Fe Doped Manganese Oxide (Mn₂O₃) and its Photocatalytic Applications

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**Abstract:** Fe-doped manganese oxide (Mn₂O₃) nanocomposites are highly regarded for their enhanced photocatalytic abilities, crucial for environmental cleanup. While Mn₂O₃ shows potential in photocatalysis, issues like charge recombination and light absorption can limit its effectiveness. Fe doping adjusts the electrical structure, improves visible light absorption, and boosts charge carrier mobility, enhancing these properties. Fe-doped Mn₂O₃ can degrade organic contaminants in water under artificial or solar light.Fe-doped Mn₂O₃ nanocomposites were synthesized using a hydrothermal method. Precursors KMnO₄ (0.2 M), urea, and 5 mol% Fe(NO₃)₂ were dissolved in 80 mL of distilled water and stirred to form a homogeneous solution. This solution was transferred to a 100 mL autoclave and heated at 140 °C for 16 hours. After cooling to room temperature, the product was washed with ethanol and distilled water and dried at 80°C for 12 hours.The resulting Fe-doped Mn₂O₃ nanocomposites exhibited enhanced photocatalytic activity. Fe improved the material’s ability to generate reactive oxygen species under light irradiation, leading to more efficient pollutant degradation. The X-ray diffraction (XRD) pattern shows distinct peaks, indicating the sample's crystalline nature. The scanning electron microscope (SEM) image confirms the presence of key elements, while the energy-dispersive X-ray spectroscopy (EDX) image reveals the elemental composition in the same or a similar region. The highest absorbance peak indicates the concentration of methylene blue before photocatalytic degradation.Fe-doped Mn₂O₃ nanocomposites demonstrate significant potential in photocatalytic applications for environmental remediation. The improved performance, due to the synergistic effects of Fe doping, suggests these materials could be effectively used in photocatalytic processes for pollutant degradation.

**Keywords:** Fe-doped manganese oxide, Mn₂O₃ nanocomposites, photocatalytic activity, SEM, XRD, EDX, environmental remediation, hydrothermal synthesis, pollutant degradation.

