



A Critical Review of the Peroxymonosulfate Activation via ZnO@Mn₃C Photo-catalyst for Dyes Degradation

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Abstract

This review article aims to give an insight into the use of nanocomposites, i.e. ZnO@Mn₃C and PMS system, for the organic pollutants degradation through peroxymonosulfate activation. One of the major type of pollutants affecting our water bodies are dyes. A large number of dyes are being released into our water systems without any treatment or with very poor treatment. There are traditional methods to treat polluted water bodies, like filtration, coagulation, oxidation, and adsorption, but all these methods have some limitations. However, Advanced Oxidation Processes are gaining much popularity in means of dye degradation. So, this review comprehensively discussed the use of a photocatalyst to degrade dyes via peroxymonosulfate activation.

Keywords: ZnO@Mn₃C, Advanced Oxidation Processes, peroxymonosulfate activation, nanocomposite

INTRODUCTION:

Water contamination has become a paramount environmental issue due to contemporary rapid industrialization and urbanisation, which have also led to considerable resource scarcity and benefits [1,2]. When a body of water becomes polluted, contamination





occurs. The potential for water contamination and scarcity renders the degradation of the water supply a paramount issue in the region [3]. Contaminated water severely affects human health. Annually, approximately 829,000 individuals succumb to diarrhoea caused by contaminated drinking water, inadequate sanitation, and poor hand hygiene, including nearly 300,000 children under five years old, who represent 5.3% of fatalities in this age group, as reported by the UNESCO World Water Development Report [4]. The principal causes of water contamination are natural disasters, industrial activities, agricultural practices, insufficient waste disposal systems, and inadequate water resources. Industrial activities, including distilleries, tanneries, pulp and paper mills, textile and food sectors, iron and steel production, and nuclear power stations, are the principal sources of water pollution. During factory operations, several hazardous chemicals, including organic and inorganic substances, toxic solvents, and volatile organic compounds, may be released.

The inadvertent release of these chemicals into aquatic systems, lacking adequate filtration, will lead to water pollution [5]. Annually, over 10,000 synthetic organic dyes are discharged into global waterways through wastewater from industries including food, pharmaceuticals, paints, paper, textiles, and cosmetics [6].

The existence of organic contaminants in aquatic systems poses significant and urgent challenges for global ecosystems and human well-being. Antibiotic and printing wastewater is particularly challenging to handle due of its low biodegradability, intense colouration, and complicated composition. Traditional water treatment procedures, encompassing physical, chemical, and biological approaches, generally do not adequately reduce the impact of these pollutants. Conversely, advanced oxidation processes (AOPs) offer a significant alternative to traditional treatment technologies including membrane separation and chemical coagulation, typically utilised for pollutant degradation. These goods are both cost-effective and eco-friendly, since they efficiently harness solar energy, rendering them a viable choice for environmental preservation [7–12]. The introduction of the sulphate radical ($\text{SO}_4^{\bullet-}$) in advanced oxidation processes (AOPs) has demonstrated a beneficial technique. PMS is extensively utilised for its catalytic properties in multiphase systems, notably for its capacity to oxidise and eliminate persistent organic pollutants (POPs). It facilitates the dissociation of per-oxygen bonds, generating reactive free radicals ($\text{SO}_4^{\bullet-}$ and $\cdot\text{OH}$) or non-free radicals ($^1\text{O}_2$). $\text{SO}_4^{\bullet-}$ is notably efficient in the remediation of organic compounds owing to its elevated redox potential (2.5–3.1 eV), extended stability, and minimal dependence on pH levels [13–15].



