

Microwave – assisted catalytic degradation efficiency of non-steroidal anti-inflammatory drug (NSAIDs) using magnetically separable magnesium ferrite (MgFe_2O_4) nanoparticles

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Abstract

In the present study, we report the green synthesis of novel magnetically separable MgFe_2O_4 nanoparticles using *Cajanus cajan* (L.) Millsp leafs via combustion method. The MgFe_2O_4 were characterized by powder X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), transmission electron microscopy (TEM), vibrating sample magnetometer (VSM), and UV-Vis spectroscopy. The crystalline structure of MgFe_2O_4 NPs was confirmed via XRD electron micrograph and TEM showed that the MgFe_2O_4 NPs were nearly spherical particles with particle size ranging between 5-15 nm. UV-vis DRS study showed the optical band gap of MgFe_2O_4 NPs was found to be 1.0 eV. Microwaves (MW) assisted degradation of PCM-dolo drug on MgFe_2O_4 were performed at different operating parameters such as time (0-30 min), drug concentration (PCM-dolo 50 mg/L), initial concentration of MgFe_2O_4 (0 mg/L -110 mg/L), and microwave power (100W-600W) to obtained the residual absorbance of PCM-dolo on MgFe_2O_4 . Experimental data was used to compute the degradation efficiency of PCM-dolo on MgFe_2O_4 . The enhanced catalytic performance could be ascribed to the production of MW-induced active species, such as holes (h^+), superoxide radicals ($\cdot\text{O}_2^-$) and hydroxyl radicals ($\cdot\text{OH}$) in the degradation process. A possible degradation mechanism and pathway was proposed in MW/ MgFe_2O_4 system. Moreover, MgFe_2O_4 as an eco-friendly catalyst could be easily separated and recycled by a magnet.

Introduction

Paracetamol based drugs (4-hydroxyacetaniline, N-acetyl-p-aminophenol, acetaminophen) come under non-steroidal anti-inflammatory drugs (NSAIDs) class. It helps in reducing pain, fever and in higher doses reduces inflammation. Dolo-650 tablet has antipyretic substance that reduces fever. Being a common analgesic and antipyretic drug, paracetamol dolo - 650 (acetaminophen) is heavily used all over the world [1–3]. It is considered one of the three most prescribed drugs, and is ranked among the 200 top prescriptions in the world [4]. Paracetamol has been detected in the surface waters, wastewater, and drinking water throughout the world, this compound reaches in the natural environment through direct disposal of domestic drugs, excretion by humans or inappropriate treatment of industrial effluents [5]. Frequent occurrence of pharmaceuticals in aquatic environments and drinking water has raised a concern about their toxic effects on environment and human health [6]. To avoid undesired accumulation of drug in aquatic environments, development of effective water treatment processes for degrading pharmaceuticals from water is a new challenge for the scientific community.

Many studies have been conducted with the main purpose of finding an effective and viable method to degrade paracetamol [7]. Among them, electrocatalysis, photo-Fenton, chemical, sonolysis, nonthermal plasma, photocatalysis, reverse osmosis, activated carbon, chlorination and ozonation [7–11]. In previous studies, only partial degradation of paracetamol was reported, between 14% and 88% instead of total mineralization [7]. By above conventional methods it is very difficult to eliminate the paracetamol dolo residue [9, 12]. For the above reason, advanced oxidation processes (AOPs) under microwave

irradiation, based on the in-situ generation of highly reactive species, (H_2O_2 , $\bullet\text{OH}$, $\text{O}_2^{\bullet-}$ and O_3) and hot spots are a promising route for the nonselective oxidation degradation of a wide variety of toxic organic and inorganic water pollutants into harmless nontoxic end-products [13–15]. Paracetamol dolo has been used as a model pollutants, and the degradation of paracetamol dolo by different techniques has been reported by several authors [16]. In recent years, heterogeneous photocatalysis degradation of paracetamol dolo and other pharmaceutical pollutants from the water has become an effective technology and complete mineralization of paracetamol into CO_2 and H_2O etc. has been confirmed [17].

Several metal oxides, metal ferrites such as TiO_2 , ZnO , WO_3 , CuO , Cu_2O , Bi_2O_3 , MFe_2O_4 and ZnFe_2O_4 [18–22] have been extensively used for the degradation of toxic pollutants. Among these, MgFe_2O_4 has drawn significant attention due to, non-toxic, stable in aqueous media above pH 4, consist only of earth-abundant elements, and its highly reactive surface, The technique still requires improvement to overcome some major drawbacks such as high cost, long exposure times that's why degradation of pollutants under microwave irradiation has gained momentum as the technique is reported to be facile, taking very less reaction time, provides uniform thermal environment and the fragments generated are non-toxic in nature [23–28].

Green nanotechnology has gained attraction in the synthesis of metallic nanoparticles due to their cost-effectiveness, simple preparation steps, and environmentally –friendly. Hence, in this present study, we synthesized MgFe_2O_4 nanoparticles via a green route using *Cajanus cajan* (L.) Millsp. leaf extracts with the aim to develop an eco- friendly and facile strategy for designing photocatalysts with minimal utilization of toxic chemicals and reagents. The spectral, thermal, morphological, magnetic and optical properties of the synthesized nanoparticles were investigated using Fourier-transform infrared (FT-IR), Thermal gravimetric analysis, scanning electron microscopy (SEM), energy dispersive X-ray (EDX) with elemental mapping, transmission electron microscopy (TEM), X-ray diffraction (XRD), VSM and UV – vis spectroscopy (UV – vis) techniques. We have explored degradation of Paracetamol Dolo-650 under microwave irradiation and have compared with the reported catalytic performance of such materials so as to establish the high efficiency of microwave-assisted catalytic degradation which could be used to safely degrade these drugs prior to their disposal in water bodies. The degradation fragments were identified by using LC-MS technique, and the degradation mechanism was proposed via oxidative radical species and hot spots under microwave irradiations.

Experimental Section

Materials

Cajanus cajan (L.) Millsp. Leaves were collected from Hardoi U. P. India. $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, NH_3 , were purchased from Sigma-Aldrich Company USA, ethanol (Merck, India), Calpol (cipla), 1,4-Benzoquinone (Sigma Aldrich, USA), tert-butanol (Merck-Millipore, India), were of analytical grade and used without further purification, ethanol, and DW.