# Introduction

Fe-doped manganese oxide (Mn₂O₃) nanocomposites have emerged as promising materials for photocatalytic applications due to their enhanced activity and stability. Photocatalysis using metal-doped oxides has shown significant potential in environmental remediation, particularly in degrading organic pollutants [(*Synthesis and Characterization of Fe-Doped Manganese Oxide Nanoparticle by Using Chemical Precipitation Method*, n.d.)](https://paperpile.com/c/R1IkcA/DQIs). The study details the synthesis and characterization of Fe-doped Mn₂O₃ nanoparticles using chemical precipitation, showing enhanced photocatalytic properties. This aligns with our research on Fe-doped Mn₂O₃ nanocomposites, demonstrating that Fe doping improves photocatalytic efficiency, making it valuable for environmental applications [(“Manganese Oxide Nanoparticles Synthesis Route, Characterization and Optical Properties,” 2023)](https://paperpile.com/c/R1IkcA/M8qA). The research covers the synthesis routes, characterization, and optical properties of manganese oxide nanoparticles. It emphasizes how different synthesis methods affect the properties and performance of the nanoparticles [(Ajay et al., 2023; Chokkattu et al., 2023; Padarthi et al., 2023)](https://paperpile.com/c/R1IkcA/XmuyX+IVgdX+Sn1ME). This is relevant to our work on Fe-doped Mn₂O₃ nanocomposites, as understanding these synthesis routes and properties is crucial for optimizing the photocatalytic efficiency of our nanomaterials [(Sikaria et al., 2024)](https://paperpile.com/c/R1IkcA/ISsw).The concept of photocatalytic degradation involves using semiconductor materials (like transition metal nanoparticles) to degrade organic pollutants under light irradiation [(Dharman et al., 2023; S. Sindhu et al., 2023; Sreenivasagan et al., 2023)](https://paperpile.com/c/R1IkcA/DmHUG+RMnxq+D0F1P). These nanoparticles, when excited by light, generate electron-hole pairs that can participate in redox reactions with organic pollutants adsorbed on their surface or in the surrounding solution [(Ali et al., 2018)](https://paperpile.com/c/R1IkcA/nMr3). Studying manganese-doped cerium oxide (CeO2) nanoparticles’ enhanced photocatalytic activity under visible and UV light provides insights relevant to our research on Mn₂O₃. It helps understand how different dopants (manganese vs. iron) affect photocatalytic efficiency, guiding optimizations for Fe-doped Mn₂O₃ under specific light conditions, crucial for environmental remediation applications [(Nikam et al., 2017)](https://paperpile.com/c/R1IkcA/Azg3). Studying the structural and magnetic properties of Fe-doped Mn₂O₃ orthorhombic bixbyite provides valuable insights for our research. Understanding these properties helps elucidate how iron doping influences the crystal structure and magnetic behavior, which are crucial for optimizing Fe-doped Mn₂O₃’s photocatalytic performance [(Ramakrishnan et al., 2023; Shenoy & Maiti, 2023; J. S. Sindhu et al., 2023)](https://paperpile.com/c/R1IkcA/LBlUa+rkT2U+555uW). This knowledge aids in tailoring dopant concentrations and structural characteristics to enhance photocatalytic efficiency for environmental remediation applications [(Soni et al., 2023)](https://paperpile.com/c/R1IkcA/R1s1). Studying Fe-doped nano-cobalt oxide green catalysts for sulfoxidation and photodegradation offers direct insights relevant to optimizing Mn₂O₃ for efficient photocatalytic degradation of organic pollutants [(Shahzadi et al., 2023)](https://paperpile.com/c/R1IkcA/h2ot). Research on the hydrothermal synthesis of Fe-doped cadmium oxide, demonstrating bactericidal behavior and highly efficient visible light photocatalysis, provides relevant insights for our study. Understanding these dual functionalities guides the optimization of Mn₂O₃ for effective visible light-driven photocatalytic degradation of organic pollutants, aiming to enhance its performance in environmental remediation applications [(Hastuti et al., 2021)](https://paperpile.com/c/R1IkcA/0YzR). Studying the effects of Fe-doping on Mn₂O₃, including phase transitions, defect structures, and electrical properties.Understanding these aspects helps optimize Mn₂O₃ for enhanced photocatalytic activity under visible light [(Radware Bot Manager Captcha, n.d.)](https://paperpile.com/c/R1IkcA/WF9I). Studying the photocatalytic performance of Fe-doped TiO₂ nanoparticles under visible-light irradiation offers insights directly relevant to optimizing Mn₂O₃ for effective visible-light photocatalysis [(Tonda et al., 2014)](https://paperpile.com/c/R1IkcA/ySB1). In addition to enhancing photocatalytic performance under natural sunlight, studying Fe-doped and -mediated graphitic carbon nitride nanosheets can provide insights into catalyst stability, reaction kinetics, and the role of dopants in improving overall efficiency and selectivity of photocatalytic processes [(Harini et al., 2024)](https://paperpile.com/c/R1IkcA/BONF).The study aims to synthesize and characterize Mn₂O₃ nanoparticles, investigating their photocatalytic efficiency under visible light for degrading organic pollutants. It seeks to understand the mechanisms enhancing their performance, assess their feasibility for environmental applications like wastewater treatment, and propose optimizations for improving their efficacy and practicality in real-world settings.

