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A Review on the Bismuth based Photocatalysts for visible light Environmental Applications

[1]Mohd Farhan and [2]Gandharve Kumar*

Author's Affiliations:
[1]Research Scholar, Department of Chemistry, Faculty of Engineering, Teerthanker Mahaveer University (TMU), Moradabad, Uttar Pradesh 244001, India
[2]Department of Chemistry, Faculty of Engineering, Teerthanker Mahaveer University (TMU), Moradabad, Uttar Pradesh 244001, India

***Corresponding Author: Dr. Gandharve Kumar**, Department of Chemistry, Faculty of Engineering, Teerthanker Mahaveer University (TMU), Moradabad, Uttar Pradesh 244001, India
E-mail: gandhravk.engineering@tmu.ac.in

ABSTRACT
This review paper includes the information related to synthesis of some bismuth-based photocatalysts.by various methods such hydrothermal, solvothermal etc and their characterization by various techniques such as XRD, Sem, HRTEM, and their photocatalytic applications.

Keywords: Bismuth Semiconductor, Photocatalyst, Degradation, Dyes, Nanomaterials

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1. INTRODUCTION

Introduction of Photocatalysis

Photocatalysis is a process that utilizes light energy to drive chemical reactions on the surface of a catalyst material. It involves the absorption of photons by the catalyst, which then induces a series of electron transfer and redox reactions. The catalyst, also known as a photocatalyst, facilitates the transformation of reactants into desired products under light irradiation.

Principles of Photocatalytic Reactions

The photocatalytic process involves several fundamental steps:

1. Light Absorption: The photocatalyst absorbs photons from a light source, typically ultraviolet (UV) or visible light.
2. Generation of Electron-Hole Pairs: Upon light absorption, the photons stimulate electrons from the valency band (VB) to the conduction band (CB), parting behind positively charged dumps in the VB.
3. Redox Reactions: The photogenerated electrons in the CB and the holes in the VB can contribute to various redox reactions with adsorbed molecules on the catalyst surface or in the surrounding environment.
4. Reactive Species Formation: The redox reactions produce highly reactive species, such assuperoxide radicals ($\bullet O^{2-}$), hydroxyl radicals ($\bullet OH$), and holes (h^+), which can oxidize or reduce organic and inorganic pollutants.
5. Degradation of Pollutants: The reactive species generated by the photocatalyst initiate the degradation of pollutants by breaking down their chemical bonds, resulting in the transformation of harmful compounds into less toxic substances, such as CO_2, and H_2O.

2. IMPORTANCE OF NANOMATERIALS IN IMPROVING PHOTOCATALYTIC EFFICIENCY

Nanomaterials as Catalysts

Nanomaterials play a vital role in improving the efficiency of photocatalytic processes. Compared to bulk materials, nanomaterials exhibit unique properties and characteristics at the nanoscale, which significantly enhance their photocatalytic performance. Some of the key advantages of nanomaterials in photocatalysis include.

Enhancement of Surface Area and Reactivity: Nanomaterials possess an in-height surface-to-volume ratio due to their small size and large surface area. This amplified exterior area affords a larger numeral of energetic positions for reactant adsorption and catalytic reactions. Consequently, more pollutants can come into contact with the catalyst, improving pollutant degradation efficiency.

Increased Light Absorption and Utilization: Nanomaterials can be engineered to have tailored optical properties, including a broad absorption range and efficient light-harvesting capabilities. By controlling the size, shape, and composition of nanomaterials, their light absorption can be optimized to match the solar spectrum, allowing for enhanced utilization of solar energy. This enables a more efficient conversion of light into the excitation of electrons and promotes the photocatalytic process.

Improved Charge Separation and Transfer: Effective responsibility leave-taking and transfer are critical for achieving high photocatalytic efficiency. Nanomaterials offer advantages in terms of endorsing the separation of photogenerated electron-hole pairs [20].Their small size and unique electronic properties facilitate the rapid transfer of charge carriers to the catalyst surface, minimizing charge recombination and maximizing the utilization of photo-excited species. This efficient charge separation and transfer contribute to the overall augmentation of photocatalytic activity.

Furthermore, nanomaterial containers remain created through tailored morphologies, such as nanoparticles, nanowires, nanosheets, and hierarchical structures. These nanostructures provide additional benefits in photocatalysis:

Enhanced Mass and Heat Transfer: Nanostructured materials possess interconnected pores and channels, allowing for efficient mass transport of reactants to the catalyst surface. This enhances the accessibility of pollutants to the active sites, leading to improved reaction kinetics. Additionally, the high surface area of nanostructures promotes effective heat dissipation, preventing overheating and maintaining stable photocatalytic performance.