Preparation of extraction

Cajanus cajan (L.) Millsp. Leaves were collected from the village of Hardoi U P India. 100 g of the leaves were washed with distilled water to remove dust particles and dried in air oven. The dried were grind to make powder, added in to 50 ml methanol: water solution (1:3) and stirred at 60 °C for 1 h. After boiling, the mixture was cooled and filtered and the filtrate was collected and stored at 40 °C for further synthesis.

Synthesis of MgFe_2O_4 nanoparticles using *Canjanus cajan* (L.) Millsp..

50 g of $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ were dissolved in 20 ml and stirred for 15 min. Take 20 ml of natural *Canjanus cajan* (L.) Millsp. Leaf extract, was mixed with the 20 ml of aqueous solution of $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and $\text{Mg}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$. After 30 min stirring, 5 ml of NH_3 (32%) was slowly added as precipitator. The solution was slowly heated for 1h at 150°C. After drying the product was suddenly ignited and release fire and smoke. The obtained brown precipitate was washed twice with distilled water. Then it was dried in oven for 12 hr at 70°C, MgFe_2O_4 nanoparticles was obtained.

Characterization

Spectral studies

Fourier Transform Infrared (FTIR) studies was performed on Shimadzu FT-IR spectrophotometer Affinity-1) for structural confirmation in the form of KBr pellet. X-Ray Photoelectron spectroscopy was done on XPS spectrometer equipped with a hemi-spherical electron energy analyzer.. For the study the electronic transitions and band gap calculation UV-vis –IR diffuse reflectance spectroscopy (Perkin – Elmer Lamda 35, USA) was used to record the diffuse reflectance spectra.

Morphological studies

MgFe_2O_4 NPs were characterized via XRD using a non-monochromatized $\text{Al}(\text{K}\alpha)$ X-ray source, yielding photons of 1486.6 eV, Perkin-Elmer Model 5300). The morphology and elemental analysis were carried out by (FESEM-EDX) (FEI, Nova nano SEM 30 KVA, Germany) coupled with EDX. The Size and shape of synthesized materials were determined using High resolution electron emission microscopy (HRTEM) (FEI, Tehnai G² 20 HRTEM 200 kV, USA).

Thermal studies

For thermal stability of sample TGA was recorded on Thermal analyzer TA/DTA 6300, EXSTAR6000 and the sample were heated from 35–810 °C at the rate of 10°C min⁻¹ in presence of N₂ gas with flow rate of 20 ml min⁻¹.

Magnetic Studies

Vibrating sample magnetometer (VSM; Lake Shore 7304) was used to measure the magnetic properties of these synthesized MgFe_2O_4 nanoparticles.

Catalytic measurements

Degradation experiments were carried out using the laboratory microwave oven (Model Ladd Research, USA). Approximately 100 mg of the catalyst was dispersed in 100 ml amoxicillin solution (100 mg L^{-1}) and the suspension was sonicated for 10 min and kept under the dark condition to stabilize the adsorption–desorption equilibrium between the drug solution and catalyst. The solution was exposed to microwave irradiation for 30 min and aliquots of drug solution (5 ml) were taken out at regular time intervals of 0, 3, 6, 9, 12, 15, 18, 24, 27, and 30 min. The UV spectrum of the drug was recorded using UV–vis spectrophotometer model Perkin-Elmer Lambda 30. The λ_{max} values of PCM-dolo at 240 nm were recorded. To further clarify the photocatalytic mechanism involved in the degradation of Paracetamol dolo 650, the degradation intermediates within the experimental duration were determined with a liquid chromatography-mass spectrometry (LC-MS). Details on the intermediates detection by using LC-MS as reported in Zia et al 2020 [29–30].

Reusability test

The reusability of MgFe_2O_4 nanoparticles were dried evaluated in the microwave-assisted degradation process up to four cycles. MgFe_2O_4 nanoparticles were collected after completion of each cycle and were washed with distilled water and in a vacuum oven at 60°C for 12h. The obtained catalysts were reused in the next cycle and the process was repeated three times.

Results and discussion

The crystalline phase structure, orientation was studied by using XRD analysis and shown in Fig. 1. XRD spectra of MgFe_2O_4 nanoparticles indicate the peaks at $2\theta = 24.40^\circ, 27.56^\circ, 31.86^\circ, 35.09^\circ, 45.69^\circ, 53.21^\circ, 56.58^\circ, 62.73^\circ, 66.41^\circ, 73.2^\circ, 75^\circ$ and 78° corresponds diffraction planes (210), (220), (311), (222), (400), (422), (511), (603), (440), (620), (533), and (444) calcined in the X-ray diffraction spectra and they confirmed the formation of a spinel structure. Most of the diffraction peak matches the standard data (JCPDS-894924) for MgFe_2O_4 . The structure of the crystalline plane indicates the FCC (face centered cubic), the average particle size of MgFe_2O_4 nanoparticles can be calculated by the width of lines by using Debye–Scherrer's equation. The particle size of the crystallinity of MgFe_2O_4 nanoparticles was found to be 12.56 nm. This was further confirmed by the HR-TEM.

The FESEM micrographs and EDX spectrum of synthesized as MgFe_2O_4 nanoparticles were given in (Fig. 2a-d) which investigates the surface morphology and elemental analysis of synthesized materials. The FESEM image shows 200 μm scale morphology of synthesized MgFe_2O_4 nanoparticles (Fig. 2a) which showed clusters in which elongated spherical particles composed which were uniformly distributed almost similar size form an agglomeration. Figure 2b shows the energy dispersive spectrum

(EDS) of synthesized MgFe_2O_4 nanoparticles and the table gives quantitative estimation of elements obtained directly from spectrum through its atomic and weight percentages and corresponding theoretical values. The EDX results confirm the presence of MgFe_2O_4 nanoparticles in the sample. They showed the main intense peaks which are related to Mg, Fe and O with 11.65 wt%, 60.32 wt% and 28.03 wt% respectively which was consistent with the optimal stoichiometry close to MgFe_2O_4 nanoparticles. No other element No elements no other peaks associated with impurities or contamination are detected which asserted the purity of MgFe_2O_4 . Further confirm the particle size and morphology of synthesized as MgFe_2O_4 nanoparticles were analyzed by TEM analysis which shown in (Figure. 2c-d). The HR-TEM image of MgFe_2O_4 (Fig. 4a-b) nanoparticles showed aggregated nanostructure with spherical like particles and the average particles size of 5–15 nm. The diffraction pattern of MgFe_2O_4 (Fig. 4b) revealed the presence of crystalline phase exhibiting lattice fringes which were in correlation with the XRD results,

