Supplementary material

Sludge-derived novel Fe_3O_4-MgO@C composites for tetracycline abatement from wastewater using sustainable bio-electro-Fenton and nutrients recovery with co-precipitation: A waste-to-resource strategy

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Text S1. Characterization of catalyst

Electrochemical analyses, including electrochemical impedance spectroscopy (EIS), linear sweep voltammetry (LSV), cyclic voltammetry (CV), and Tafel analyses, were conducted using an electrochemical workstation (Metrohm, Switzerland). The workstation was comprised of a three-electrode system with glassy carbon, platinum, and Ag/AgCl serving as working, counter, and reference electrodes, respectively. All electrochemical measurements were carried out in a 50 mM Na_2SO_4 solution at a scan rate of 0.01 mV/s. Morphological analysis of the catalyst was performed using scanning electron microscopy (SEM) equipment (Carl Zeiss, USA). Fourier-transform infrared spectroscopy (FTIR) was conducted within the wavenumber range of 400 to 4000 cm^{-1} using Thermo Fisher Scientific Instruments, USA equipment. X-ray diffraction (XRD) was utilized to investigate the structural characteristics and composition of the waste-derived catalyst and sludge. The XRD analysis involved scanning 2θ from 10 to 80° at a scanning rate of 2° min^{-1} and a step size of 0.02 using a Bruker D2 Phaser instrument from Germany.

The surface area of the composite catalyst was measured using a multipoint Brunauer–Emmett–Teller (BET) analyser from BEL, Japan, Inc. X-ray photoelectron spectroscopy (XPS) was employed to determine the structural characteristics of the catalyst, utilizing equipment from ULVAC Physical Electronics, USA. Additionally, the magnetic properties of the waste-derived catalyst were analysed using a vibrating sample magnetometer (VSM) from Lake Shore Cryotronics, USA.

Text S2. Economic analysis

The economics of electro-Fenton operation was aimed at assessing the real-scale capability of the process. It is established on the operating cost (OC_{total}) needed to eliminate contaminants by unit order of magnitude per m^3 of contaminated water, which is also recognized as OC_{total} per order. The OC_{total} includes the catalyst cost, chemical cost, and electricity cost, which were determined by calculating the energy consumption (*W*) and electrical energy per order (*EEO*) as per Eq. (S1) − Eq. (S5)

$$W\left(\frac{kWh}{m^3}\right)=\frac{UIT}{V} \tag{S1}$$

$$EEO\left(\frac{\frac{kWh}{m^3}}{log}\right)=\frac{W}{log(\frac{C_o}{C})} \tag{S2}$$

OC_{total} = Catalyst cost + Chemical cost + Electricity cost (S3)

Where, U is the voltage (V), I is the imposed current (A), T is the treatment duration (h), V is the volume (m^3), and C_o and C are the initial and final concentrations of contaminants (mg/L), respectively.

Chemical cost (\$/m^3) = Electrolyte utilized (kg/m^3) × cost of electrolyte (\$/kg) (S4)

Electricity cost (\$/m^3) = EEO (kWh/m^3/log) × per unit cost of electrical energy (\$/kWh) (S5)

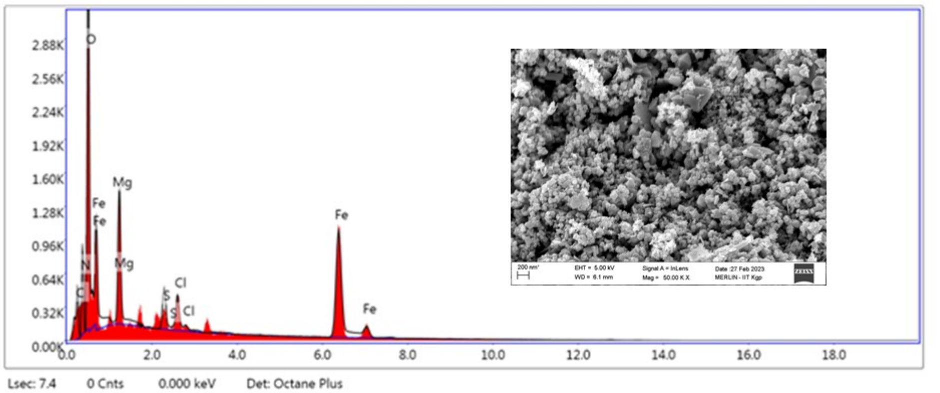
Additionally, the mineralization current efficiency (MCE%) was computed with ΔTOC (mg/L) using Eq. (S6)