Tunable Bandgap and Energy Levels: The bandgap of nanomaterials can be engineered by controlling their size and composition. This tunability allows for the absorption of a broader range of light wavelengths, extending the photocatalytic activity hooked on the observable light region. Furthermore, the energy levels of nanomaterials can be modified, enabling better alignment with the energy levels of reactants and facilitating efficient charge transfer processes.

The combination of these advantages makes nanomaterials highly attractive for improving the efficiency and effectiveness of photocatalytic processes. The ability to design and tailor nanomaterials with specific properties offers opportunities to overcome limitations associated with traditional photocatalysts and opens up new avenues for advanced environmental remediation technologies.

3. FUNDAMENTALS OF BISMUTH-BASED NANOMATERIALS

Introduction to Bismuth-Based Nanomaterials

Bismuth-based nanomaterials have garnered substantial courtesy trendy current ages outstanding toward their single assets and probable submissions in several fields, together with photocatalysis. Bismuth, a heavy metal element, exhibits distinct electronic, optical, and catalytic properties at the nanoscale, making it an attractive applicant for the expansion of advanced nanomaterials. Bismuth-based nanomaterials encompass a wide range of compositions and structures, offering diverse opportunities for tailoring their properties to specific applications.

Types and Structures of Bismuth-Based Nanomaterials

Bismuth-based nanomaterials can exist in numerous forms, including nanoparticles, nanosheets, nanowires, nanorods, and hierarchical structures. These materials can be synthesized using different techniques, such as chemical precipitation, sol-gel methods, hydrothermal synthesis, and template-assisted methods. The choice of synthesis method and conditions influence the size, shape, and crystalline structure of the resulting nanomaterials, thereby affecting their properties and performance in photocatalytic applications.

Some common types of bismuth-based nanomaterials include bismuth oxide (Bi_2O_3), bismuth oxyhalides (BiOX, where X = Cl, Br, I), bismuth-based chalcogenides (such as Bi_2S_3, Bi_2Se_3, Bi_2Te_3), and bismuth-based mixed-metal oxides. Each type of nanomaterial possesses unique structural characteristics, such as crystal phase, lattice symmetry, and surface chemistry, which influence their photocatalytic behavior. The specific composition and structure of bismuth-based nanomaterials can be tailored to optimize their photocatalytic properties for specific applications.

Unique Properties of Bismuth-Based Nanomaterials and Their Relevance to Photocatalysis

Bismuth-based nanomaterials exhibit several unique properties that make them attractive for photocatalytic applications. These properties include:

a) Visible Light Absorption: Bismuth-based nanomaterials possess a wide bandgap that allows them to absorb visible light, extending the range of the solar spectrum that can be utilized for photocatalysis. This feature is particularly advantageous as visible light comprises a significant portion of solar radiation, making bismuth-based nanomaterials promising candidates for solar-driven photocatalytic processes.

b) High Charge Carrier Mobility: Bismuth-based nanomaterials often exhibit high charge carrier mobility, enabling efficient charge transport and separation. This property facilitates the quick movement of photogenerated responsibility carters to the material's surface, minimizing recombination losses and enhancing photocatalytic efficiency.

c) Reactive Surface Sites: Bismuth-based nanomaterials possess a high density of reactive surface sites, which can facilitate the adsorption and activation of target molecules during photocatalytic reactions. The availability of abundant surface sites increases the chances of interaction between the catalyst and the reactants, promoting efficient catalytic processes.

d) Unique Redox Chemistry: Bismuth-based nanomaterials exhibit unique redox chemistry, enabling them to participate in a variety of photocatalytic reactions. Their ability to undergo multiple oxidation states allows for versatile catalytic pathways, making them suitable for various environmental remediation applications, such as pollutant degradation and water purification.

The unique properties of bismuth-based nanomaterials make them attractive for photocatalytic applications, offering new possibilities for efficient and sustainable environmental remediation. Understanding these properties and their relevance to photocatalysis is crucially aimed at the project besides the development of advanced bismuth-based nanomaterials with improved photocatalytic performance.