The FT-IR spectrum of the synthesized MgFe_2O_4 nanoparticles via green route was shown in Fig. 3 (a). The characteristics peaks of MgFe_2O_4 were noticed at 672 cm^{-1} , 704 cm^{-1} , 775 cm^{-1} and 860 cm^{-1} which are related to stretching vibrations of $\text{Fe}^{+3}-\text{O}^{2-}$ and $\text{Mg}^{+2}-\text{O}^{2-}$. The peak at 1145 cm^{-1} , 1080 cm^{-1} and 990 cm^{-1} are associated with vibrations of M-O-M ($\text{M} = \text{Mg}^{+2}$ or Fe^{+3}) in the fingerprint region corresponding to the orthorhombic crystalline structure of synthesized MgFe_2O_4 nanoparticles, while the peaks at 1353 cm^{-1} , 1418 cm^{-1} , 1605 cm^{-1} and broad band absorption at 3245 cm^{-1} are attributed to the bending and stretching vibration of O-H bond which were associated with the free and absorbed water molecules as well as the hydroxyl functional groups on the surface of the synthesized BaFe_2O_4 nanoparticles [28, 31–32]. Magnetic properties of synthesized MgFe_2O_4 nanoparticles were investigated by the magnetization versus applied magnetic field (M– H) curves at room temperature, and the results are shown in Fig. 3(b). It can be found that the magnetic response of MgFe_2O_4 nanoparticles shows a hysteresis or loop with the increase in the external applied magnetic field up to 10 kOe, which indicates the soft magnetic nature of the synthesized MgFe_2O_4 nanoparticles. The value of the saturation magnetization (Ms), coercivity (Hc), retaintivity (Mr) were obtained from this curve as 15.07 emu/g, 53.14, 98.53 emu/g Respectively. The synthesized material displayed normal (S-shaped) narrow hysteresis loop. Narrow loops indicated low coercivity value which indicates that the prepared material can be easily demagnetized. The Magnetic parameters like Ms, Mr, and Hc of the samples depend upon a number of factors such as anisotropy density, grain growth and A-B exchange interactions. *Smit and Wijn* [33] have reported saturation magnetization value for the bulk particle of MgFe_2O_4 as 27 emu g^{-1} , whereas in the present report, the value of the magnetic saturation of synthesized MgFe_2O_4 nanoparticles comes out to be 15.07 emu g^{-1} . The difference in the value of saturation magnetization can be explained on the basis of cation distribution. If any change in the concentration and nature of ions causes the resultant magnetization to be different from the reported on. Figure 3(c) shows the thermo gravimetric analysis (TGA) curve of the magnesium ferrite (MgFe_2O_4) nanoparticles examined at

room temperature upto 800°C under N₂ with a heating rate of 10°C per minute. The study of mass loss of the sample with the temperature increase is useful in determining the absorption of water, sample purity, carbonate content, removal of organic impurity, and the decomposition reactions. The decomposition process consists of three regions. They are 25–280°C, 280–365°C, and 365–800°C. The initial weight loss from 25 to 280°C is due to the removal of physically adsorbed water. The second weight loss in the temperature range of 280–365°C is due to the dehydration of OH group and the oxidation of complexes, and formation of metal oxide and spinel ferrites. The third stage of weight loss occurs between 365 and 800°C. This is due to the formation of the spinel phase. There is no weight loss observed above 800°C. This indicates the formation of pure magnesium ferrite (MgFe₂O₄) nanoparticles. The net weight loss is found to be 22.57% in the temperature range of 25 to 800°C and the maximum weight loss takes place before 400°C. TGA result showed that the MgFe₂O₄ nanoparticles more thermal stable. The UV-vis diffuse reflectance spectra (DRS) of MgFe₂O₄ nanoparticles shown in Fig. 3(d). The ferrite exhibited the adsorption properties at the region of visible light with the broad hump from 550 nm-800 nm. Optical band gap was calculated using the Kubelka–Munk function. The band gap values of MgFe₂O₄ nanoparticles was estimated to be 1.0 eV.

Microwave-assisted Catalytic activity

In this work, to investigate the catalytic performances of MgFe₂O₄ nanoparticles were evaluated by the microwave-assisted degradation of paracetamol dolo a toxic pharmaceutical pollutant as well as a common model for testing degradation capability. The degradation of the paracetamol dolo drug was performed using 50 ppm of drug solution (50 ml) containing 50 mg MgFe₂O₄ nanoparticles which were exposure under microwave irradiation for 30 min along with continuous stirring and degradation were investigated by the UV-Vis spectroscopy, Fig. 4(a). The absorption peak of PCM-dolo was observed at 240 nm, decreases gradually with time under microwave irradiation. The degradation efficiency of PCM-dolo, Fig. 4(a) was found to be 26.41% under microwave irradiation alone for 30 min without catalysts, while 81% (at peak 240 nm) degradation achieved with MgFe₂O₄ catalyst under microwave irradiation for 30 min.

The degradation of drug was attributed to the synergetic effect of MW irradiation and MgFe₂O₄. The plots of C/C₀ vs time and ln C/C₀ versus time for MgFe₂O₄ nanoparticles as catalysts Fig. 4(b), the fitting results showed that the microwave catalytic degradation of PCM-dolo follows the pseudo-first-order kinetics in all cases. The catalytic degradation of PCM-dolo process was fitted using a following pseudo-first-order kinetic model: $\ln(C_t/C_0) = -kt$ (where C_t and C₀ are drug pollutants concentration at each given time and t = 0, respectively) and the rate constant k is the slope of the corresponding fitting curves, t represents the reaction time. As shown in Fig. 4(c), the fitting curves of PCM-dolo photocatalytic degradation were accorded with the pseudo-first-order reaction dynamics. The reaction rate constant (k) and coefficients (R₂) of the as-obtained samples was found to 0.02048 and 0.9953. Thus, a higher rate of degradation is observed with the MgFe₂O₄ catalyst.