Traditional ways to degrade dyes:

Annually, diseases caused by polluted drinking water result in the deaths of 2.4 million individuals. Various forms of pollution, including pathogens, viruses, and toxic compounds, may be present in water. These pollutants are generated by industrial activities, residential areas, and agricultural practices. The removal of dyes from wastewater has garnered significant attention in environmental and materials research in recent years. Consequently, numerous wastewater treatment procedures have been devised to remove or diminish the colours present in the effluent. Elimination techniques can be classified into physical, chemical, and biological categories [17-20]. The physical methods of isolation include centrifugation, adsorption, filtration, sedimentation, reverse osmosis, and electrophysical techniques such as electrolysis, electrodeposition, indirect oxidation, electrocoagulation, and electro-floatation. Chemical processes encompass coagulation, ultraviolet irradiation, oxidation, flocculation, and ion exchange; biological processes comprise aerobic methods (comprising enzymes, microorganisms, and plants) and anaerobic techniques [21-26]. Research has shown that many currently employed strategies are ineffective in entirely eliminating hazardous contaminants. Despite their advantages, they also present challenges, including increased energy consumption, suboptimal elimination efficacy, generation of toxic byproducts with the introduction of hazardous substances, and the accumulation of substantial secondary sludge detrimental to aquatic life and human health [17]. Despite the existence of other alternative ways, the utilisation of photocatalysts has gained significant prevalence. This method uses a combination of light and semiconductor nanoparticles to decompose viruses, bacteria, fungi, algae, and toxic chemical waste through photocatalysis. These compounds experience numerous partial breakdown reactions that yield CO₂, H₂O, and inorganic anions. ZnO and Mn-based catalysts are regarded as some of the most effective currently accessible due to their well-documented attributes, including chemical stability, cost-effectiveness, non-toxicity, insolubility, photoactivity, and photostability [27,28].

Photocatalysis:

Another technique for the breakdown of dyes in wastewater has been presented: photocatalysis, which has recently received more research [29]. The process of photolysis, which occurs when a molecule in question interacts with artificial or natural UV light, can break into intermediate products and cause entire mineralization to occur at the same time [30]. It has been demonstrated that sunlight, or UV radiation in the solar spectrum, which only makes up 4-5% of power, limits the amount of contaminants in water that can be absorbed on a broad scale [31].

Because it doesn't produce secondary pollutants or release hazardous substances into the environment, this technology is incredibly successful. Non-biodegradable organic contaminants are transformed into carbon dioxide, water and inorganic ions through photocatalysis [32].

Advanced oxidation techniques utilising peroxymonosulfate:

Sulphate radical-based Advanced Oxidation Processes (SR-AOPs) have garnered significant interest as efficient and promising techniques for the degradation and mineralisation of refractory pollutants since 2003, following the pioneering research of Anipsitakis and Dionysiou [33]. Advanced oxidation methods, a group of technologies, are predicated on the generation of highly destructive entities capable of decomposing refractory molecules into less harmful substances or even mineralising them into carbon dioxide and water [34]. For an extended period, the predominant mechanism of Advanced Oxidation Processes (AOP) depended on the generation of hydroxyl radicals as the active agent responsible for the degradation of organic molecules [35]. Figure demonstrates that peroxymonosulfate-based advanced oxidation processes have lately emerged as a significant research focus due to their unique properties and advantages.

