Journal of Mines, Metals and Fuels, *71(10): 1682-1688; 2023. DOI: 10.18311/jmmf/2023/35875*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Current Advancements in Use of Nanoparticles Synthesized from Metal Oxides for Some Typical Prescription Antibiotics Degradation

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Abstract

Antibiotics are the most commonly utilized medications worldwide, with extensive usage not only in human healthcare but also in veterinary medicine and agriculture. The widespread misuse and overuse of antibiotics have led to their presence in various environmental sources such as soil, surface water bodies, groundwater reservoirs, drinking water, and other ecological media. This, along with insufficient sewage treatment capacity, causes a surge in antibiotic pollution in the environment. Unrestricted use of antibiotics encourages the development of antimicrobial resistance, which can lead to a range of problems. Presently, the predominant methods employed to eliminate antibiotic contaminants from water comprise physical adsorption onto adsorbents, chemical flocculation and chemical oxidation. Regrettably, these methodologies yield substantial volumes of sludge laden with chemical agents and polymer electrolytes, there by complicating the management of these sludge accumulations. Antibiotic pollutant residuals can be broken down using a variety of photo catalysts synthesized from metal oxides, offering a multitude of efficient solutions to the challenges involved. This study presents a comprehensive exploration of several facets. It encompasses an examination of the removal processes applied to four frequently prescribed antibiotics and delves into the latest progressions involving diverse nanostructure-based photo catalysis with help of metal oxide nanoparticles. Simultaneously, it addressed the conceivable origins of antibiotic pollutants disseminated throughout the ecological continuum. Moreover, it delves into the adverse consequences and risks posed by antibiotics present in wastewater, both in terms of their impact on the environment and their potential implications for human health.

Keywords: *Antibiotics, Degradation, Metal Oxides, Nanoparticles, Photo Catalysis*

1.0 Introduction

Alexander Fleming can be credited as a key player in the discovery of antibiotics. He was a British scientist who, by mistake, found that Penicillium notatum prevented the growth of *Staphylococcus aureus* in one of his long-forgotten colonies. The questionable molecule was refined and given the name penicillin[1]. Initially, the term "antibiotic" encompassed any agent within modern medicine demonstrating biological efficacy against living organisms. However, its current usage is specific to drugs possessing antibacterial, antifungal or anti-parasitic attributes. A contemporary interpretation categorizes antibiotics as chemotherapeutic remedies capable of impending or halting the proliferation of bacteria, fungi, or protozoa[2]. The various types of antibiotics can be categorised according to their chemical makeup, mode of action, range of effects, and route of administration[3].

The use of antibiotics for the healthcare of human and animals, and in agriculture is connected to the

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contamination of the various environmental media such as water bodies, groundwater sources, drinking water, municipal wastewater, soil, fruits, veggies, and sludge from wastewater treatment plants[4]. Antibiotic misuse and overuse on a large scale have had unforeseen repercussions, such as an increase in the number of microorganisms carrying antibiotic resistance genes in various environments and has detrimental ecological effects. Which might spread from the environment to humans and animals and cause chances to increase the likelihood that human medical treatments will fail, lengthen the course of sickness, and increase morbidity and mortality[4,5].

Due to effects of antibiotics in human health and aquatic environments, the importance in removal of antibiotics rises. The conventional methods cannot effectively remove these polluting chemicals. Many advanced removal methods were developed in recent days. However, the utilization of these systems faced significant restrictions owing to their elevated expenses, inadequate stability, and limited reusability potential. Therefore, scientists have been searching for novel ways to degrade antibiotics in wastewater[1,6].

It has been shown that photo catalysis with metal oxides is efficient at treating wastewater because it simultaneously oxidises a variety of organic and inorganic pollutants into water, and carbon dioxide[7]. Since photocatalytic methods are more advantageous than alternative ones in terms of cost and effectiveness at low antibiotic doses, as well as the stability and environmental friendliness of the photocatalytic materials employed[8].