The effect of the drug concentration was investigated in the microwave –assisted catalytic degradation of PCM-dolo, as is depicted in the Fig. 5(a). The degradation efficiency of PCM-dolo was noticed to decrease from 99–80% when increasing the concentration of PCM-dolo from 10 to 50 mg/L in presence of MgFe_2O_4 nanoparticles under microwave irradiation. In order to demonstrate the effect of catalysts dosages on the degradation efficiency of aqueous solution of PCM-dolo, Fig. 5(b), different experiment were carried out in catalysts dosage from 30–120 mg. Results showed that the degradation efficiency of the PCM-dolo also increased with an increase in the catalyst concentration. The degradation efficiency of PCM-dolo was noticed to increases from 93–261% upon increasing the catalysts dosage from 30 to 120 m in the presence of MgFe_2O_4 as catalyst due to the growth of active sites for the microwave absorption. The increase in the microwave power showed an increase in the degradation efficiency, Fig. 5(c) due to a greater number of hot spots on the catalyst surface with higher temperatures which provide more no of reactive radical species that were used to enhance the MW absorption.

Reusability studies

To evaluate the reusability of the MgFe_2O_4 catalyst, recyclability experiments were conducted up to four cycles, Fig. 6(a). The catalytic activity of the MgFe_2O_4 catalyst revealed a slight decline of 10% after the fourth cycle. The regenerated MgFe_2O_4 catalyst was investigated for the change in its structural features. The structural quality of MgFe_2O_4 is found in the pristine condition even after 6

cycles, as has been confirmed by XRD patterns. The XRD profile of the recycled MgFe_2O_4 catalyst revealed a similar pattern as that of pristine MgFe_2O_4 , Fig. 6(b). The peaks were observed to be sharp and distinct, confirming that the catalyst was able to retain its crystalline nature even after four cycles. Confirming that the catalyst was structurally intact and could be safely used up to four cycles.

Radical confirmation by scavenger studies and degradation pathway of PCM-dolo via LCMS.

To find the roles of the trapping agents, the scavenging experiments were carried out. EDTA, IPA, BQ, and AgNO_3 (1 mM) were added to the antibiotic solutions to investigate the effects of h^+ , $\cdot\text{OH}$, $\cdot\text{O}_2^-$, and e^- , respectively, Fig. 7(a). It can be noted that the degradation efficiencies are remarkably reduced after the additions of the active species. It is observed that the effects of $\cdot\text{OH}$, $\cdot\text{O}_2^-$, and e^- scavengers are more pronounced for the SNFO catalyst (the degradation efficiency is found to be 37.9%, 45.03%, and 51.74%, respectively), whereas h^+ are the dominant active species for the MgFe_2O_4 catalyst (the degradation efficiency is found to be 56.69%, respectively)

The intermediate products of PCM-dolo obtained during the catalytic degradation were identified by LC-MS technique, Fig. 7(b). The LC-MS chromatogram of the degraded PCM-dolo fragments in presence of MgFe_2O_4 as catalyst is provided in Fig. 7(c).

Degradation of paracetamol and its derivatives i.e. one of the main component of PCM-dolo has been reported by various researcher using different kind of catalysts/photocatalysts which are briefly

discussed in the Table 1.

Table 1
Comparative studies of degradation of paracetamol using different light sources.

Catalysts	Drug Concentration	Degradation Efficiency	Light Source	Degradation Time
Pd-BiVO ₄ [34]	50mg/L	100%	Visible light	60 min
Ag-Ag ₂ O/PTh [30]	(80mg/L)	79%	MW radiations	20 min
ZnO-Hap [35]	20 mg/L	98%	UV light	120 min
M/TiO ₂ M-Ag, Au, Pt [36]	20mg/L	73.7%, 68.8%, 78.0%	Solar light	180 min
WO ₃ -TiO ₂ [37]	50mg/L	99%	Natural Sun light	3.5 h
Co(II)-sulfite [38]	20mg/L	87%	Visible light	30 min
TiO ₂ /SiO ₂ , WO ₃ /TiO ₂ /SiO ₂ [39]	5mg/L	42%, 95%	UV-Visible light	4 h
CoFe ₂ O ₄ , MnFe ₂ O ₄ [40]	0.2mg/L, 10mg/L	76.4%, 100%	Visible light	60 min
ZnFe ₂ O ₄ , ZnFe ₂ O ₄ -GR [41]	10MG/l	60%, 100%	Visible light	180 min
CoFe ₂ O ₄ @Nb ₅ O ₂ [42]	20mg/L	100%	UV-Visible light	240 min

Hence, it can be concluded that microwave-assisted degradation of paracetamol-dolo using MgFe₂O₄ was found to be far superior to UV and visible light irradiation methods reported for the degradation of paracetamol and its derivatives. Moreover, the fragments produced in our case were mainly diols, hydrocarbons, water and CO₂ as confirmed by LCMS studies. This technique could therefore be utilized as a green technology for the rapid and eco-friendly mode of degradation of toxic pharmaceuticals.

Conclusion

MgFe₂O₄ was successfully synthesized and characterized using FTIR, UV-DRS, TGA and XRD studies. TEM formed the formation of MgFe₂O₄ NPs with particle size ranging between 5-15 nm. UV-vis DRS study showed the optical band gap of MgFe₂O₄ NPs was found to be 1.0 eV. Microwave (MW) assisted degradation of PCM-dolo drug on MgFe₂O₄ were performed. The enhanced catalytic performance could be ascribed to the production of MW-induced active species, such as holes (h⁺), superoxide radicals (•O₂⁻) and hydroxyl radicals (•OH) in the degradation process. The degradation mechanism confirmed

the fragmentation and formation of compounds that were less toxic. MgFe_2O_4 could be easily separated and recycled by a magnet and could be used as a potential catalyst for degradation of organic pollutants.

Declarations

Conflict of interest

The authors declare no conflict of interest.

Author Contribution

Jannatun Zia wrote the first draft. Mudassir Rafi carried out the catalytic studies Elham S Aazam wrote the morphological interpretation. Ufana Riaz conceptualized and wrote the final draft.