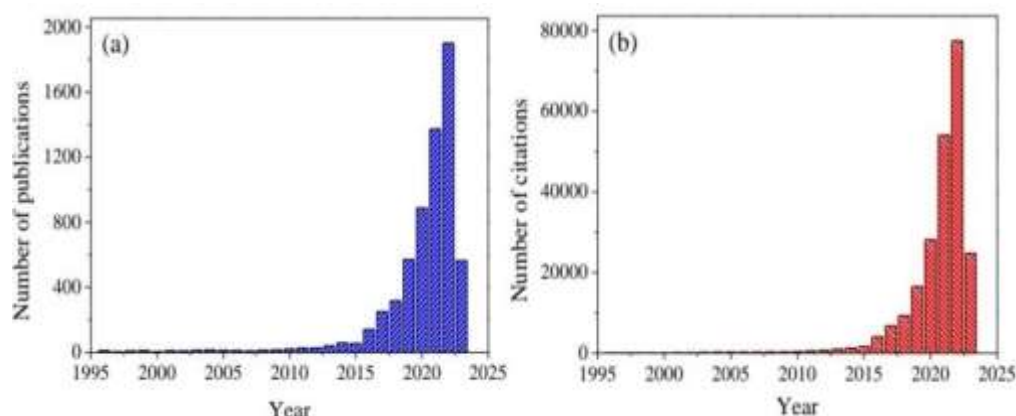


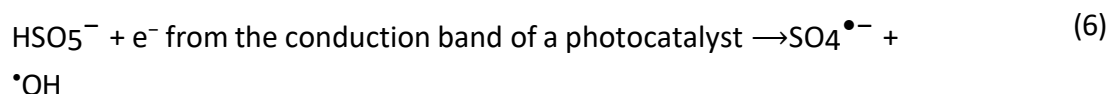
Figure.1 Number of publications (a) and citations (b) per year since 1996 based on the search for “peroxymonosulfate” [36].

Technologies to trigger PMS activation:

SR-AOPs primarily decompose pollutants and transform them into CO₂, H₂O, and other compounds by generating reactive species, including hydroxyl radicals ($\cdot\text{OH}$), sulphate radicals ($\text{SO}_4^{\cdot-}$), singlet oxygen ($^1\text{O}_2$), and superoxide anion ($\cdot\text{O}_2^-$) [37]. Benefits of SR-AOPs encompass their applicability across a broad pH spectrum (2–11), predominantly non-toxic byproducts (with

sulphate as the sole residual product), user-friendliness, cost-effectiveness, and elevated mineralisation efficiency [38,39]. Peroxymonosulfate (PMS, HSO_5^-) and peroxydisulfate (PDS, $\text{S}_2\text{O}_8^{2-}$) ions are the two principal recognised sources of sulphate radicals ($\text{SO}_4^{\bullet-}$). These ions require activation through heat, ultraviolet light, ultrasound, microwaves, photocatalysts, transition metal ions, or carbon-based materials to generate the radical component [40,41]. Peroxymonosulfate in PMS-AOP can be activated to generate sulphate radicals, which exhibit greater selectivity and reduced sensitivity to pH fluctuations compared to hydroxyl radicals ($\text{OH}^\bullet$). They possess an extended half-life ($\text{OH}^\bullet$: 20 ns; $\text{SO}_4^{\bullet-}$: 30–40 μs), an elevated redox potential ($\text{OH}^\bullet$: 1.8–2.7V; $\text{SO}_4^{\bullet-}$: 2.5– 3.1V), and a prolonged half-life. Peroxymonosulfate is an asymmetric derivative of hydrogen peroxide, wherein a SO_3 group replaces an H-atom in H_2O_2 . The peroxide bond (O-O) lengths in H_2O_2 and PMS are 1.453Å and 1.460Å, respectively. Thus, compared to H_2O_2 , PMS necessitates less energy for cleavage due to its longer O-O bond relative to the O-O bond of H_2O_2 . This facilitates PM stimulation. A potassium triple salt ($\text{KHSO}_5 \cdot 0.5\text{KHSO}_4 \cdot 0.5\text{K}_2\text{SO}_4$), known commercially as Oxone, is the precursor of PMS. In addition to its high solubility (> 250g L^{-1} at 20°C), stability, low cost, and non-toxicity, it is easier to transport and store than aqueous H_2O_2 [42].

Although PMS is a powerful oxidant, it requires activation due to its sluggish reaction with most pollutants directly. The two predominant mechanisms for inducing PMS to generate $\text{SO}_4^{\bullet-}$ species are the application of external energy or the transfer of electrons, which disrupt the peroxo (O-O) bond inside the particle's structure. Eq. 1–3 indicate that energy-based stimulation can be achieved through heat, ultrasound, or UV radiation; conversely, electron-transfer-based activation may occur via photocatalytic reactions (Eq. 6) or catalytic reactions involving transition metals ($\text{M} = \text{Mn}^{2+}, \text{Fe}^{2+}, \text{Co}^{2+}, \text{Ni}^{2+}$) (Eq. 4 and 5) [43].