$$MCE\ (\%)=\frac{nFV\Delta TOC}{CmIt} \tag{S6}$$

Where, n is the total number of electrons consumed by SDS for mineralization, t is the treatment duration (h), V is the wastewater volume (L), F indicates the Faraday's constant (96485 C mol^{-1}), c represents the conversion factor (4.32×10^7), and I is the external applied current (A).

Text S3: Synthetic urine

The synthetic urine contained 1.36 g/L $NaCH_3COO\cdot3H_2O$, 0.74 g/L KCl, 0.58 g/L NaCl, 0.68 g/L KH_2PO_4, 0.87 g/L K_2HPO_4, 0.28 g/L NH_4Cl, 0.1 g/L $MgSO_4\cdot7H_2O$, 0.1 g/L $CaCl_2\cdot2H_2O$ and 0.1 mL/L of a trace element mixture.



Element	Weight %	Atomic %	Net Int.	Error %	Kratio
C K	4.07	9.68	364.36	7.67	0.0199
N K	7.44	15.15	652.18	6.03	0.0419
O K	18.19	32.46	3361.72	4.33	0.1098
MgK	7.21	8.46	1599.65	5.36	0.0389
S K	2.84	2.53	537.76	5.57	0.0191
ClK	3.17	2.55	524.20	7.69	0.0207
FeK	57.08	29.17	2390.25	3.76	0.3868

Fig. S1. Elemental composition of sludge waste-derived catalysts according to EDX analysis

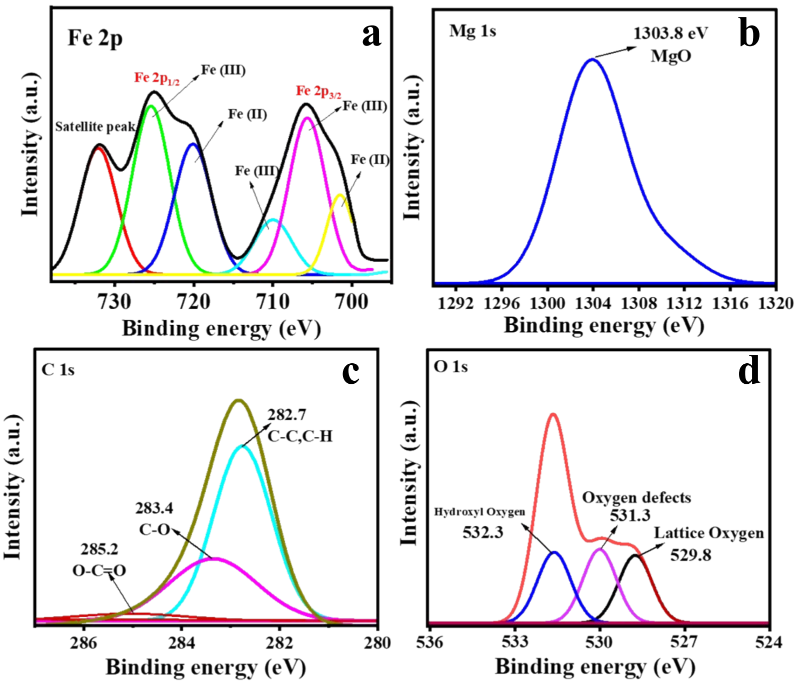


Fig. S2. (a) Fe 2p; (b) Mg 1s; (c) C 1s; and (d) O 1s spectra of Fe_3O_4-MgO@C during XPS analysis