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Figures

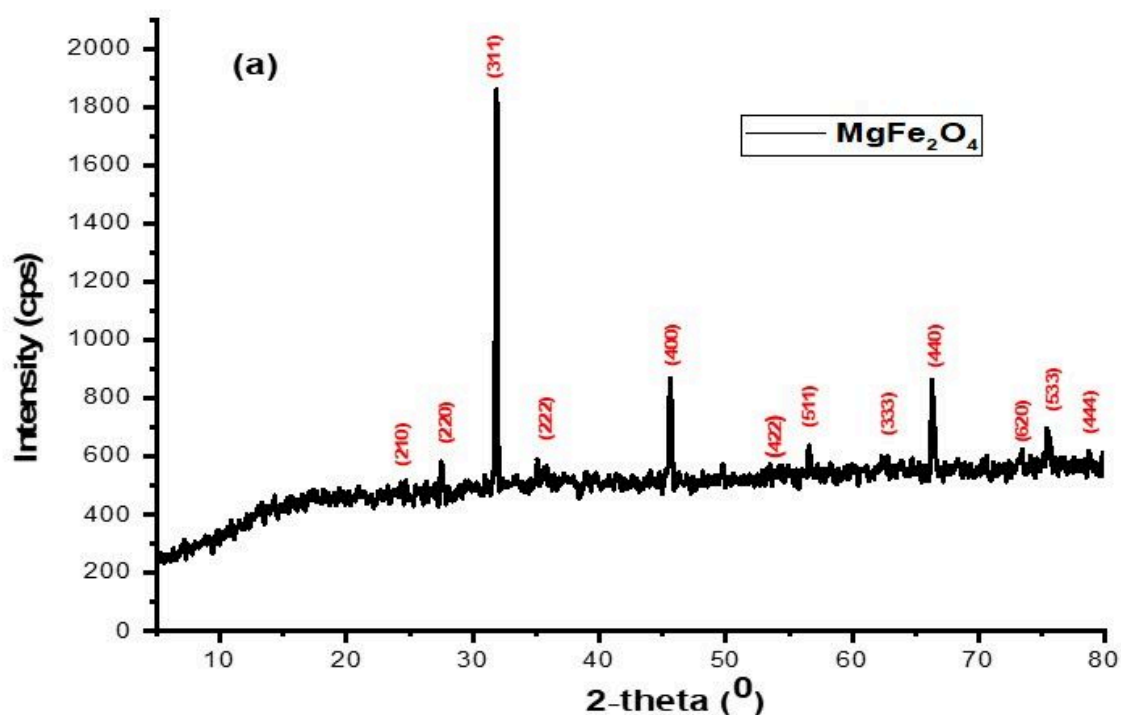


Figure 1

XRD pattern of synthesized MgFe_2O_4 nanoparticles

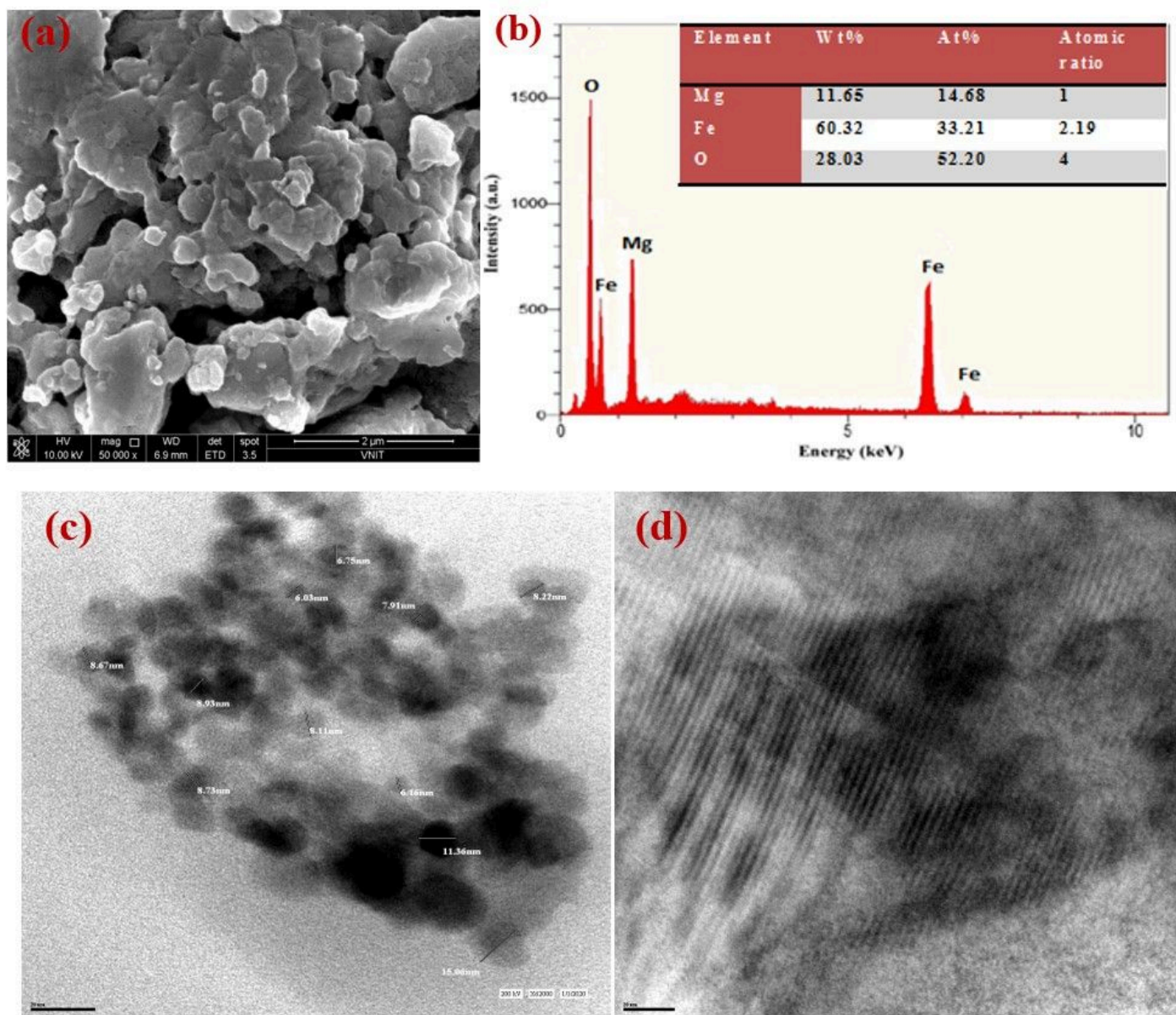


Figure 2

(a) FESEM image, (b) EDX spectrum, (c) HRTEM image and (d) Diffraction pattern of MgFe₂O₄ nanoparticles