2.0 Effects of Antibiotics on Environment and Human Health

There are several explanations for how antibiotics enter the environment and affect human health. They can be divided into two categories: those used in animal medicine and those used in human medicine[1]. Humans ingest antibiotics, depending on the drug class, 40-90% of antibiotic dose is excreted as the parent component, which is the active form, in the urine and faeces[4]. Once the effluents have been treated at the sewage treatment plant, they release bio solids and effluent that pollute the soil and aquatic environment. Moreover, antibiotics are administered to cattle in veterinary treatment, who eventually excrete the drugs. Excretions lead to lagoons and animal waste sites, which contaminate the soil and the aquatic ecosystem. Within this segment, a noteworthy instance of a factor that directly contributes to aquatic environment pollution is the utilization of antibiotics in aquaculture[9].

There are other, less common ways for the environment to become contaminated, such as when old medications aren't recycled. Drug recycling is a potential defence against this entrance point. To do this, it is required to research various techniques for recycling active medications from outdated pharmaceutical items. According to studies, a drug's active medicinal ingredients may make up 90% or even more of the product when it has expired[10]. There are both immediate and secondary pathways that lead to individuals whenever soil and aquatic environments are contaminated because the water treatment plant, which is where drinking water is generated, is directly accessed by the contaminated waters. Unintentionally, due to the use of polluted water for irrigation, there is a risk of people and animals consuming crops that have absorbed these contaminants. Subsequently, these harmful chemicals find their way into the ocean, polluting the seafood we rely on for sustenance. Furthermore, this same water source is employed to provide hydration to livestock, which ultimately becomes part of the human food supply[9]. Additional human practice, such as the application of antibiotics in agriculture and aquaculture, as well as the use of antibiotics in non-human contexts and the management of waste, contribute to the emergence of significant environmental resistance reservoirs, these reservoirs can ultimately find their way into drinking water sources for livestock, which may eventually be consumed by humans[11].

A significant amount of antibiotic residues has been exposed to bacterial communities and ecosystems as a result of increased use. The presence of antibiotics in the environment is influenced by both their chemical and pharmacokinetic characteristics as well as the dynamic of the microbial communities that live there, which may be changed and result in bacterial mutations that become resistant to antibiotics[12]. Early antibiotic therapies showed considerable promise in treating bacterial infections.

Due to overuse and antibiotic pollution, a decrease in susceptibility in a bacterial strain relative to the susceptible wild type is referred to as antibiotic resistance, increased rapidly[13]. Antibiotic resistance is rising to alarmingly high levels over the entire world. A growing variety of illnesses are becoming harder to treat and, on occasion, incurable as antibiotics lose their efficacy[14].

3.0 Principle and Mechanism of Removal of Antibiotics by Metal Oxide Nanoparticles

In the process of photocatalytic degradation using metal oxides, contaminants undergo oxidation and hydrolysis

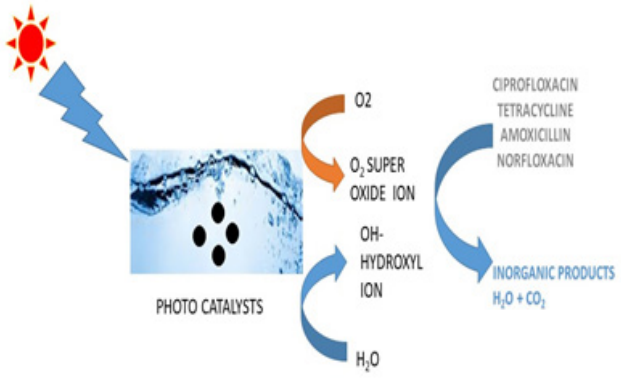


Figure 1. Mechanism of Photo catalysis on Antibiotics by the formation of Hydroxide and Superoxide ions.