The extensive applicability of ultrasonic and heat-induced PMS activation is hindered by the requirement for expensive processors [44]. Due to the high energy consumption associated with UV radiation, it is advisable to utilise direct light or sunlight to activate PMS under milder conditions [45]. PMS serves as an oxidant that can be employed in photocatalytic reactions as an electron acceptor. Consequently, both hydroxyl and sulphate radicals can be formed when photogenerated electrons are captured by PMS (Eq. 6). Consequently, the introduction of PMS into the reaction medium may enhance the generation of reactive radicals that decompose organic molecules, hence expediting the separation of electron-hole pairs and improving the efficacy of the photocatalytic process [42].

Zinc oxide (ZnO), a prevalent photocatalyst in environmental initiatives, has attracted significant attention due to its low cost, ease of production, non-toxicity, and robust photocatalytic efficacy. ZnO facilitates the activation of PMS via surface interactions, producing highly oxidative reactive species, including hydroxyl radicals ($\cdot\text{OH}$) and sulphate radicals ($\text{SO}_4^{\bullet-}$), which can efficiently degrade various organic pollutants. Reactive oxygen species are generated when ZnO donates electrons to PMS, initiating oxidation processes [27]. Manganese-based materials have been recognised as heterogeneous catalysts for activating PMS due to their environmental abundance, variable valence, low cost, and good stability [28,46-49]. Manganese-based materials exhibit enhanced potential as active sites for PMS activation due to electron transfer associated with the oxidation state change ($\text{Mn}^{2+}/\text{Mn}^{4+}$) [50].

Mn3C-Based Materials:

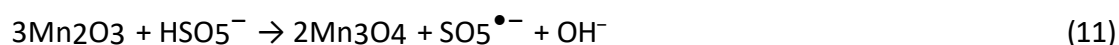
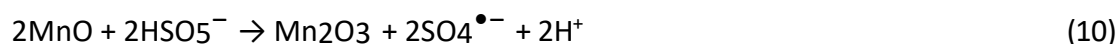
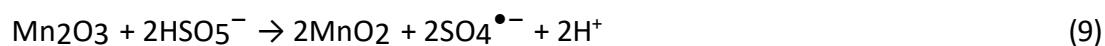
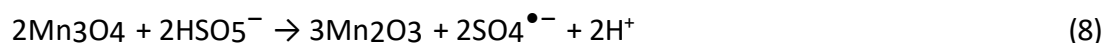
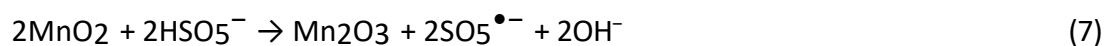
Khan et al. [51] assert that Mn-based magnetic nano-photocatalysts exhibit remarkable degradation efficacy for organic pigments. Deng et al. [52] activated PMS with $\alpha\text{-MnO}_2$ in 60 minutes, resulting in over 94% breakdown of ciprofloxacin. In the $\text{MnO}_2/\text{MnFe}_2\text{O}_4$ + PMS system, Chen et al. accomplished 98% degradation of RhB within 15 minutes [53]. Eslami et al. found that the combination of MnO_2/UV and PMS resulted in complete oxidation of 4-chlorophenol within 30 minutes [54]. Huang et al. reported that 100% phenol removal was accomplished in 40 minutes using Cu- MnO_2 and PMS [55].

A multitude of researchers has investigated the efficacy of several single-metal Mn oxide catalysts as triggers for PMS [56-65]. This includes manganese oxides in different oxidation states, supported manganese oxides, and manganese oxides with diverse crystallographic dimensions (α -, β -, and γ - MnO_2). A multitude of factors affects the catalytic activity of Mn oxides, including: (i) the availability of oxygen, which enhances oxidative transitions among various Mn oxidation states; (ii) the density of reactive components, such as MnO_6 edges with a double



tunnelled configuration; (iii) the presence of mixed valence Mn; (iv) the redox potential of the different Mn oxidation states; (v) specific surface area; and (vi) the level of crystallinity [57-59,66].