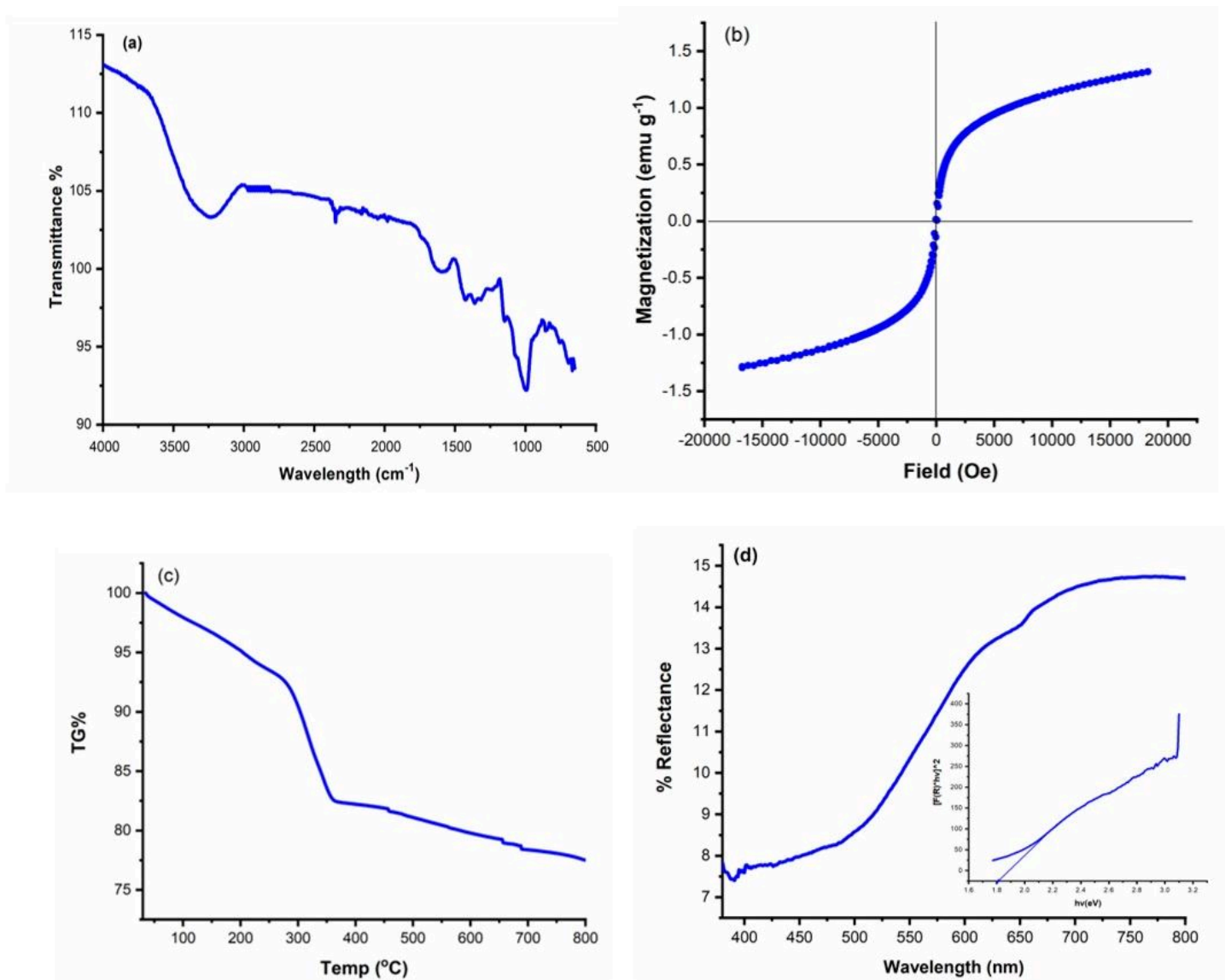


Figure 3

(a) FT-IR spectrum of MgFe_2O_4 , (b) Magnetic hysteresis loop of MgFe_2O_4 nanoparticles at room temperature, (c) TGA curve of MgFe_2O_4 nanoparticles, (d) UV-vis diffuse reflectance spectra (DRS) of MgFe_2O_4 nanoparticles, inset of Kubelka–Munk plot for band gap