as they absorb photons across the electromagnetic spectrum in three distinct regions of light energy. When the photocatalytic material is activated by light, it prompts photosensitive electrons to transition from the valence band to the conduction band, resulting in the formulation of electron-hole pairs due to photoexcitation. As these photo-induced electron-hole pairs interact with oxygen, water, and hydroxyl groups, they generate reactive oxygen species. These radical, when engaged with pollutant molecules, have the capacity to either partially or completely breakdown persistent pollutants (Figure 1)[15]. Energy absorption, electron excitation, and chemical reaction are the three primary phases that can be summed up as the main mechanisms for antibiotic photocatalytic degradation[16].

4.0 Recent Studies on Removal of Antibiotics by Metal Oxide Nanoparticles

4.1 Removal of Ciprofloxacin by Photo Catalysis

A quinolone structure and a piperazine moiety make up the second-generation fluoroquinolone antibiotic ciprofloxacin (C17H18FN3O3). It has been regarded as an effective medication for treating skin infections, complex urinary tract and stomach infections. Ciprofloxacin restricts photosynthetic processes and even causes morphological abnormalities in higher plants. Also, it seriously harms people's health[17]. Both human and veterinary patients receive a lot of ciprofloxacin medication. Ciprofloxacin is most frequently discovered in wastewater treatment facilities, with concentrations of 11-99 mg/L. People who consume water may experience headaches, tremors, nausea, diarrhoea, and anxiety. Stomatitis, leucopenia, skin conditions, and impairment to the immune system are other side effects[18].

To break down ciprofloxacin, a manganese oxide/cobalt oxide photo catalyst was created using the sol-gel process. Both photo catalysis with a catalyst present and photo catalysis of antibiotics under sunlight were explored. The produced photo catalyst was determined to have catalytic activity since the photo catalysis was found to be greater than the photolysis[19]. Using a straightforward co-precipitation technique, CeO_2/ZnO nanocomposites were created to break down ciprofloxacin. It has been shown that two parallel pathways were used for the degradation of CIP over CeO_2/ZnO nanocomposites: path I (dominant), which involved the selective oxidation of the piperazine moiety of CIP molecules by h^+, and path II, which involved the degradation of both the fluoroquinolone and piperazine moieties of the antibiotic. The latter process needs both Hydroxyl radicals (HO•) and h^+ to participate[20].

By employing an environmentally friendly approach and utilizing extract from media Azedarach fruit, the photocatalytic degradation of Ciprofloxacin (CIP) was achieved in the presence of silver nanoparticles supported on amorphous silica derived from the rice husk. Optimal conditions, including an initial pH of 6.7, a reaction duration of 180 minutes, and a catalyst loading of 0.12

grams, were identified. Under these optimized conditions, the degradation efficiency significantly improved, reaching a remarkable 98%[21]. The investigation focused on utilizing nitrogen-doped TiO_2 (N-TiO_2) in both suspended and coated formats to explore their effectiveness in photo catalytically degrading ciprofloxacin in wastewater under UV light exposure. Employing a 5wt% N-TiO_2 coating, aa notable ciprofloxacin removal efficiency of 94.5% was attained within a 2–hours period of photocatalytic degradation. The findings underscored that elevating the initial ciprofloxacin concentration had a positive impact on ciprofloxacin removal efficiency, while increasing the feed flow are had a diminishing effect on it[22]. The Study examined the synthesis of zinc ferrite immobilized on chitosan and its application in the photo degradation of ciprofloxacin. The results indicated a high degradation efficiency, with ciprofloxacin showing a degradation of 99.8%. Furthermore, the analysis revealed that both photo degradation and adsorption processes were concurrent during the ciprofloxacin photodegradation[23]. For testing the degradation, ciprofloxacin-containing water was subjected to photo catalysis using solar energy and Fe-doped ZnO nanoparticles. Under sunlight conditions with an intensity ranging from 120,000 to 135,000 lux, the most efficient operation of a catalyst system comprised of 100mg/l Fe-doped ZnO nanoparticles was observed at both 30°C and 40°C, with pH maintained at 9. Spectrophotometric analysis conducted under these conditions indicated complete degradation of ciprofloxacin (10mg/L) within 210 minutes[24].