The degree of crystallinity of Mn oxide is more critical in determining its catalytic activity than its specific surface area. Saputra et al. [60] reported that crystalline MnO₂ (146m²g⁻¹) surpassed amorphous MnO₂ (179m²g⁻¹) by almost eightfold (0.359min⁻¹ vs. 0.0457min⁻¹). Manganese can be utilised in various applications because to its versatility in forming several durable oxides. The subsequent techniques might be employed to ascertain how heterogeneous Mn oxides (exhibiting 25 unique oxidation states) activate PMS [57]:

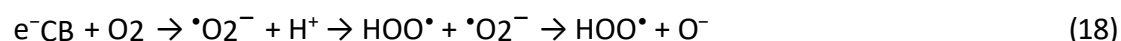


Mn oxides have been found to enhance the catalytic activity of different metal oxides, including Co₃O₄ and CuO [63,67-69]. Keerthana et al. [70] successfully synthesised pure 0.2M and 0.4M Mn-doped TiO₂ photocatalysts by a hydrothermal technique. Subsequent to increased Mn addition, the pure TiO₂ underwent a phase transition from its rutile phase. The photocatalytic technique significantly benefited from the phase change of TiO₂. The dopant (Mn), responsible for the redshift and alteration of the bandgap, was the reason for the decrease in the bandgap. Doped TiO₂ photocatalysts exhibited enhanced formation of nanoparticles and nanorods, together with the reduction of agglomeration. The enhanced configuration increased the recombination rate and surface area. The MG dye was diminished in the samples for assessment as an illustration of pollutants. The 0.4M Mn-TiO₂ photocatalyst exhibited exceptional efficacy in entirely eradicating the pollutant under reduced light exposure.

Zn based materials:

In an ideal photocatalytic reaction, organic pollutants are mineralised into carbon dioxide (CO₂), water (H₂O), and mineral acids in the presence of ZnO particles and reactive oxidising agents, such as oxygen or air. Photons with energies exceeding the band gap energy of ZnO particles initiate photocatalytic activities upon absorption. Consequently, on the outermost

layer of the ZnO particle, the photo- induced electron transitions from the valence band (VB) to the conduction band (CB), resulting in the formation of a positive hole h^+_{VB} and an electron e^-_{CB} (Eq. 12).



It is crucial to note that the photo-induced vacancies in the valence band would dissipate as radiation upon recombination with the photo-excited electrons in the conduction band (Eq. 13). Consequently, oxygen functions as an electron scavenger, prolonging the recombination of electron-hole pairs while producing superoxide radicals ($\cdot\text{O}_2^-$) (Eq. 14). The generation of hydroxyl radicals may occur from the interaction of h^+_{VB} with OH^- (Eq. 15). Organic materials may undergo partial or complete mineralisation due to the hydroxyl radical, a highly strong and non-selective oxidant ($E^0 = +3.06\text{V}$) (Eq. 16). Moreover, as seen by Eq. 17, the direct oxidation of organic matter to reactive precursors is facilitated by the photocatalyst's high oxidative capacity of the hole. Eq. 18-20 demonstrate that the radicals containing superoxide were further protonated to produce hydroperoxyl radical ($\text{HOO}^\cdot$) and subsequently hydrogen peroxide (H_2O_2). Furthermore, the $\text{HOO}^\cdot$ functions as an electron scavenger, seizing conduction band electrons to further delay recombination.

A multitude of studies has been undertaken to assess the influence of photocatalysts on the degradation of dyes. Kansal et al. [71] examined the photocatalytic degradation of rhodamine 6 G and methyl orange under UV and solar light exposure, employing easily available ZnO, SnO_2 , ZnS, and CdS as photocatalysts. Likewise, Lizama et al. [72] indicated the use of ZnO or TiO_2 as catalysts for the photocatalytic decolorisation of Reactive Blue 19 (RB-19) in aqueous solutions, finding that ZnO outperformed TiO_2 as a catalyst. ZnO has been demonstrated to be an effective