# Materials and methods

## Materials

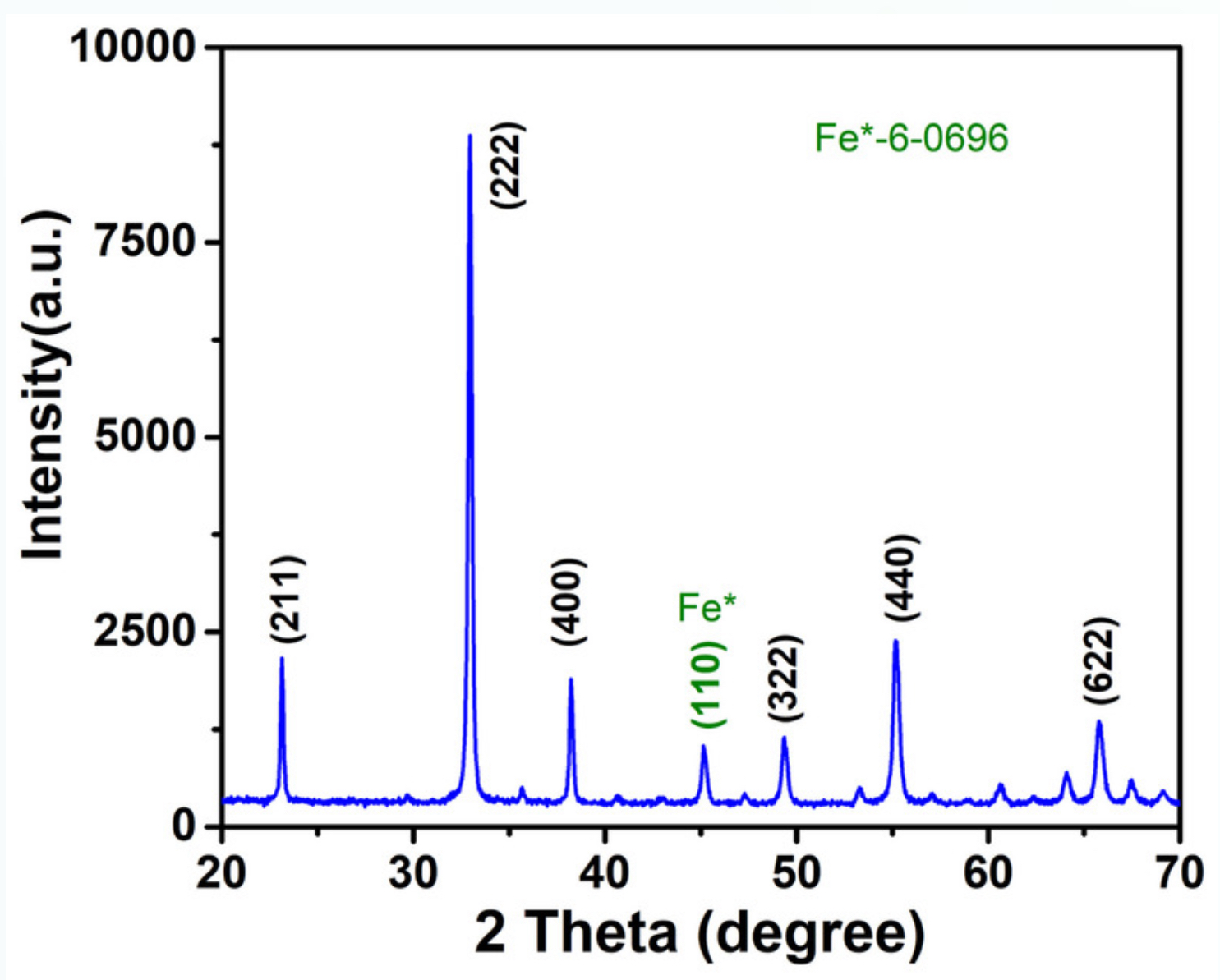
KMnO₄ (Potassium permanganate), Urea, Fe(NO₃)₂ (Iron(II) nitrate),Distilled water, Ethanol.

## Methodology

Mn₂O₃ nanocomposites have gained significant attention due to their potential in photocatalytic applications. In this study, we synthesized Fe-doped Mn₂O₃ nanocomposites using a hydrothermal method. The precursors included KMnO₄ (0.2 M), urea, and 5 mol% Fe (NO₃)₂ dissolved in 80 mL of distilled water. The solution was homogenized by stirring, transferred to a 100 mL autoclave, and heated at 140 °C for 16 hours. After cooling, the product underwent washing with ethanol and distilled water, followed by drying at 80 °C for 12 hours. The resulting Fe-doped Mn₂O₃ nanocomposites exhibited enhanced photocatalytic activity, highlighting their potential for environmental remediation. This improvement is attributed to the synergistic effects of Fe doping, which enhances the generation of reactive oxygen species under light irradiation. These findings underscore the utility of Fe-doped Mn₂O₃ in photocatalytic processes for pollutant degradation.

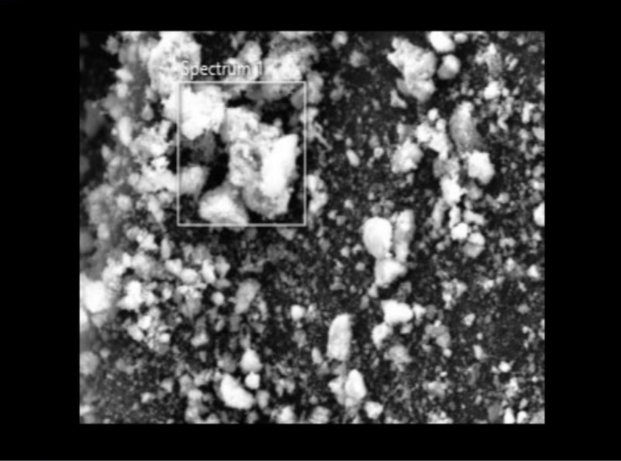
# Results

The following images and graphs are obtained as results of this research. Mn₂O₃ is a photocatalyst with enhanced properties due to the incorporation of iron (Fe).Figure 1 shows the X-ray Diffraction (XRD) pattern shows distinct peaks (e.g., (211), (222), (400)), indicating the crystalline nature of the sample. The peak at (222) suggests high crystallinity in that plane. Annotations “Fe\*” and “Fe+-6-0696” indicate iron phases, possibly iron oxide. Peak intensities (measured in a.u.) reveal the relative abundance of these phases. XRD is crucial for identifying crystal phases, their parameters, and understanding material properties.