4.2 Removal of Tetracycline by Photo Catalysis

One of the often used, reasonably priced, and easily accessible antibiotic medications is tetracycline[25]. Tetracyclines are all anti-inflammatory and immunosuppressive drugs that have been used to treat rheumatism in the past[26].

A simple hydrothermal technique was used to make monoclinic scheelite bismuth vanadate (BVO) microballs, which were then photo deposited with 2 weight percent of noble metals (NM = Au, Ag, Cu, Pt, and Pd). Tetracycline antibiotic degradation was used to test the photocatalytic activity in the presence of visible light. It was discovered that BVO alteration with all of the examined NMs led to a notable boost in photocatalytic performance[27]. In this study, a hydrothermal approach was used to easily and cheaply create a needle-shaped SnO_2/g-C3N4 photo catalyst that is driven by visible light. The catalyst was then examined for its ability to oxidatively photodegrade the organic contaminant Tetracycline (TCN) when exposed to visible light[25]. The kinetics and mechanism of the photocatalytic decomposition of Tetracycline (TC) using an organic photo-catalyst composed of perylene diimide with a three- dimensional network structure known as 3D-PDI. Under visible light exposure, 3D-PDI exhibited effective degradation capabilities for various antibiotics belonging to the tetracycline family. Notably the rates of TC adsorption and degradation by 3D-PDI surpassed those achieved by bulk-PDI by factors of 8.21 and 12.7, respectively[28]. The first subject covered in this research is the tetracycline photo-degradation employing generated hetero-structured titanium oxide nanotubes and cuprous oxide photo-catalyst. At pH 5, 7, and 9, 1.5 g/L of 10% C-TAC (100% photo-degradation rate in 60 min) was used to show the maximal efficiency of visible-light-driven photo-degradation of tetracycline. This substance has a narrower band gap of 2.58 eV and more nanotube surface area[29].

4.3 Removal of Amoxicillin by Photo Catalysis

Amoxicillin, an antibiotic of the penicillin family, is frequently used to treat a variety of bacterial diseases, including chest infections, tooth infections, and other illnesses.[30] Amoxicillin, however, is regarded as a developing contaminant since it might have a number of negative health consequences on aquatic life when water-soluble molecules are present.[13]

It was investigated how UVA (365 nm) radiation caused TiO_2 photo Catalysis to break down amoxicillin in aqueous solution. Amoxicillin completely degraded in 30 minutes when H_2O_2 was added with TiO_2 at 1.0g/L and ambient pH 5. The study examines the degradation of Amoxicillin (AMX) in aqueous solution utilising sono-photo catalysis and TiO_2 photo catalysis under exposure to UV-A (365 nm) and sunshine[31]. Hydrogen peroxide was also combined with photo catalysis and sono-photo catalysis to evaluate the improvement in AMX degradation. AMX dosage of 30mg/l, TiO_2 dosage of 450mg/l, hydrogen peroxide concentration of 150mg/l, pH of 7.0, and UV irradiation of 672W/m^2 were the ideal

conditions for maximum breakdown (80%) of AMX[32]. To remove possible antibiotics (amoxicillin and tetracycline) using less damaging UV-A radiation, the Ce^{3+}/TiO_2 thin film catalyst is being used in the current study. A straight forward, one-step template approach using polyethylene glycol as the templating agent produces reduced cerium ion-doped TiO_2. Antibiotics that were mineralized significantly suggest that the photo catalytic catalyst may have some use[33]. Under the specific experimental conditions of 200mL amoxicillin solution (100 mgL^{-1}) employing 0.5 g of calcium titanate, maintaining a pH of 3, and subjecting it to 120 minutes of irradiation with the addition of 0.058 g of sodium chloride as the electrolyte, the electro-photocatalytic degradation efficiency can achieve a maximum of 79% at 318.5K[34].