Hirose et al., 2005 used an easy hydrothermal approach to work on three well-known types of bismuth molybdenum catalysts (α-$Bi_2Mo_3O_{12}$, β-$Bi_2Mo_2O_9$, and γ-Bi_2MoO_6). By adjusting the Bi/Mo ratio, bismuth molybdate formation can be produced and regulate pH levels. The synthesis of α-$Bi_2Mo_3O_{12}$ was caused by a low pH and a high molybdenum content γ-Bi_2MoO_6 was formed as a result of high pH and bismuth concentrations. The pure beta-phase was created by calcining hydrothermal material at 560°C. The prepared sample's XRD pattern indicated unsatisfactory intensities at pH 5, indicating that the sample had not crystallized well. These intensities were attributed to the catalysts α-$Bi_2Mo_3O_{12}$, and γ-Bi_2MoO_6 which were used in the preparation process. The orthorhombic γ-Bi_2MoO_6 phase was simple to distinguish between pH 7 and pH 9. Studies on photophysical and photocatalytic processes demonstrate that the Aurivillus (γ-Bi_2MoO_6) compared to α-$Bi_2Mo_3O_{12}$ and β-Bi2Mo_2O_9, exhibits a significant photocatalytic activity band and an excessive absorption band.[1]

Andreozzi et al., 2010 utilized the co-precipitation approach to create the 200°C for $BiVO_4$. According to XRD outcomes, smaller Bi_2O_3 phases made up the N-doped $(BiO)_2CO_3$ samples as they were created. It (Bi_2O_2) based totally on the crystal structure of $(BiO)_2CO_3)^{2+}$ layers had been orthogonally intergrown. Which were measured to be between 250 and 300 nm. The small-scale aggregation of fundamental particles produced this debris. In the case of a pattern produced with the aid of a solid-state response at 700°C, the fee become measured as 0.3 m^2g^{-1}, at the same time as the BET evaluation discovered that the pattern had a floor place of 1.5 m^2g^{-1} at 200°C. UV spectroscopy is used to observe each substance's diffuse mirrored image. The difference in the electricity band hole turned into calculated as for the samples, the relative energies have been 2.27 eV (co-precipitation technique) and a pair of 2.31 eV (solid-country response). [2]

Zhang et al., 2006 A quick hydrothermal procedure was used to create a novel heterojunction of bismuth oxy hydrates (BHO) and BiOCl. The TGA curve showed that the material was unstable upon heating for pure BHO, and lost coordinated water and hydroxyl groups, which resulted in a weight reduction of about 9.36% of its initial value. The absolute weight loss point also alluded to the original $Bi(OH)_3$ composition of BHO, which was exactly equal to the 1/3 Bi/O atomic ratio determined in pure BHO using EDS. The TGA results supported the novel BHO process's hydration state and were in line with the EDS data obtained for this study. A "standing" thin plate's lattice image showed a layered BHO structure and an inter-planar phase gap of 0.32 nm. [3]

Trovo et al., 2008 worked on the simple combustion synthesis of the m-$BiVO_4$ photocatalyst. TEM images of $BiVO_4$ (small volume combustion (SVC)) revealed particle aggregation and dispersion during burning powder with an average particle size of between 10 and 20 nm and was found to have nanoparticles on the surface. The catalyst's composition of bismuth, vanadium, and oxygen was validated by an EDX spectrum. SVC-$BiVO_4$ (13.86 m^2g^{-1}) had a 20 times greater surface area than traditional solid-state synthesized $BiVO_4$ (0.7 13.86 m^2g^{-1}), according to BET surface area measurements. Using Tauck's figure, the get-up-and-go group hole of SVC- $BiVO_4$ was determined to be 2.52 eV. According to the authors, the kind of fuel utilized in the combustion reaction process and the synthesis pathway (the amount of precursor employed) affect physicochemical parameters including surface area and particle size. [4]

Putra et al., 2009 using the solution combustion synthesis technique produced Bi_2O_3 nanocatalyst the usage of Bi nitrate as an oxidant and citric acid as gasoline. They considered the impact of calcination infection on the morphology, section transition, and the scope of the Bi_2O_3 nanocatalyst. Bi_2O_3 nanoparticles had been created by way of an answer combustion method 1.471 g of $C_6H_8O_7$ and 2.9106 g of $Bi(NO_3)_3.5H_2O$ 10 ml of HNO_3 (0.04 mol L^{-1}) were then brought earlier than 0.04 g of PEJ-20000 turned into dissolved inside the aggregate. After 5 minutes of energetic stirring, a clean, obvious solution is created. The liquid was heated for 2 hours at 300°C before being cooled to room temperature. The temperature and duration of the calcination process affect the crystal levels and size of flammable substances, inclusive of the molar ratio of $C_6H_8O_7.H_2O$ to $Bi(NO_3)_3.5H_2O$. [5]