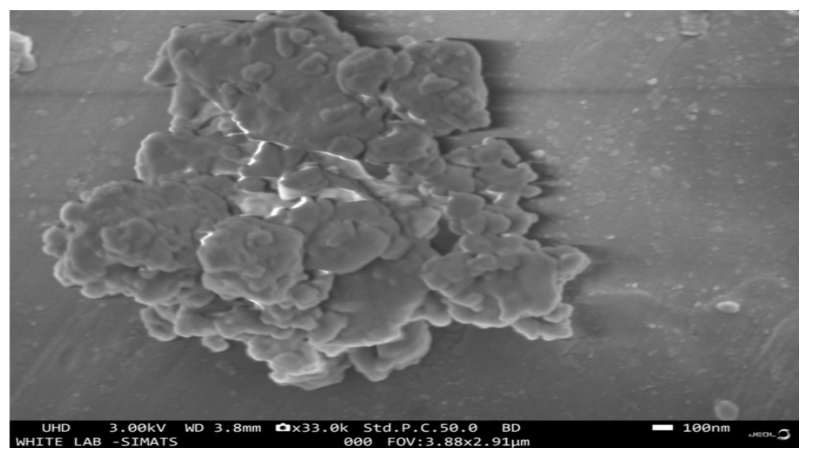


**Figure1:** XRD ( X ray diffraction) pattern of Fe

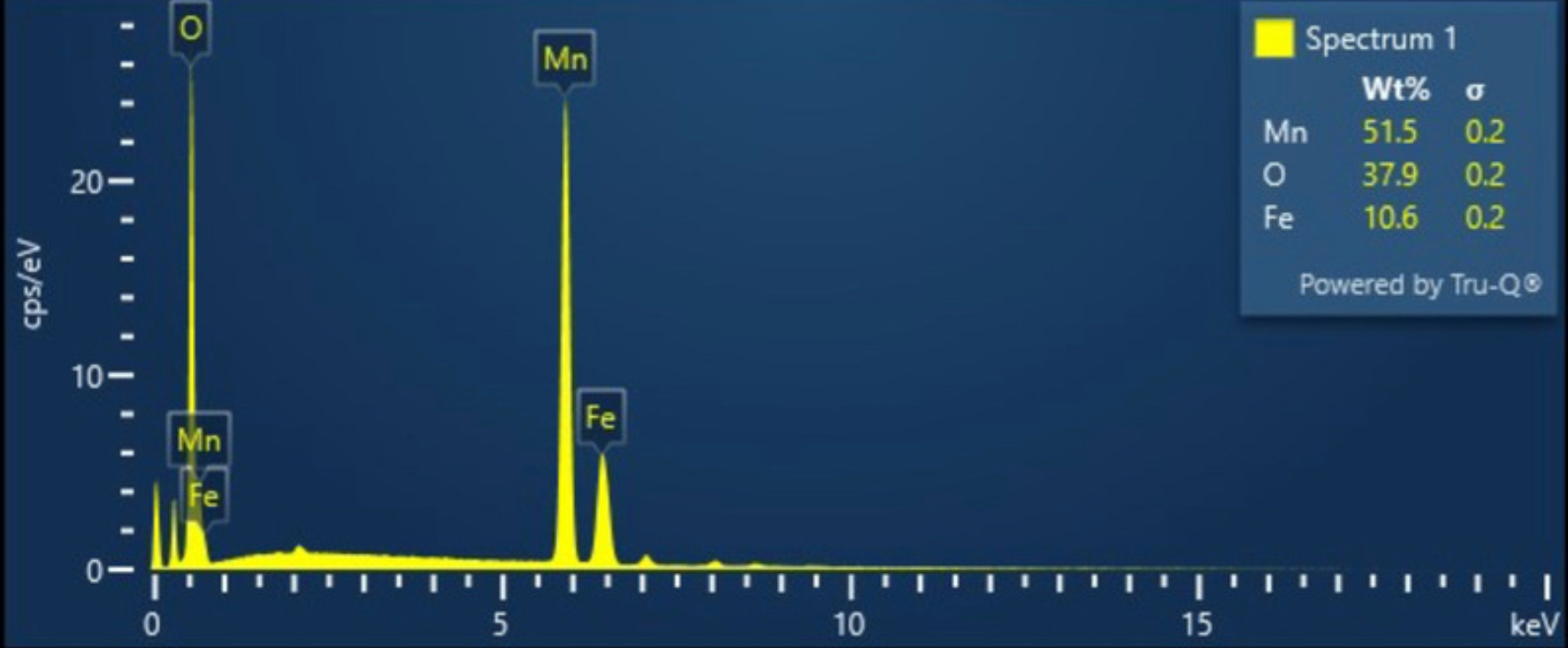
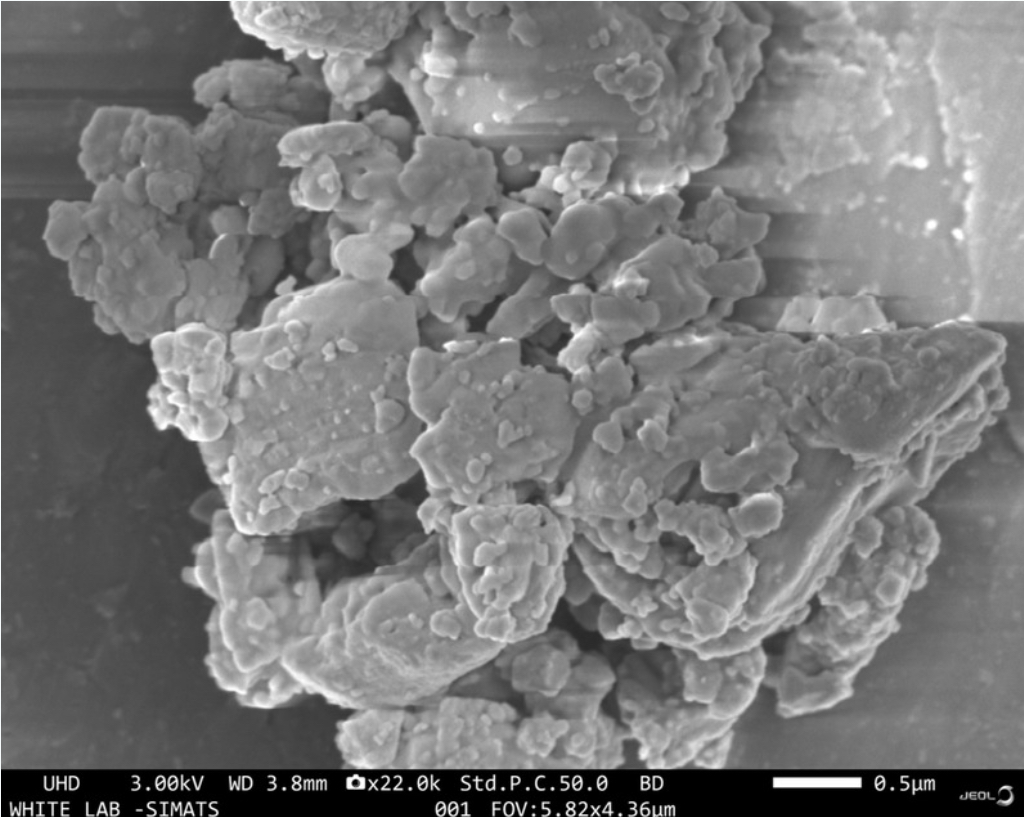
Figure 2 (SEM EDX) shows a detailed surface morphology of the sample, with a square marked "Spectrum 1" indicating the region selected for elemental analysis. This area was analyzed using Energy Dispersive X-ray Spectroscopy (EDS) to determine its elemental composition. Figure 3 (SEM 000) presents the EDS spectrum obtained from the selected region in the SEM EDX image. The spectrum reveals significant peaks for manganese (Mn), iron (Fe), and oxygen (O), confirming the presence of these elements in the analyzed area.