alternative to TiO_2 in the degradation of Acid Red 14, an azo dye, with a photodegradation mechanism analogous to that of TiO_2 , as reported by Daneshvar et al. [73]. Nagaraja et al. [74] conducted further research utilising ZnO nanopowder synthesised via solution ignition to evaluate the photocatalytic degradation of Rhodamine B dye under UV and solar radiation. The dye was found to completely decompose in around 8 minutes of churning during irradiation with the ZnO catalyst at an alkaline pH under sun light exposure. Both the COD method and UV-visible spectrophotometry verified that the dye had been entirely decolorised. Danwittayakul et al. effectively photodegraded Methylene Blue using ZnO ; after 180 minutes of exposure to light at an intensity of 1060Wm^{-2} , an 80% degradation efficiency was achieved [75]. ZnO was employed to decompose Orange II under UV light exposure. After 60 minutes of exposure, complete photodegradation efficiency was achieved [76]. The degradation of Methyl Green was evaluated under visible light at an intensity of 4.8Wm^{-2} , leading to complete colour loss after 16 hours at pH 10 [77]. Furthermore, it has been found that ZnO effectively destroys Acid Red 18 [78], Methyl Orange [79], and Acridine Orange [80].

Mixed metal catalyst:

However, MnO_2 particles tend to agglomerate, significantly diminishing their surface area, accessibility of active sites, and catalytic efficiency [81]. Manganese dioxide particles must be affixed to a robust support to provide optimal distribution and catalytic efficacy [82]. The rapid recombination of photo-generated electron/hole (e^-/h^+) pairs, low quantum efficiency, sluggish electron transfer rates, and limited optical response of pure ZnO constrain its potential application in the photodegradation of compounds [83]. As a result, pure ZnO demonstrates significant photo-corrosion and fails to provide substantial photocatalytic activity for contaminants. The research identifies the most effective techniques for resolving these challenges as the incorporation of additional photocatalysts, surface modification, ion doping, dye sensitisation, inclusion in porous materials, and doping with metals or non-metals [27,84]. In comparison to single metal oxide catalysts, mixed metal oxide catalysts demonstrate enhanced redox activity, superior catalytic efficiency, increased durability (reduced leaching), and polyfunctionality (e.g., photoactivity, magnetic separability, etc.). This results from the catalyst's enhanced specific surface area, the presence of mixed-valence transition metals, the density of basic sites on its outer layer, and the synergistic redox coupling of multiple metals [85].



Table. Comparison of photocatalytic performance of synthesized photocatalysts with literature.

Lightsource (time)	Pollutantdye (concentration)	Photocatalyst	Catalyst amount	Rate constant (K)	Degradation efficiency	Ref.
UV (60 min)	Malachite green (15 ppm)	Ni-doped ZnO (6 wt. %)	0.1 g/L	0.0042 min ⁻¹	76%	[86]
UV (120 min)	Methyl green (40 ppm)	Nickel- dimethylglyoxime/ ZSM-5 Zeolite	0.6 g/L	0.036 min ⁻¹	76.5%	[87]
Visible (50 min)	Methyl green	Cu-doped ZnO (5 wt. %)	—	0.04 min ⁻¹	75%	[88]
UV (50 min)	Methyl green	Tb-doped ZnO (1 wt. %)	—	0.022 min ⁻¹	77%	[89]
UV (120 min)	Methylene blue (10 ppm)	Mn-doped ZnO (2 wt. %)	0.3 g/L	0.03 min ⁻¹	99%	[29]
Natural sunlight (240 min)	Congo red (100 ppm)	Mn-doped ZnO (7 wt. %)	1 g/L	0.0089 min ⁻¹	87%	[90]
Natural sunlight (60 min)	Methyl green (20 ppm)	Pure ZnO	0.1 g/L	0.01792 min ⁻¹	62.78%	[91]
Natural sunlight (60 min)	Methyl green (20 ppm)	Mn-doped ZnO (2 wt. %)	0.1 g/L	0.02072 min ⁻¹	66.44%	[91]