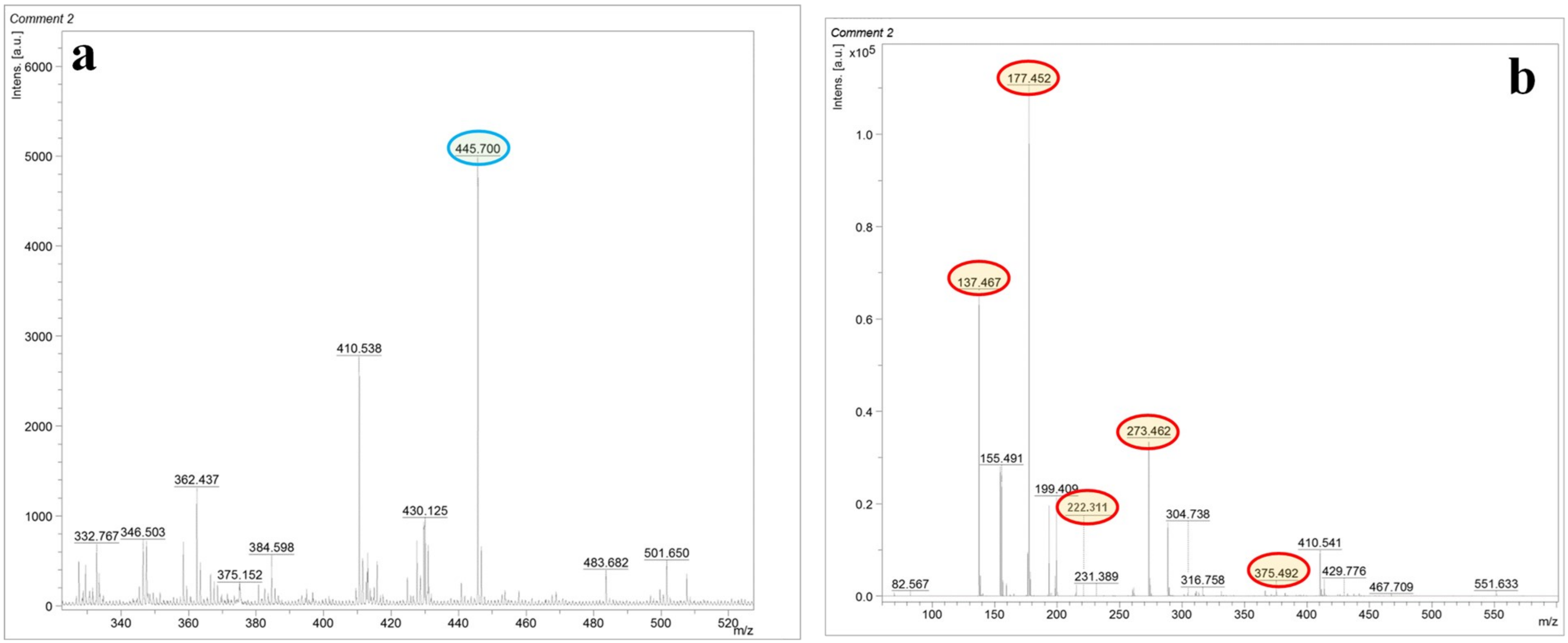


Fig. S3. MALDI-TOF spectra of (b) initial TC sample; (c) treated effluent

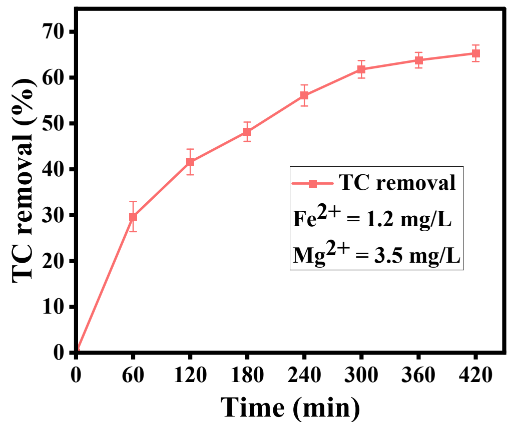


Fig. S4. Degradation of TC antibiotic in homogeneous BEF process (TC = 10 mg/L and pH = 7.0)