**Figure 2** SEM EDX



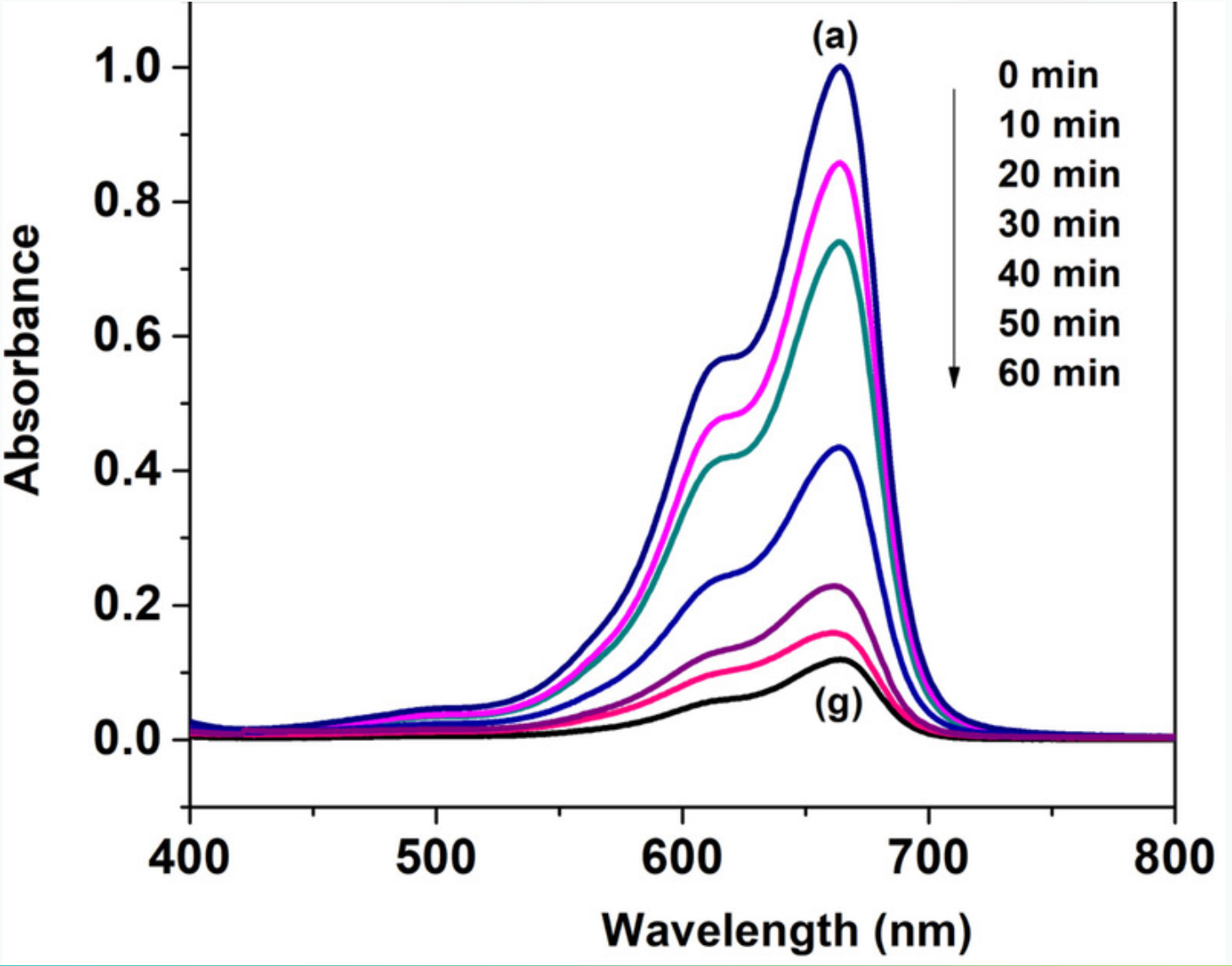
**Figure 3** SEM 000 pictures of Fe doped manganese oxide.



1. (b)

Figure 4 (a) (b) SEM 001 and EDX graph of Fe doped manganese oxide

In Figures 4 and 5, the SEM 001 image provides a detailed morphological analysis of the particle cluster, while the EDX image offers the elemental composition of the same or a similar region. Together, these images present a holistic view of the sample by combining structural details with compositional information. This integrated approach is crucial for comprehensive material characterization, as it helps correlate the material's structure with its chemical composition and potential functionalities.



**Figure 5:** Photocatalysis MB.

Figure 6 shows that the highest absorbance peak is around 665 nm, indicating the concentration of methylene blue before any photocatalytic degradation. Over time, the absorbance at 665 nm decreases, demonstrating a reduction in methylene blue concentration due to photocatalytic activity. By 60 minutes, the absorbance is significantly lower, indicating substantial degradation of methylene blue.