4.4 Removal of Norfloxacin by Photo Catalysis

Norfloxacin, a different fluro-quinolone antibiotic, is used to treat urinary tract infections. it is found in wastewater in substantial amounts (especially in hospitals). Fluoroquinolone drugs' widespread use and negative effects on the environment have raised a lot of concerns in recent years[35].

Heterogeneous photo catalysis and ceria (CeO_2) are two promising methods for eliminating antibiotic residues from water sources. To remove the widely used antibiotic Norfloxacin (NOF), pure ceria nanoparticles in ultra-small dimensions were created using a straight forward precipitation technique starting with cerium nitrate. Investigations on the photo catalytic deterioration of Norfloxacin under UV, visible, and solar light were conducted. Ceria produced by adding 2M NH_3 to the precursor solution caused Norfloxacin to degrade to its highest possible level by 98.9%[36]. In a study, an easy one-pot hydrothermal method was used to generate a new immobilised TiO_2/Ti film with exposed 001 facets for the degradation of Norfloxacin from aqueous medium. The preparation of the 001 faceted TiO_2/Ti film at pH 2.62, HT for 3 hours, and HF concentration of 0.02M resulted in the greatest photocatalytic performance. Field-emission scanning electron microscopy (FE-SEM), X-ray diffraction (XRD), high resolution transmission electron microscope (HR-TEM), and X-ray photoelectron spectroscopy were used to completely evaluate the as-prepared 001 faceted TiO_2/Ti films (XPS)[37].

5.0 Conclusions

The present review addressed multiple aspects. It encompasses an exploration of antibiotics' destiny and impacts on the environment, as well as the associated health effects on humans. Additionally, it delves into the significance and mechanism of photocatalytic break down of antibiotics with help of nanoparticles prepared from metal oxides though the generation of free radicals and active oxygen species. Furthermore, the documents elucidate the process of removing commonly employed antibiotics from wastewater via photo catalysis.

In light of these findings, future research avenues should concentrate on diverse strategies. These include incorporating non-metal elements through doping, modifying photo catalysts by establishing heterojunctions with other semiconductors, and harnessing solar radiation and visible light sources for antibiotics degradation .

6.0 References

1. de Ilurdoz MS, Sadhwani JJ, Reboso JV. Antibiotic removal processes from water & wastewater for the protection of the aquatic environment - a review. J Water Process Eng. 2022; 45:102474.
2. Kümmerer K. Antibiotics in the aquatic environment a review: part I. Chemosphere. 2009; 75(4):417–34.
3. Gothwal R, Shashidhar T. Antibiotic Pollution in the Environment: A Review. Clean – Soil, Air, Water. 2015; 43(4):479–89.
4. Polianciuc SI, Gurzău AE, Kiss B, Georgia Ștefan M, Loghin F. Antibiotics in the environment: causes and consequences. Med and Pharm Rep. 2020; 93(3):231.
5. Kraemer SA, Ramachandran A, Perron GG. Antibiotic Pollution in the Environment: From Microbial Ecology to Public Policy. Microorganisms. 2019; 7(6):180.
6. Bai X, Chen W, Wang B, Sun T, Wu B, Wang Y. Photocatalytic Degradation of Some Typical Antibiotics: Recent Advances and Future Outlooks. Int J Mol Sci. 2022; 23(15):8130.
7. Moles S, Mosteo R, Gómez J, Szpunar J, Gozzo S, Castillo JR, *et al.* Towards the Removal of Antibiotics Detected in Wastewaters in the POCTEFA Territory: Occurrence and TiO_2 Photocatalytic Pilot-Scale Plant Performance. Water. 2020; 12(5):1453.
8. Apostolescu N, Tataru Farmus RE, Harja M, Vizitiu MA, Cernatescu C, Cobzaru C, *et al.* Photocatalytic Removal