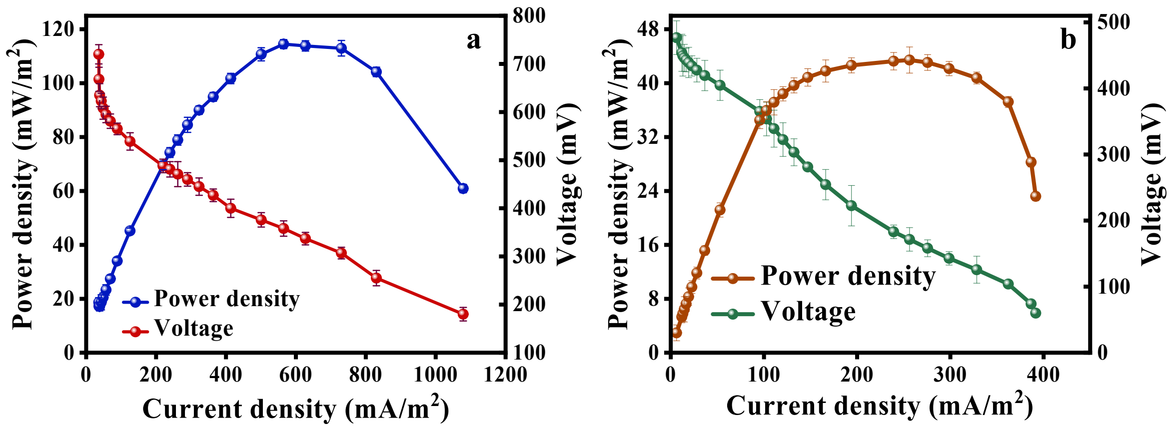


Fig. S5. Power density and voltage in (a) Fe_3O_4-MgO@C; and (b) Control BEF system

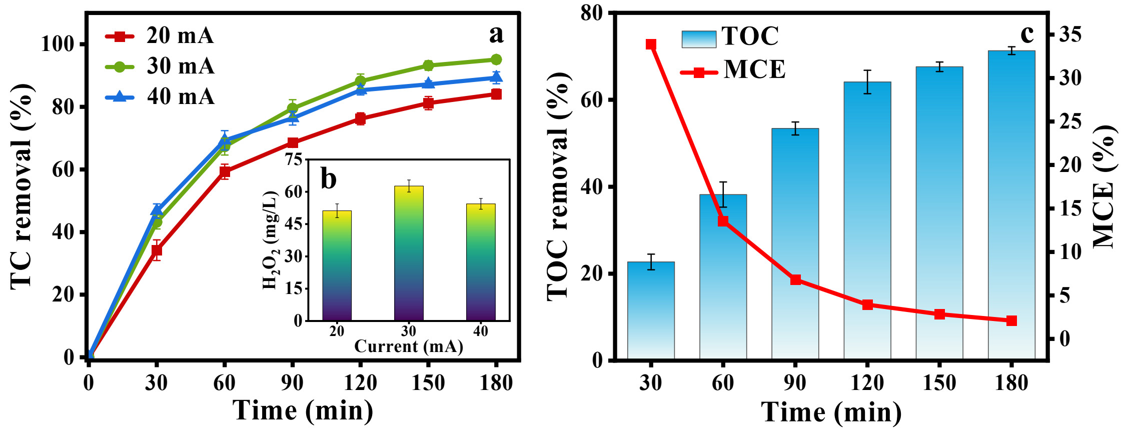


Fig. S6. Influence of current (a) TC removal; (b) H_2O_2 production; and (c) TOC removal and mineralization current efficiency in EF system

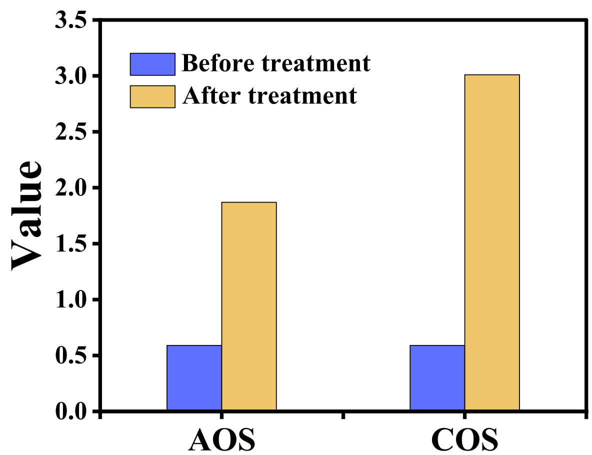


Fig. S7. AOS and COS of raw and BEF-treated wastewater representing biodegradability