# Discussion

The SEM images reveal a porous surface with aggregated particles and intricate flower-like structures, suggesting a high surface area and beneficial morphologies for enhanced photocatalytic activity [(Lakshmi Anvitha et al., 2024)](https://paperpile.com/c/R1IkcA/zG3L). EDX analysis confirms the presence of iron-manganese oxides, with significant amounts of Mn and Fe identified. XRD analysis indicates high crystallinity matching iron-manganese oxide standards, crucial for efficient charge separation. UV-Vis spectra demonstrate effective methylene blue degradation, correlating with the material's structural and compositional characteristics observed in SEM and XRD analyses, highlighting its potential for catalytic applications [(C et al., 2024)](https://paperpile.com/c/R1IkcA/LK36).Both studies focus on enhancing advanced oxidation processes for environmental remediation. They utilize composite materials Fe₃O₄-MnO₂ to enhance catalytic performance. In our study, we used Fe-Mn₂O₃ for photocatalytic applications. Characterization techniques like SEM, EDX, and XRD are used to analyze morphology, composition, and crystal structure. Both evaluate photocatalytic efficiency under specific conditions and aim to degrade environmental pollutants like bisphenol A, highlighting their applications [(Dong et al., 2020)](https://paperpile.com/c/R1IkcA/ooro). Manganese oxide-coated tin oxide nanowires for capacitive behavior and Fe-doped manganese oxide nanoparticles for photocatalytic activity. They employ similar characterization techniques to analyze morphology and composition, aiming to optimize functional outcomes relevant to their respective applications in energy storage and environmental remediation [(Yan et al., 2010)](https://paperpile.com/c/R1IkcA/PmlL). The study on Mn-doped Fe2O3/diatomite granular composite as a Fenton catalyst for rapid organic dye degradation shares similarities with research on Fe-doped manganese oxide nanoparticles for photocatalytic applications [(Kasabwala et al., 2021; Rajeshkumar & Lakshmi, 2021; Varghese et al., 2023)](https://paperpile.com/c/R1IkcA/gSmV0+oQI75+eYZBg). Both focus on enhancing catalytic performance through composite design [(Dai et al., 2021)](https://paperpile.com/c/R1IkcA/GcD1). The research on mixed iron-manganese oxide nanoparticles explores their potential applications, likely focusing on their catalytic, magnetic, or environmental properties. These nanoparticles are synthesized to combine the beneficial characteristics of both iron and manganese oxides, aiming for enhanced performance in various technological fields [(*Mixed Iron-Manganese Oxide Nanoparticles*, 2009)](https://paperpile.com/c/R1IkcA/yefW). The research on low-temperature spin glass transition in bixbyite-type FeMnO3 shares similarities with Our study on Fe-doped manganese oxide nanoparticles [(Keerthana & Ramesh, 2021; Murugesan, 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/R1IkcA/2ORGi+Y5n5H+mjmCf)[(Keerthana & Ramesh, 2021; Murugesan, 2021; Subramanian et al., 2021; Tiwari & Jain, 2021)](https://paperpile.com/c/R1IkcA/2ORGi+Y5n5H+mjmCf+sfFXu). Both explore material properties involving iron (Fe) and manganese (Mn), employing similar characterization techniques to understand structural and magnetic behaviors for their respective (Nikalje et al., 2024) (Chehelgerdi et al., 2023) applications in magnetic transitions and photocatalytic activity [(“Evidence of Low Temperature Spin Glass Transition in Bixbyite Type FeMnO3,” 2017)](https://paperpile.com/c/R1IkcA/BWNz). Prussian blue analogue-derived Mn-Fe oxide nanocubes as highly efficient oxygen evolution reaction (OER) electrocatalysts is similar to Our research on Fe-doped manganese oxide nanoparticles for photocatalytic applications. Both studies focus on designing advanced catalyst materials, using similar characterization techniques to understand morphology, structure, and composition [(Zhao et al., 2020)](https://paperpile.com/c/R1IkcA/uuHd). This study focuses on the sonochemical synthesis of MnFe2O4 nanoparticles. Sonochemistry involves using ultrasound waves to induce chemical reactions, which can lead to the formation of nanoscale materials like MnFe2O4 The nanoparticles synthesized are evaluated for their electrochemical and photocatalytic properties [(Evaluation Composite Restoration Posterior Teeth Proanthocyanidin Pretreatment Liner Using Fédération Dentaire Internationale Criteria: Split-Mouth Randomized Controlled Trial, n.d.; Pranati et al., 2021; Sakthi 2021)](https://paperpile.com/c/R1IkcA/o0kxJ+uP8TP+fWhzF)[(G. & Ganapathy, 2022; Kumar & Ramesh, 2021)](https://paperpile.com/c/R1IkcA/tlLu+rt2D)). This research is relevant as it explores another oxide system (MnFe2O4) and its potential in catalytic applications, similar to how you investigate Fe-doped Mn2O3 for photocatalysis [(“Sonochemical Synthesis of MnFe2O4 Nanoparticles and Their Electrochemical and Photocatalytic Properties,” 2021)](https://paperpile.com/c/R1IkcA/8rWt). Here, researchers employ a solvothermal synthesis method to create magnetically separable rGO/MnFe2O4 hybrids. These hybrids combine reduced graphene oxide (rGO) with MnFe2O4 nanoparticles, enhancing their photocatalytic efficiency under visible light for the degradation of methylene blue (MB) [(Mathew et al., 2024)](https://paperpile.com/c/R1IkcA/lehV). This study showcases the development of composite materials for efficient pollutant degradation, analogous to Our research on enhancing photocatalytic activity with Fe-doped manganese oxide nanoparticles [(“One-Pot Solvothermal Synthesis of Magnetically Separable rGO/MnFe2O4 Hybrids as Efficient Photocatalysts for Degradation of MB under Visible Light,” 2019)](https://paperpile.com/c/R1IkcA/9dIW). This study explores MnFe2O4 decorated reduced graphene oxide heterostructures as nanophotocatalysts. Similar to the previous study the focus is on combining MnFe2O4 with reduced graphene oxide to enhance catalytic properties, specifically for methylene blue dye degradation. The heterostructures formed and their catalytic performance highlight advancements in composite materials for environmental remediation, akin to Our investigation with Fe-doped Mn2O3 [(“MnFe2O4 Decorated Reduced Graphene Oxide Heterostructures: Nanophotocatalyst for Methylene Blue Dye Degradation,” 2020)](https://paperpile.com/c/R1IkcA/3cBF). Researchers use ultrasound-assisted synthesis to create Fe3O4/ɑ-MnO2 nanocomposites. These nanocomposites are designed for efficient photodegradation of organic dyes, leveraging the synergistic effects of Fe3O4 and ɑ-MnO2. This study underscores innovative synthesis techniques and composite design principles similar to those explored in Our research on Fe-doped manganese oxide nanoparticles [(“Ultrasound Assisted Synthesis of Magnetic Fe3O4/ɑ-MnO2 Nanocomposite for Photodegradation of Organic Dye,” 2021)](https://paperpile.com/c/R1IkcA/hMLm). This review or study likely discusses various nanostructured composites of metals, focusing on their synthesis methods and applications. Understanding these synthesis techniques and composite structures is crucial for advancing material design principles, relevant for both Our research and the studies mentioned above [(“Synthesis of Nanostructured Composites of Metals,” 2011)](https://paperpile.com/c/R1IkcA/6OSh). Investigating the antibacterial effects of Fe3O4 nanoparticles, this study explores their interactions with bacterial cells and their potential biomedical applications. Although focusing on different applications (antibacterial rather than photocatalytic), it highlights diverse functionalities of iron oxide nanoparticles, pertinent for understanding broader applications in nanotechnology [(Gabrielyan et al., 2019)](https://paperpile.com/c/R1IkcA/5T4v). Synthesis and characterization of Mn-Pt/AC nanoparticles for photocatalytic and antibacterial applications. This study combines manganese and platinum nanoparticles on activated carbon for enhanced catalytic and antibacterial properties, illustrating advanced composite design principles similar to Our research focus on Fe-doped Mn2O3 [(Gul et al., 2022)](https://paperpile.com/c/R1IkcA/whx3). Preparation of Fe2O3 nanoparticles doped with In2O3 for photocatalytic degradation of rhodamine B dye. This research explores the doping of iron oxide nanoparticles with indium oxide to improve their photocatalytic activity, demonstrating strategies to enhance catalytic efficiency similar to those in Our Fe-doped manganese oxide nanoparticles study [(Gul et al., 2022; “Preparation of Fe2O3 Nanoparticles Doped with In2O3 and Photocatalytic Degradation Property for Rhodamine B,” 2020)](https://paperpile.com/c/R1IkcA/whx3+ubFC). Hydrothermal preparation of core–shell Fe3O4@PbS nanocomposites for photo-degradation of toxic dyes. The focus here is on creating core-shell nanocomposites with iron oxide (Fe3O4) cores and lead sulfide (PbS) shells for efficient dye degradation under light irradiation. This approach parallels our investigation into enhancing photocatalytic properties through composite materials [(Hedayati et al., 2016)](https://paperpile.com/c/R1IkcA/oIp8). This study focuses on the synthesis of Fe-doped MnO2 nanoparticles and their application as efficient photocatalysts under visible light for degrading organic pollutants. It aligns well with our research interest in Fe-doped manganese oxide nanoparticles and could provide valuable insights into synthesis methods and photocatalytic performance [(Can et al., 2021)](https://paperpile.com/c/R1IkcA/4eW6).

# Conclusion

The synthesized iron-manganese oxide material exhibits promising characteristics for photocatalytic applications. SEM analysis revealed a porous structure with aggregated particles and intricate morphologies conducive to high surface area, while EDX confirmed the presence of essential elements like Mn and Fe. XRD analysis indicated a crystalline nature beneficial for charge separation. The efficient degradation of methylene blue observed in UV-Vis spectra further underscores its potential as an effective photocatalyst. These findings collectively suggest that the material holds strong prospects for addressing environmental challenges through advanced catalytic processes.

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