of Antibiotics from Wastewater Using the CeO_2/ZnO Heterojunction. Materials. 2023; 16(2):850.
9. Carvalho IT, Santos L. Antibiotics in the aquatic environments: A review of the European scenario. Environ Int. 2016; 94:736–57.
10. Basha SC, Babu KR, Madhu M, Kumar Y. Recycling of Drugs from expired drug products: Comprehensive Review. J. Glob. Trends Pharm Sci. 2015; 6(2):2596–9.
11. Doyle MP, Busta F, Cords BR, Davidson PM, Hawke J, Hurd HS, et al. Antimicrobial Resistance: Implications for the Food System. Compr Rev Food Sci Food Saf. 2006; 5(3):71–137.
12. Polianciuc SI, Gurzău AE, Kiss B, Georgia Ștefan M, Loghin F. Antibiotics in the environment: causes and consequences. Med Pharm Rep. 2020; 93(3):231–40.
13. Kraemer SA, Ramachandran A, Perron GG. Antibiotic Pollution in the Environment: From Microbial Ecology to Public Policy. Microorganisms. 2019; 7(6):180.
14. Antibiotic resistance [Internet]. [Cited 2023 Apr 28]; Available from: https://www.who.int/news-room/fact-sheets/detail/antibiotic-resistance
15. Alves DC da S, de Farias BS, Breslin C, Pinto LA de A, Cadaval TRSA. Carbon nanotube-based materials for environmental remediation processes. Advanced Materials for Sustainable Environmental Remediation: Terrestrial and Aquatic Environments. 2022; pp. 475–513.
16. Zhu S, Wang D. Photo Catalysis: Basic Principles, Diverse Forms of Implementations and Emerging Scientific Opportunities. Advanced Energy Materials. 2017; 7(23):1700841.
17. Fief CA, Hoang KG, Phipps SD, Wallace JL, Deweese JE. Examining the Impact of Antimicrobial Fluoroquinolones on Human DNA Topoisomerase IIα and IIβ. ACS Omega 2019; 4(2):4049.
18. Shehu Imam S, Adnan R, Mohd Kaus NH. Photocatalytic degradation of ciprofloxacin in aqueous media: a short review. Toxicol Environ Chem. 100(5–7):518–39. https://doi.org/10.1080/02772248.2018.1545128
19. Alam A, Rahman WU, Rahman ZU, Khan SA, Shah Z, Shaheen K, *et al.* Photocatalytic degradation of the antibiotic ciprofloxacin in the aqueous solution using Mn/Co oxide photo catalyst. J Mater Sci Mater Electron. 2022; 33(7):4255–67.
20. Wolski L, Grzelak K, Muńko M, Frankowski M, Grzyb T, Nowaczyk G. Insight into photocatalytic degradation of ciprofloxacin over CeO_2/ZnO nanocomposites: Unravelling the synergy between the metal oxides and analysis of reaction pathways. Appl Surf Sci. 2021; 563:150338.
21. Golmohammadi M, Hanafi-Bojd H, Shiva M. Photocatalytic degradation of ciprofloxacin antibiotic in water by biosynthesized silica supported silver nanoparticles. Ceram Int. 2023; 49(5):7717–26.
22. Wang H, Luis Vilas Vilela J, Ruiz-Rubio L, Abdulrahman SA, Shnain ZY, Ibrahim SS, *et al.* Photo catalytic Degradation of Ciprofloxacin by UV Light Using N-Doped TiO_2 in Suspension and Coated Forms. Catalysts. 2022; 12(12):1663.
23. Hassan Mohamed NA, Shamma RN, Elagroudy S, Adewuyi A. Visible Light-Driven Photocatalytic Degradation of Ciprofloxacin, Ampicillin and Erythromycin by Zinc Ferrite Immobilized on Chitosan. Resources. 2022; 11(10):81.
24. Das S, Ghosh S, Misra AJ, Tamhankar AJ, Mishra A, Lundborg CS, *et al.* Sunlight Assisted Photocatalytic Degradation of Ciprofloxacin in Water Using Fe Doped ZnO Nanoparticles for Potential Public Health Applications. Int J Environ Res Public Health. 2018; 15(11):2440.
25. Oluwole AO, Olatunji OS. Photocatalytic degradation of tetracycline in aqueous systems under visible light irradiation using needle-like SnO_2 nanoparticles anchored on exfoliated g-C_3N_4. Environ Sci Eur. 2022; 34(1):1–14.
26. Florou DT, Mavropoulos A, Dardiotis E, Tsimourtou V, Siokas V, Aloizou AM, *et al.* Tetracyclines Diminish In Vitro IFN-γ and IL-17-Producing Adaptive and Innate Immune Cells in Multiple Sclerosis. Front Immunol. 2021; 12:739186.
27. Wu L, Yue X, Chang Y, Wang K, Zhang J, Sun J, *et al.* Photocatalytic Degradation of Tetracycline under Visible Light Irradiation on $BiVO_4$ Microballs Modified with Noble Metals. Catalysts. 2022; 12(11):1293.
28. Zhang Q, Jiang L, Wang J, Zhu Y, Pu Y, Dai W. Photocatalytic degradation of tetracycline antibiotics using three-dimensional network structure perylene diimide supramolecular organic photo catalyst under visible-light irradiation. Appl Catal B: Environ. 2020; 277:119122.
29. Sharma M, Mandal MK, Pandey S, Kumar R, Dubey KK. Visible-Light-Driven Photocatalytic Degradation of Tetracycline Using Hetero structured Cu_2O-TiO_2 Nanotubes, Kinetics, and Toxicity Evaluation of Degraded Products on Cell Lines. ACS Omega. 2022; 7(37):33572–86.
30. Abdurahman MH, Abdullah AZ, Shoparwe NF. A comprehensive review on sonocatalytic, photocatalytic, and