Akram et al. [91] synthesised pure and manganese (Mn) doped ZnO (2 weight percent) nanoparticles using the chemical precipitation method and examined their photodegradation of methyl green (MG) dye pollution under ambient light settings. Manganese was integrated into the host ZnO lattice, leading to a reduction in crystallite size from 21.10nm to 18.76nm. Surface structural analyses utilising FESEM indicated the existence of nanoparticle-like particles measuring between 50 and 100nm. The incorporation of Mn and ZnO enhanced the active region and surface area-to-volume ratio of the photocatalytic reaction. It was found that pure and Mn- doped (2 weight percent) ZnO photocatalysts could photocatalytically degrade MG aqueous solution by 62.78 percent and 66.44 percent, respectively, after 60 minutes of exposure to natural sunlight. The results indicated that pure ZnO nanoparticles doped with



manganese exhibited 5.83 percent superior photocatalytic performance compared to intrinsic ZnO. In conclusion, the markedly enhanced photocatalytic efficacy of the Mn-doped ZnO photocatalyst resulted from synergistic interactions involving various charge transfer channels, improved electron-hole pair charge separation, increased surface area, and effective production of hydroxyl radicals. Previous research by Ullah and Dutta [92] demonstrated that the incorporation of Mn (ZnO: Mn²⁺) into ZnO enhances the photodegradation of methylene blue dye, as Mn²⁺ doping substantially increases the quantity of defect sites. Saleh and Djaja's [93] research illustrated the degradation of methyl orange (MO) upon exposure to UV light. The catalyst concentration was 0.2g/L, and the irradiation duration was 120 minutes. ZnO had a photodegradation efficiency of 60%, while ZnO doped with Mn demonstrated an efficiency of 85%.

Degradation of organic pollutants via photocatalysis:

Semiconductor-based photocatalysis has gained popularity in recent years as a cost-effective and environmentally sustainable approach for purifying wastewater and water containing organic pollutants. Various pure and modified photocatalysts have been created for wastewater treatment. Economically viable photocatalysts encounter numerous challenges for practical implementation, including: i) diminished photocatalytic efficiency at low pollutant concentrations; ii) complicated post-use regeneration; iii) particle agglomeration in suspension; and iv) reliance on UV light and/or high-intensity irradiation, which may pose health risks. Therefore, it is imperative to discover and create innovative photocatalysts capable of operating under low-intensity irradiation or visible light.

Development of novel nanomaterials for environmental catalysis:

Contemporary breakthroughs in nanotechnologies have enabled new opportunities for enhancing the viability and safety of synthesising innovative nanomaterials. Nanosized photocatalysts has potential capabilities due to their particle size situated in the transition between molecular and bulk phases [94]. Bands effectively segregate into distinct electronic states inside the valence and conduction bands due to the spatial confinement of charge within a potential well, as the size of the semiconductor molecule falls below a specific diameter [47]. The increase in band gap energy with smaller particles is a principal advantage in the applications of nano- semiconductor materials [95]. Some semiconductors are considered optimal photocatalysts due to their high photoactivity, safety, cost-effectiveness, and non- toxicity. The semiconductors are TiO₂, WO₃, SrTiO₃, α-Fe₂O₃, and ZnO [95,96]. The stability of nanosized





catalysts can be enhanced, along with their efficacy in organic matter removal, through the application or integration of metal ions or metal oxides. Consequently, it is feasible to develop potent and environmentally friendly catalysts utilising modified nanomaterials. Zinc oxide (ZnO), a photocatalyst, has attracted considerable attention due to its straightforward production, availability, non-toxicity, exceptional photocatalytic performance, and cost-effectiveness [27]. Manganese-based materials, because to their substantial natural abundance, variable valence, low cost, and superior strength, are promising heterogeneous catalysts for PMS activation [28]. Due to their extensive surface areas and unique structures, nanoparticles are considered to be effective promotional materials. The utilisation of nanomaterial-supported Zn and Mn photocatalysts is an effective environmentally sustainable method for the degradation of organic compounds in wastewater through the activation of peroxymonosulfate.

Conclusion

Polluted water systems is a world wide problem due to ever increasing population and industrialization. Numerous techniques are available to deal with these pollutants specifically organic pollutants but these techniques have limitations. However, AOP based techniques are new emerging techniques to deal with organic pollutants. Use of nanocomposites as a photocatalyst are well cited in the literature. This review proved that nanocomposites, specifically Zn and Mn nonamaterial based photocatalyst can be used to deal with organic pollutants. Use of such remedies could be a step forward to achieve a safe and clean environment for ourselves and our future generations as well.

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