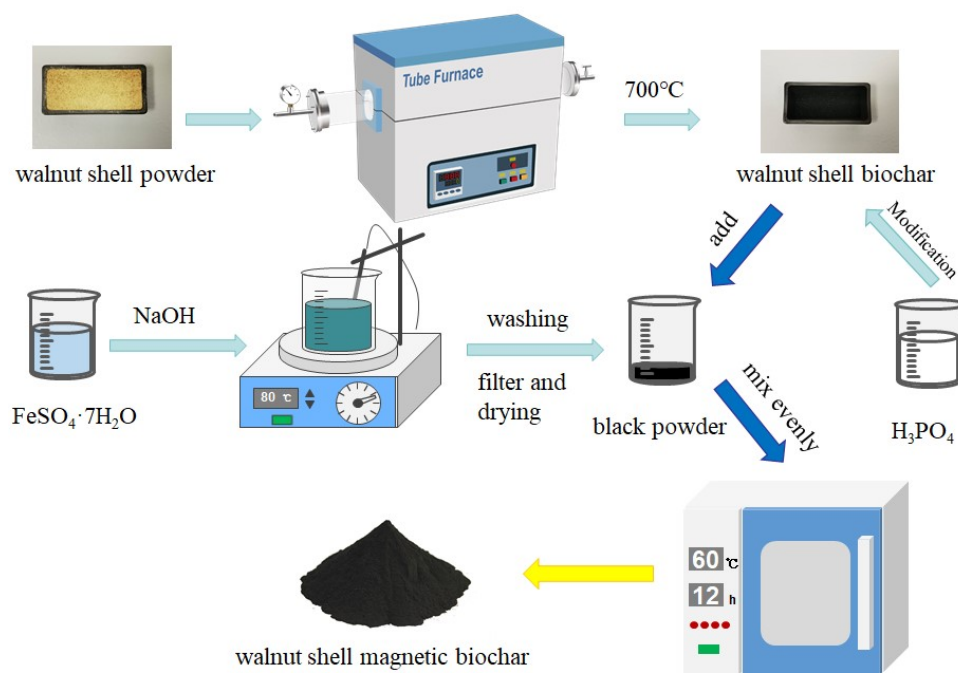


Fig. S3 Synthesis scheme of Fe₃O₄/P-WSBC.

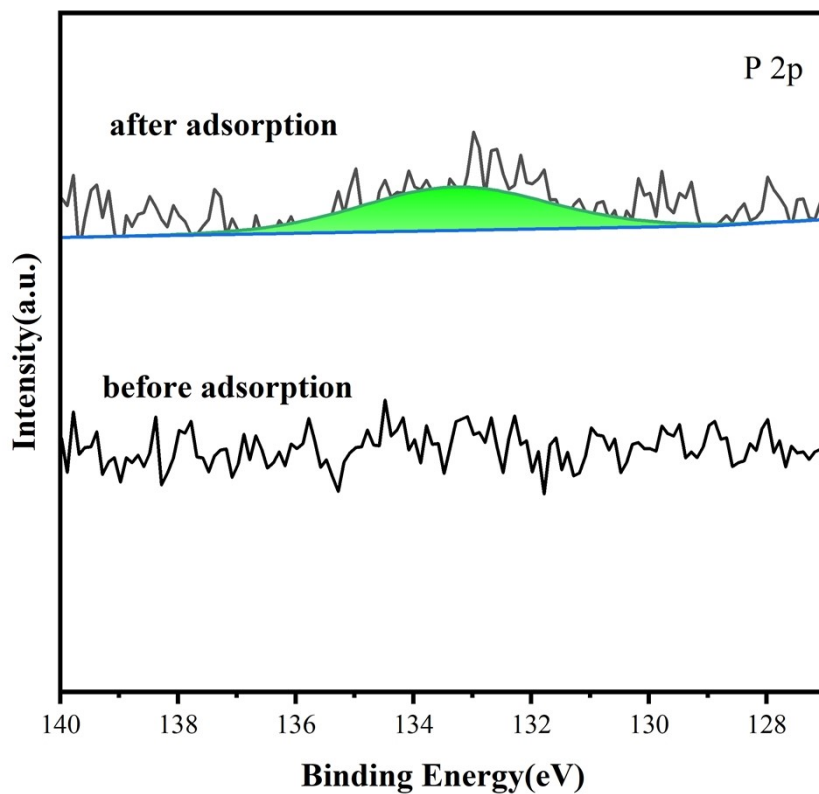


Fig. S4 XPS P2p peak of Fe₃O₄/P-WSBC.