sonophotocatalytic processes for the degradation of antibiotics in water: Synergistic mechanism and degradation pathway. Chem. Eng. J. 2021; 413:127412.
31. Elmolla ES, Chaudhuri M. Photocatalytic degradation of amoxicillin, ampicillin and cloxacillin antibiotics in aqueous solution using UV/TiO_2 and UV/H_2O_2/TiO_2 photocatalysis. Desalination. 2010; 252(1–3):46–52.
32. Verma M, Haritash AK. Photocatalytic degradation of Amoxicillin in pharmaceutical wastewater: A potential tool to manage residual antibiotics. Environ Technol Innov. 2020; 20:101072.
33. Lalliansanga, Tiwari D, Lee SM, Kim DJ. Photocatalytic degradation of amoxicillin and tetracycline by template synthesized nano-structured Ce^{3+}@TiO_2 thin film catalyst. Environ Res. 2022; 210:112914.
34. Zhou L, Guo X, Lai C, Wang W. Electro-photocatalytic degradation of amoxicillin using calcium titanate. Open Chem. 2018; 16(1):949–55.
35. Ezelarab HAA, Abbas SH, Hassan HA, Abuo-Rahma GEDA. Recent updates of fluoroquinolones as antibacterial agents. Arch der Pharm 2018; 351(9):e1800141.
36. Remani KC, Binitha NN. Photocatalytic degradation of Norfloxacin under UV, visible and solar light using ceria nanoparticles. Materials Today: Proceedings. 2020; 25:246–51.
37. Sayed M, Shah LA, Khan JA, Shah NS, Nisar J, Khan HM, *et al.* Efficient photocatalytic degradation of Norfloxacin in aqueous media by hydrothermally synthesized immobilized TiO_2/Ti films with exposed (001) facets. J Phys Chem. A. 2016; 120(50):9916–31.