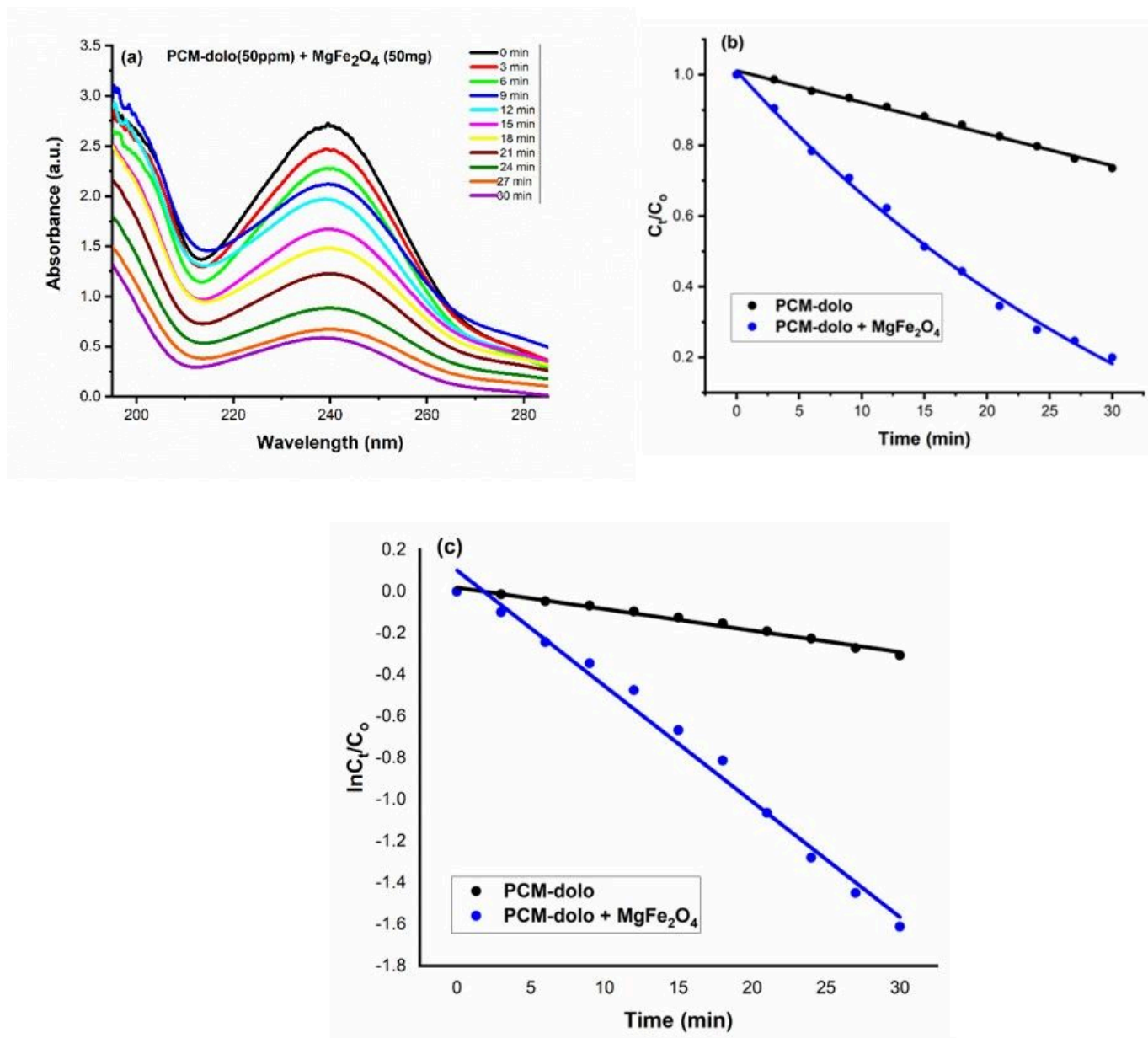


Figure 4

(a) UV plot of PCM-dolo degradation (b) C_t/C_0 vs. time plot for degradation of PCM-dolo using MgFe_2O_4 nanoparticles, (c) $\ln C_t/C_0$ vs. time plot.

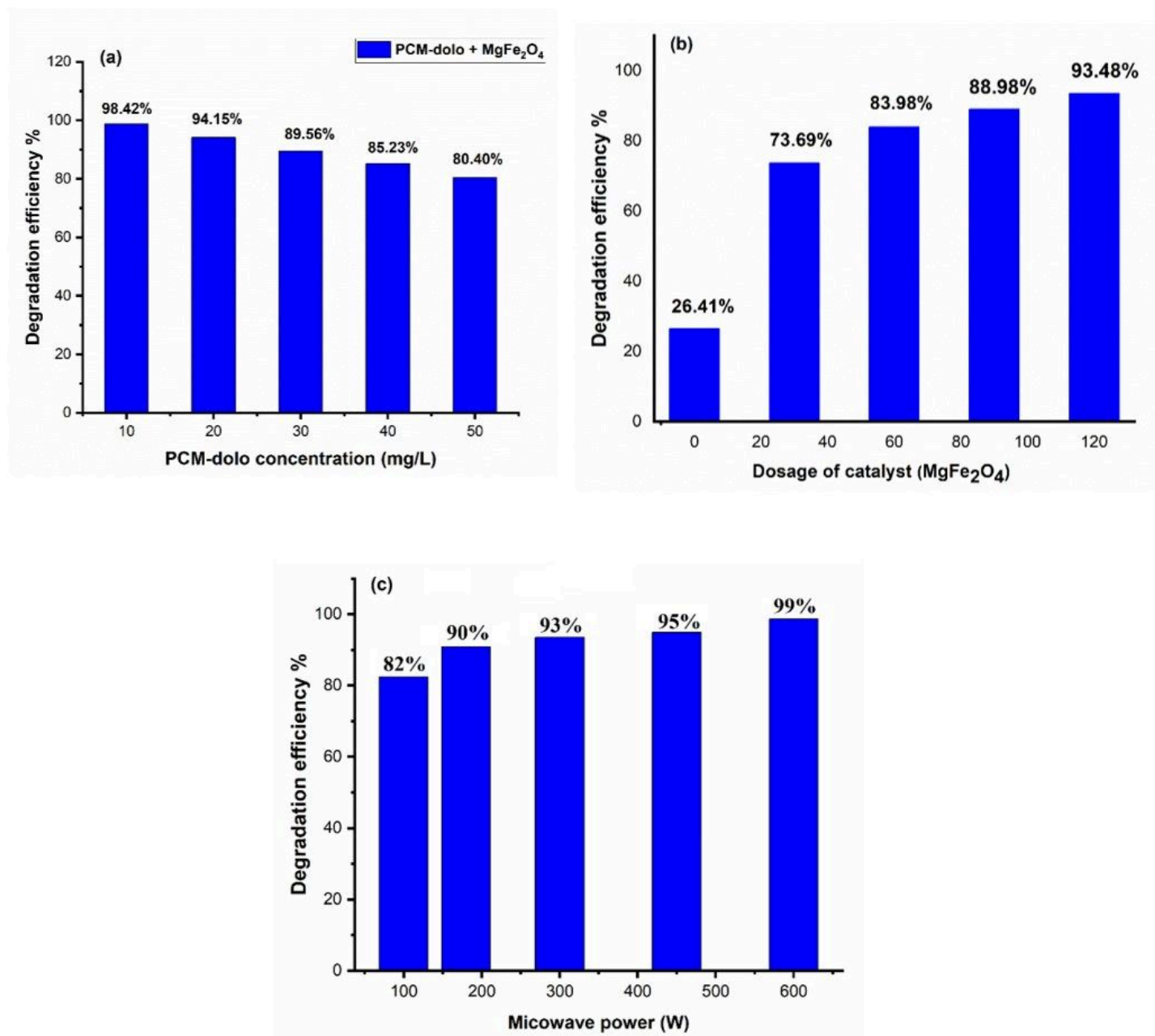


Figure 5

(a) Effect of concentration of PCM-dolo solution on the degradation efficiency using MgFe_2O_4 catalyst, (b) Effect catalyst dosages on degradation efficiency of PCM-dolo solution using MgFe_2O_4 catalysts, (c) Effect of microwave power on degradation efficiency of PCM-dolo solution using MgFe_2O_4 catalysts.

