Supplementary Information

For

Copper-Based Metal–Organic Framework (MOF) Photocatalyst Immobilized on Glass Beads for Sustainable Removal of Ciprofloxacin from Water.

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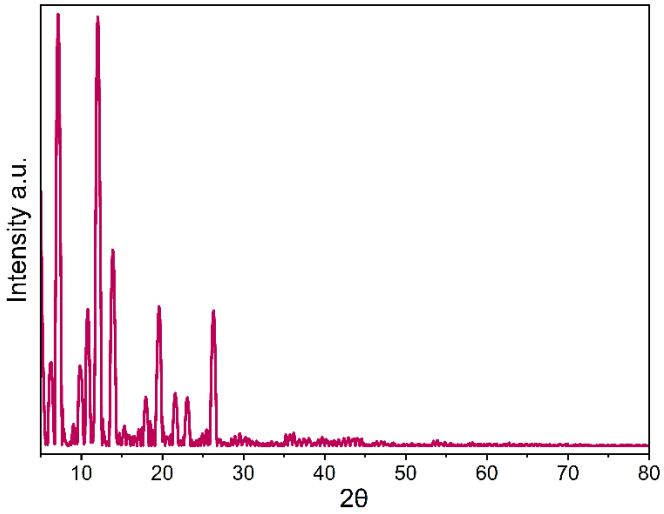


Figure S1. X-Ray Diffraction (XRD) analysis of TiO_2/HKUST-1@GB.The diffraction peaks observed at low 2θ values (~6–15°) are characteristic of the crystalline HKUST-1 framework and correspond to its well-ordered porous structure. Additional peaks around ~17–20° and ~25–30° further confirm the preservation of MOF crystallinity after immobilization on glass beads. The TiO_2 peaks around 26° indicate that TiO_2 is dispersed.

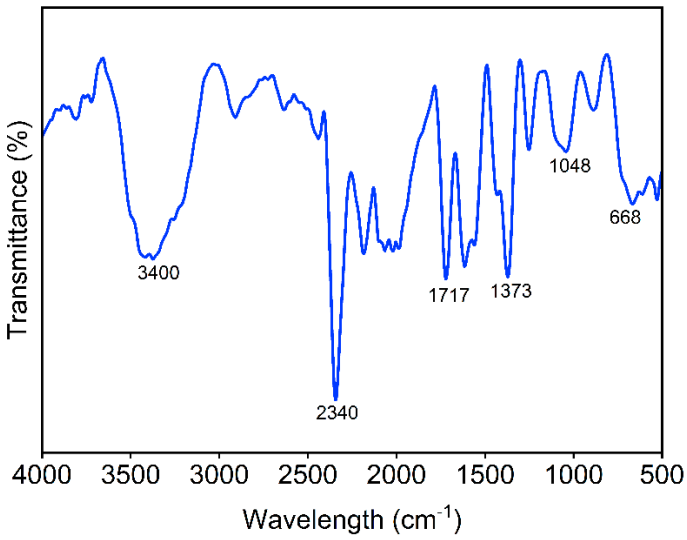


Figure S2. FTIR analysis of TiO_2/HKUST-1@GB.The FTIR spectrum of TiO_2/HKUST-1@GB shows a broad band around 3400 cm^{-1}, corresponding to surface –OH groups. The band at 1717 cm^{-1} is assigned to C=O stretching of the carboxylate groups from the BTC linker of HKUST-1, confirming the composite's integrity after immobilization. Peaks at 1373 and 1048 cm^{-1} arise from C–O and C–C vibrations, while the low-wavenumber band at ~668 cm^{-1} is associated with Ti–O/Ti–O–Ti vibrations, indicating the presence of TiO_2 in the composite.

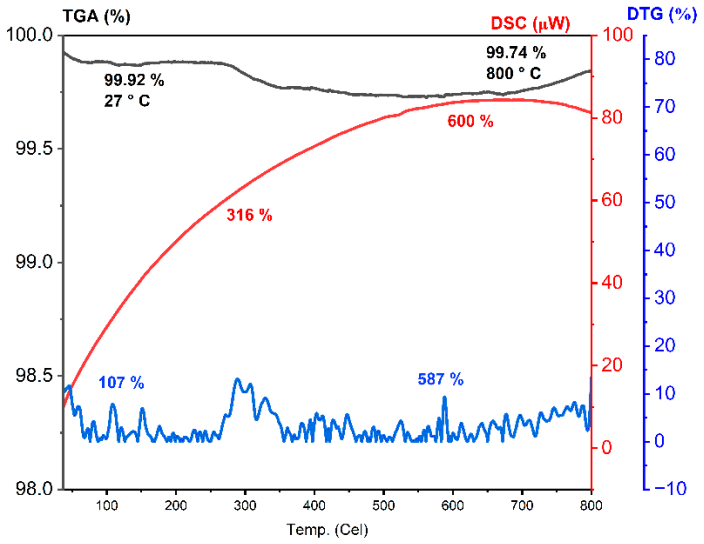


Figure S3. Thermogravimetric analysis of TiO_2/HKUST-1@GB.The TGA–DTG–DSC results demonstrate that TiO_2/HKUST-1@GB exhibits exceptional thermal stability, with negligible mass loss even at high temperatures. This stability is crucial for reusability, long-term photocatalytic operation, and practical water treatment applications, where thermal and structural integrity under irradiation is required.

