

CeO₂-MXene Composites for Efficient Ibuprofen Destruction via Hybrid Catalytic Ozonation Photodegradation

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Highlights

- CeO₂-MXene composite demonstrated high efficiency for ibuprofen degradation in a hybrid catalytic ozonation-photodegradation system.
- Synergistic interaction between CeO₂ and MXene enhanced ozone activation and charge transfer, improving catalytic performance.
- Increased generation of reactive oxidative species (ROS) significantly accelerated the destruction of pharmaceutical contaminants.
- MXene-based composites show strong potential as multifunctional catalysts for advanced and sustainable wastewater treatment of emerging contaminants.

1. Introduction

With the continuous growth of the global population at an unsustainable rate, the depletion of clean water resources worldwide is becoming increasingly severe [1]. Consequently, the need for efficient wastewater treatment has become more critical than ever. Currently, more than 700 emerging contaminants (ECs), originating from both synthetic and natural sources, are discharged into water bodies in an uncontrolled manner, leading to the formation of recalcitrant wastewater containing hazardous pollutants [2, 3]. These ECs include personal care products, organic industrial compounds, and pharmaceutically active substances that may pose significant risks to both environmental and human health.

Ibuprofen (IBU), chemically known as 2-(4-isobutylphenyl) propionic acid, is a widely used non-steroidal anti-inflammatory drug frequently detected in wastewater systems, as reported in several studies [4–6]. Therefore, the development of sustainable strategies for treating contaminated water has become a global priority. Most currently applied advanced wastewater treatment technologies rely on physical separation processes and biological oxidation methods, which are often costly and face various operational limitations [7, 8]. In this context, integrating treatment techniques such as ozonation and photodegradation, along with the use of non-conventional catalytic materials, represents a promising and sustainable approach for water purification [9].

Advanced oxidation processes (AOPs) are widely recognized as effective technologies for the removal of a broad range of organic pollutants from wastewater [6]. These processes include several major categories such as photocatalysis (PC), ozonation (O₃), Fenton reactions, wet air oxidation (WAO), hydrogen peroxide (H₂O₂)-based oxidation, and sonication. Additionally, hybrid systems combining multiple processes have been developed, including PC/H₂O₂, PC/chlorine, O₃/H₂O₂, and PC/O₃ systems [10]. The fundamental mechanism underlying AOPs involves the generation of highly reactive oxidizing radicals capable of degrading complex organic pollutants [11].

Among these technologies, hybrid ozonation systems have demonstrated significant potential for the degradation, mineralization, and detoxification of various contaminants present in wastewater effluents [11]. Moreover, these hybrid approaches help overcome the limitations associated with single ozonation processes, such as the selective reactivity of ozone, limited mass transfer, relatively slow reaction rates, and the high energy demand required for ozone generation [11, 12].

2. Methods

CeO₂-5%MXene composite was synthesized via a modified etching-hydrothermal method. The MAX phase (Ti₃AlC₂) was first exfoliated using a LiF/HCl solution instead of HF to produce MXene. Specifically, 1 g of Ti₃AlC₂ was etched using 0.67 g LiF in 10 mL of 9 M HCl, followed by five washing and decantation cycles to obtain purified MXene. The material was then functionalized with CeO₂ using a hydrothermal route with a CeO₂:MXene molar ratio corresponding to 5% MXene loading. The resulting CeO₂-MXene composite was dried overnight at room temperature.

The synthesized materials were characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM) coupled with energy-dispersive spectroscopy (EDS), nitrogen physisorption for BET surface area determination, and UV-Vis diffuse reflectance spectroscopy (UV-DRS) for optical properties and bandgap estimation.

Catalytic performance was evaluated in a semibatch gas-liquid reactor for the destruction of ibuprofen (IBU) in a hybrid ozonation-photodegradation system. The reactor (1100 mL) was connected to an ozone generator producing approximately 60 mg L⁻¹ ozone at an oxygen flow rate of 450 mL min⁻¹. UV irradiation was provided by a 6 W lamp. Reaction parameters such as temperature and pH were controlled, and samples were periodically collected over 3 h. IBU concentration was quantified using HPLC analysis.