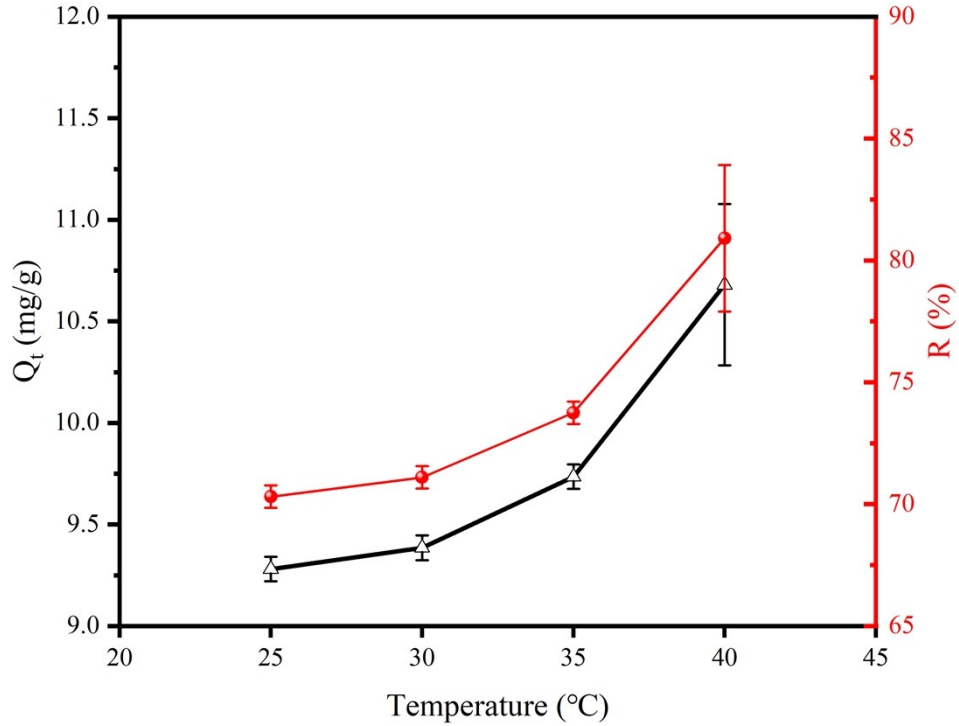


Fig. S5 The influence of temperature on uranium removal from Fe₃O₄/P-WSBC ($C_0=5$ mg/L, time= 60min, dosage= 0.4 g/L, pH=6).

3. Table

Table S1 BET results for WSBC and Fe₃O₄/P-WSBC

	Average pore size (nm)	Specific surface area (m ² /g)	Total Hole Volume (cm ³ /g)
WSBC	2.1606	348.4179	0.1882
Fe ₃ O ₄ /P-WSBC	3.5110	257.8157	0.2263

Table S2 Pseudo-first-order, pseudo-second-order and Intraparticle diffusion kinetic model parameters of Fe₃O₄/P-WSBC on uranium

Pseudo-first-order			Pseudo-second-order			Intraparticle diffusion					
k_1 (min ⁻¹)	q_e (mg/g)	R^2	k_2 g.(mg ⁻¹ .min ⁻¹)	q_e (mg/g)	R^2	k_{i1}^2 mg/g. min ^{1/2}	R_{i1}^2	k_{i2}^2 mg/g. min ^{1/2}	R_{i2}^2	k_{i3}^2 mg/g. min ^{1/2}	R_{i3}^2
0.0266	4.23	0.885	0.0461	10.79	0.998	0.643	0.962	0.307	0.900	0.108	0.885

Table S3 ANOVA analysis of different models

Mode	RSS	χ^2 (MSE)	RMSE	Prob > F
Pseudo-first-order	20.91	3.48	1.87	4.93×10^{-4}
Pseudo-second-order	110.69	18.45	4.30	< 0.0001
Intra-particle diffusion (Stage 1)	2.54	2.54	1.59	0.12578
Intra-particle diffusion (Stage 2)	1.14	1.14	1.07	0.20447
Intra-particle diffusion (Stage 3)	0.026	0.026	0.16	0.22039
Langmuir	106.90	21.38	4.62	< 0.0001
Freundlich	76.81	15.36	3.92	2.28×10^{-4}

Table S4 Langmuir and Freundlich isothermal model parameters for uranium adsorption by Fe₃O₄/P-WSBC

Langmuir			Freundlich		
K_L	q_{max} (mg/g)	R^2	K_F	n	R^2
1.138	23.05	0.963	10.973	4.504	0.947

Table S5 Thermodynamic modeling parameters of uranium adsorption by Fe₃O₄/P-WSBC

T (K)	$\ln(K_d)$	ΔG (kJ/mol)	ΔS (J/(mol·K))	ΔH (kJ/mol)
298	1.78	-4.10		
303	1.82	-4.76		
308	1.95	-5.43	133.51	35.69
313	2.37	-6.10		

References

1 U. K. Banala, N. P. I. Das and S. R. Toleti, *J. Hazard. Mater.*, 2021, 411, 125053.