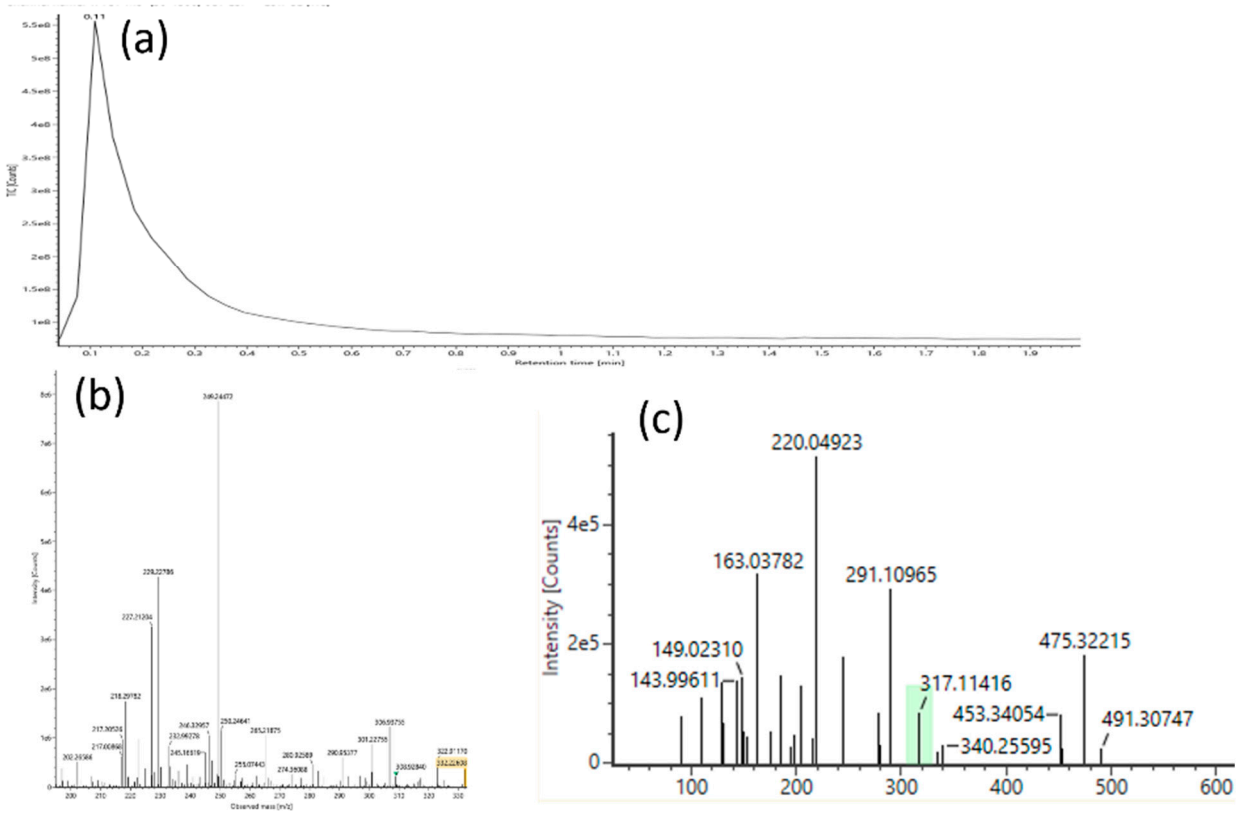


Figure S4. QTOF-MS spectra. Panel (a) shows a sharp chromatographic peak at a short retention time, indicating rapid elution and effective separation of ciprofloxacin degradation products. The mass spectrum in (b) confirms the formation of multiple intermediates, evidencing extensive molecular fragmentation during photocatalytic treatment. In (c), prominent m/z signals correspond to key transformation products arising from piperazine ring cleavage, decarboxylation, and oxidation reactions.

Table S1. Kinetic model parameters for the adsorption of CIP on TiO_2/HKUST-1@GB composite.

Pseudo-first-order kinetic		Pseudo-second-order kinetic	
k_1 (min^{-1})	R^2	K_2 (min^{-1})	R^2
0.032	0.98	0.0036	0.97

Table S2. Adsorption isotherm model parameters

	Langmuir isotherm model			Freundlich isotherm model		
	q_{max} (mg g^{-1})	K_L (L mg^{-1})	R^2	K_F mg $(g\cdot(L\ mg^{-1})^{1/n})^{-1}$	n	R^2
Non-linear	20	29	0.95	78.75	1.653	0.88