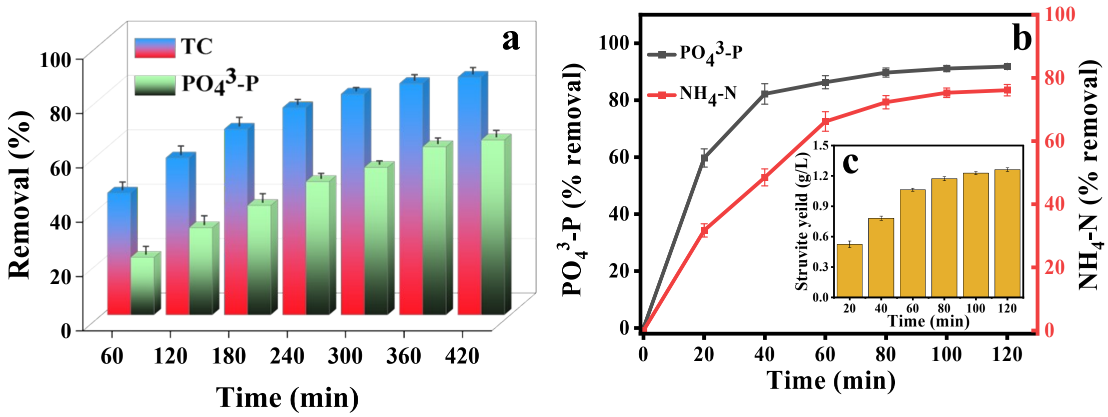


Fig. S8. Removal of (a) TC and PO_4^{3-} from synthetic urine during the BEF process; (b) removal of PO_4^{3-} and NH_4^+ during precipitation; and (c) struvite yield from urine with the addition of Fe_3O_4-MgO

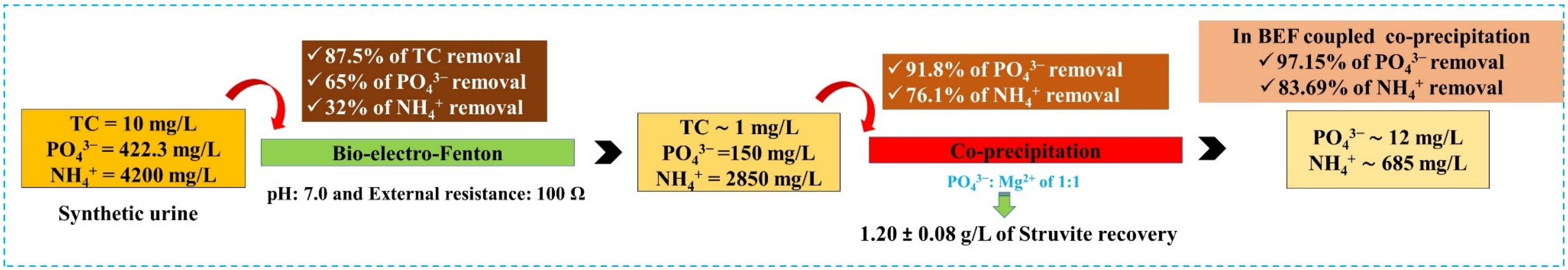


Fig. S9. Schematic of BEF and co-precipitation revealing contaminant removal in each process

Table S1. Characteristics of raw municipal wastewater

Parameters	**Value**
COD (mg L^{-1})	295 ± 15
pH	7.1 ± 0.2
TOC (mg L^{-1})	130 ± 10
Turbidity (NTU)	97.5 ± 6.0
Cl^- (mg L^{-1})	70 ± 10
Conductivity (µS cm^{-1})	520 ± 20
SO_4^{2-} (mg L^{-1})	15.5 ± 3.0
SDS (mg L^{-1})	3.3 ± 0.1