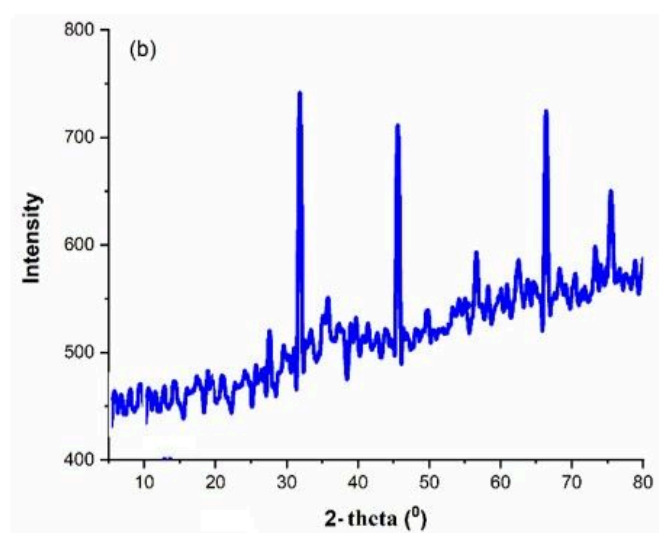
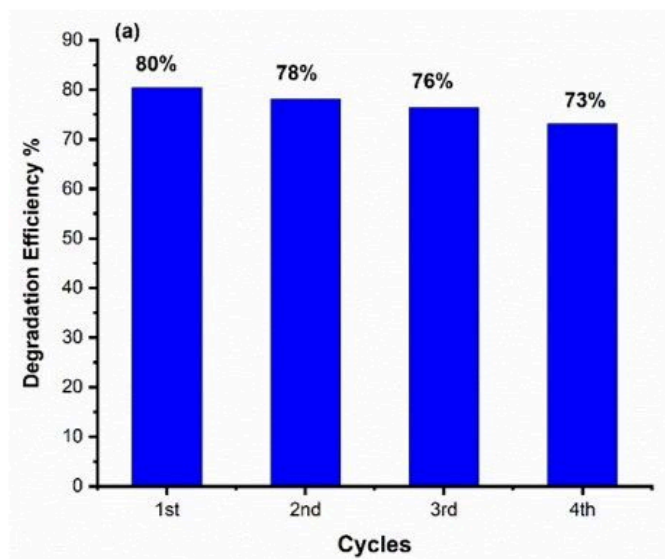


Figure 6

(a) Recyclability of MgFe_2O_4 catalyst up to four cycle, (b) XRD pattern of used MgFe_2O_4 catalyst

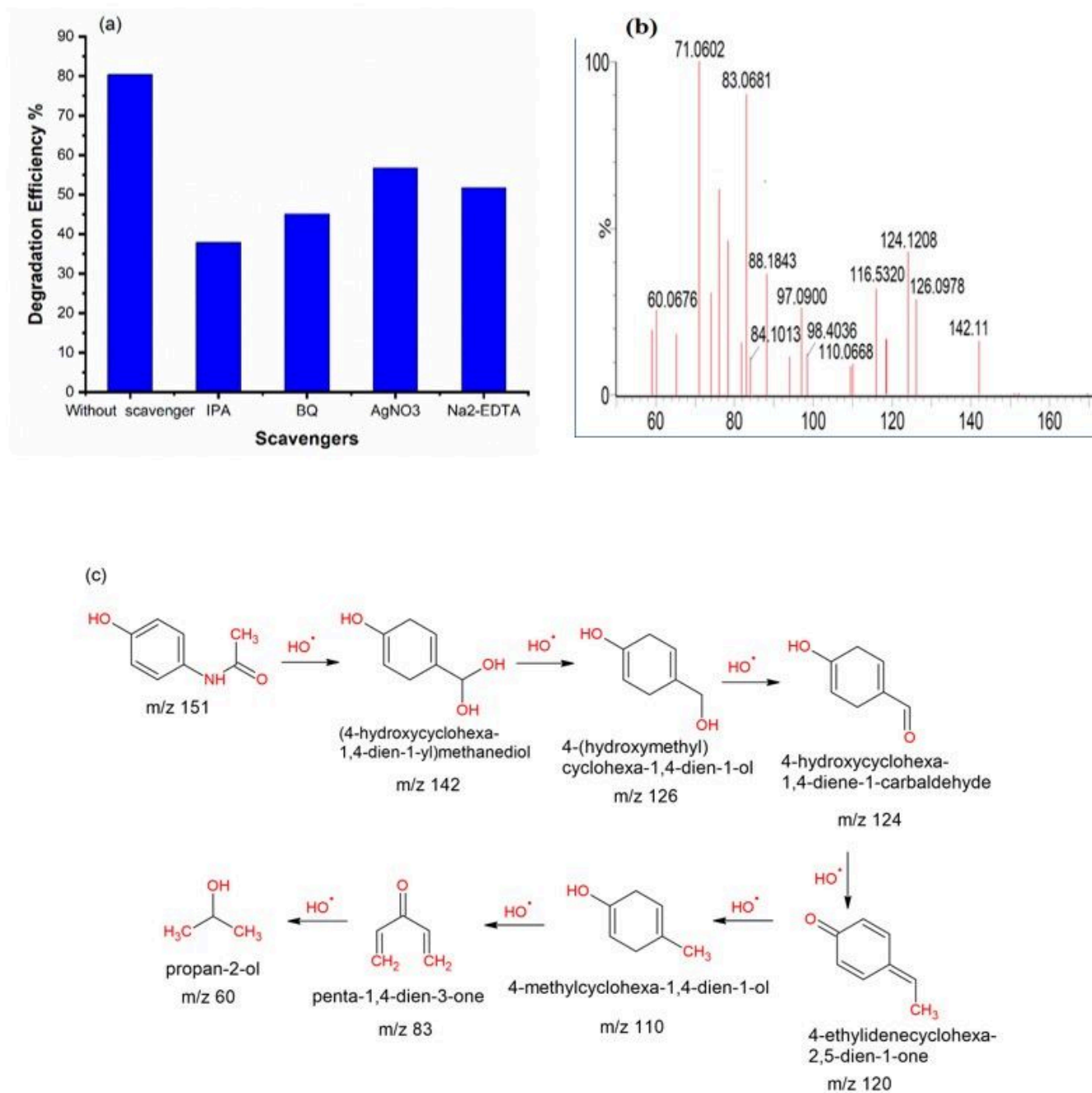


Figure 7

(a) confirmation of radical generation using scavengers,(b) LCMS profile, (c) degradation pathway of PCM dolo