Text 1: Supplementary characterization of free radical trapping and quenching effects

1. Radical Trapping and Quenching:

(1) To further elucidate the mechanisms of antibiotic photodegradation by Fe_2O_3, *B. megaterium*, and the Fe_2O_3/*B. megaterium* composite, this study employed probe molecule techniques to capture hydrogen peroxide (H_2O_2), hydroxyl radicals (·OH), and superoxide anion radicals ($\cdot O_2^-$) generated under different catalytic conditions.

(2) ·OH were qualitatively and quantitatively detected using fluorescence spectroscopy (PL) with terephthalic acid as the probe molecule. Samples were collected at 0, 5, 10, 20, 40, 60, and 90 min, filtered through a 0.45 μm membrane, and analyzed using a fluorescence spectrophotometer at an excitation wavelength of 315 nm and an emission wavelength of 425 nm. The ·OH concentration was quantified via the external standard method, with 2-hydroxyterephthalic acid as the reference standard.

(3) H_2O_2 concentrations were rigorously quantified using two complementary methods: (1) The Amplex Red assay (detection limit = 0.1 μM), which utilizes HRP-catalyzed conversion to fluorescent resorufin (λex/em = 563/587 nm), and (2) HPLC-PDA analysis (retention time = 3.2 min at 240 nm).

(4) For O_2^- detection, nitroblue tetrazolium (NBT) was used as the probe molecule, and its reduction was measured to indirectly quantify $\cdot O_2^-$ levels.

(5) To verify the roles of $\cdot O_2^-$ and ·OH in the photodegradation process, radical quenching experiments were conducted by adding scavengers to suppress specific radicals. NBT (0.1 mM) and PTA (1 mM) were used as quenchers for $\cdot O_2^-$ and ·OH, respectively. Antibiotic degradation efficiency was evaluated before and after quenching, following the method outlined in Section 2.3.

2. Result

(1) These results show that H_2O_2 accumulation did not detected.

(2) *B. megaterium* -mineral interactions generated higher ROS levels (•OH and O_2•$^-$) compared to either component alone (p<0.01), quenching experiments (tert-butanol/SOD) showed no measurable impact on antibiotic degradation. Crucially, no H_2O_2 accumulation (<0.1 μM) was observed. These results fundamentally differentiate our system from conventional Fenton-like processes, highlighting the unique dominance of direct microbial electron transfer over radical-mediated pathways in biofilm systems. These results demonstrate that the degradation of antibiotics by the biofilm formed through the interaction between *B. megaterium* and iron minerals is independent of free radicals.

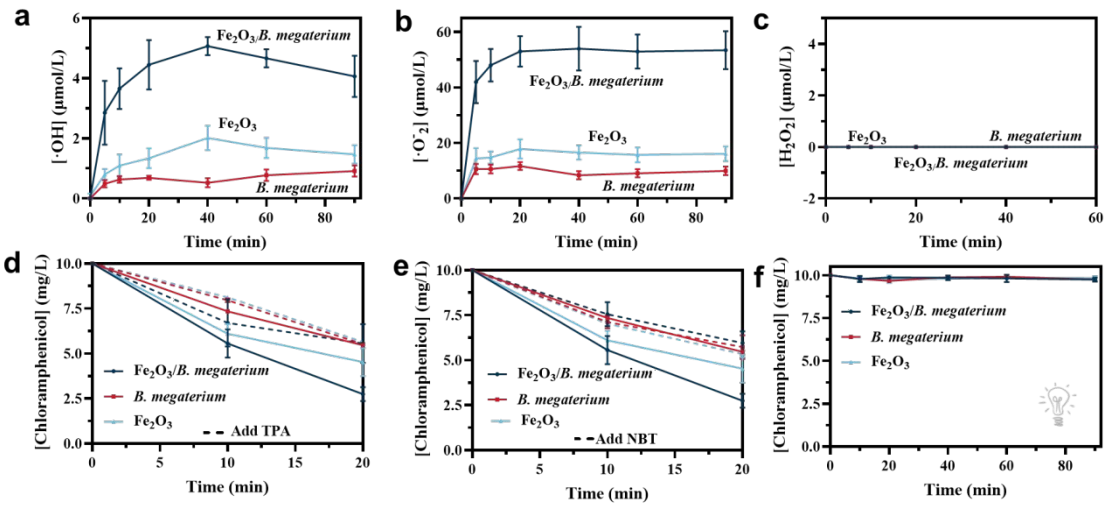

Figure 1. The types and concentrations of ROS generated by Fe_2O_3/*B. megaterium*, *B. megaterium* alone, and Fe_2O_3 alone (a-c). CPL degradation with/without ROS quenching (d-f); CPL degradation in dark (f).