3. Results and discussion

XRD analysis confirmed the successful formation of the CeO₂-MXene composite. The characteristic MXene diffraction peak (~7.8°) was not clearly visible due to its low loading (5%). SEM images revealed the typical layered sheet-like morphology of MXene and the composite structure, while EDS confirmed the presence of titanium in the CeO₂-MXene material. BET analysis showed surface areas of 49.6, 2.4, and 14.2 m² g⁻¹ for CeO₂, MXene, and CeO₂-MXene, respectively. UV-DRS analysis indicated absorption edges around 410 nm for both CeO₂ and the composite, with estimated bandgap energies of 2.53 eV for CeO₂ and 2.34 eV for CeO₂-MXene, suggesting improved light absorption after MXene incorporation.

Catalytic tests demonstrated that the CeO₂-MXene composite significantly enhanced the degradation kinetics of ibuprofen in the hybrid ozonation-photodegradation system compared with CeO₂ and MXene alone. This improved activity is attributed to the formation of a Schottky junction between CeO₂ and MXene, which promotes electron transfer from CeO₂ to MXene and suppresses electron-hole recombination, thereby enhancing reactive oxidative species generation. The results will be presented to highlight the potential of CeO₂-MXene composites as efficient catalysts for advanced wastewater treatment.

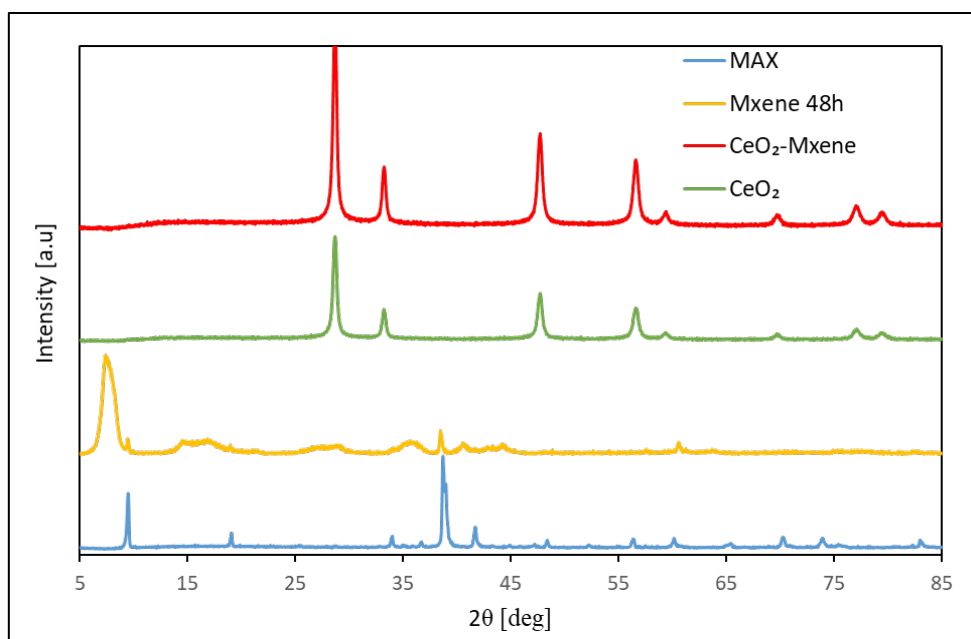


Figure 1 XRD spectra of Max, CeO₂, Mxene and CeO₂-Mxene composite.

4. Conclusions

In summary, the CeO₂-Mxene composite was fabricated via hydrothermal method and characterized to be tested in the catalytic ozonation-photocatalytic hybrid system for the destruction of IBU. The improved catalytic performance was attributed to the Schottky junction in the CeO₂.Mxene structure, which promoted the movement of the photoinduced electrons and hindered holes from approaching Mxene, resulting in the spatial separation of the electron-hole pairs. Further studies should focus on the by-products of the reaction and the corresponding mechanism using this hybrid system.

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Keywords

CeO₂-MXene composite; Hybrid Catalytic ozonation; Photodegradation; Ibuprofen removal