Ghauch et al., 2009 Monoclinic (α-phase) bismuth vanadate ($Bi_4V_2O_{11}$) nanoparticles through an element extent of fewer than 30 nm showed that α- $Bi_4V_2O_{11}$was composed of randomly sized 20–25 nm particles. Whereas γ-$Bi_4V_2O_{11}$ was about 0.5-1.0 nm in size, shaped nanoparticles. Although the particle form/shape is thought to remain random, it is assumed that the particle size rises with the annealing temperature. When the annealing temperature was raised from 20 to 25 nm to 0.5 to 1.0 nm, the particle size increased, demonstrating that the surface-to-volume proportion of the $Bi_4V_2O_{11}$ particles had decreased. Tauc's equation was used to compute the band gap of the materials, which came out to be 1.97 eV and 2.44 eV for γ-$Bi_4V_2O_{11}$ and α-$Bi_4V_2O_{11}$, respectively. The authors concluded that the bandgap of α-$Bi_4V_2O_{11}$. [6]

Elmolla et al., 2009 using the solvothermal approach, created the nano-spherical shape of β-Bi_2O_3. As a bismuth precursor, bismuth nitrate pentahydrate was used. It had a spherical nanosphere with a diameter of between 70 and 90 nm. The nanosphere shrank as a result of structural changes and the evaporation of organics adsorbed on its surface. That morphology was revealed by a thorough morphological analysis. The calcination temperature, solvent, and D-fructose concentration all had a significant impact on the synthesis. Acetaminophen (APAP) was photo-catalytically degraded using the generated β-Bi_2O_3 sample under the illumination of visible light. Without a catalyst, negligible APAP degradation was seen when the material was exposed to visible light. 93.6% of the sample of β-Bi_2O_3 exhibited advanced photocatalytic action for the breakdown of paracetamol then generated the nano spherical shape of β-Bi_2O_3 using the solvothermal method. The precursor for bismuth was bismuth nitrate pentahydrate. It possessed a spherical nanosphere that was between 70 and 90 nm in diameter. Due to structural modifications and the evaporation of organics deposited on its surface, the nanosphere shrunk. The comprehensive morphological examination made that morphology clear. The synthesis was significantly influenced by the solvent, D-fructose content, and calcination temperature. Under the influence of visible light, paracetamol (APAP) was photo-catalytically broken down utilizing the created - Bi_2O_3 sample. When exposed to visible light without a catalyst, APAP deterioration was hardly noticeable. The breakdown of paracetamol was more photo-catalytically active in 93.6% of the sample of Bi_2O_3. [7]

Elmolla et al., 2009 Maleic acid was used to create the Bi_2O_3/TiO_2 heterojunction, and the composite was then annealed at 300°C to remove the maleic acid. Accordingly, a rod-like structure was seen, with rods varying in length and diameter between 4-33 and 0.4- 3.0 µm, respectively. The combination of Bi_2O_3 and TiO_2 catalysts had been significantly aided by maleic acid. The Bi_2O_3/TiO_2 composite included progressively more Bi_2O_3 from 0 to 100%, according to XRD. At the optical absorption wavelength of 450 nm, the energy ring break of the Bi_2O_3/TiO_2 combination was discovered to be 2.75 eV. The photon cutting-edge the observable portion of the solar spectrum can be absorbed by composite, according to the UV-DRS data, supporting photocatalytic activity. For the eradication of, the Bi_2O_3/TiO_2 composite had the highest degrading efficiency of 75% 2-propanol after exposure to visible radiation for 60 minutes. [8]

Elmolla et al., 2009 created a Bi_2O_3 heterostructure that is magnetically separable by combining a hydrothermal synthesis process with microwave assistance. Bi_2O_3 heterostructures with lengths of 20–40 µm were visible in SEM pictures. The thickness of 200-450 nm. A 50% heterostructure of Bi_2O_3 was discovered to have a 1.67 eV band gap. Below the brightness of observable light, the photocatalytic bustle of a heterostructure of Bi_2O_3 was examined for the elimination of tetracycline (TC) at various mass ratios. When 50% was placed on the Bi_2O_3, the heterostructure of Bi_2O_3 demonstrated improved visible-light-driven photocatalytic action, producing the greatest squalor rate of 90.78% in 90 min and the K_{app} of 0.360 min^{-1}. This notable improvement was evident as a result of the interfacial junction's successful parting of electron-hole pairs. [9]

Elmolla et al., 2010 for the guidance of BiOBr, BiOI, and $BiOI_{0.5}Br_{0.5}$, hired the easy co-precipitation system, low-temperature answer training, and chemical etching, respectively. NaBr precursors and $Bi(NO_3)35H_2O$ had been utilized for the advent of BiOBr. The resulting interruption remained hypnotically moved for 24 hours at the area temperature. By dispersing 2g of formerly arranged BiOBr in 400 mL of deionized water that was altered using constant stirring in glacial acetic acid at pH 2.65 the heterojunction of $BiOI_{0.5}Br_{0.5}$ was additionally created. The BiOBr suspension solution turned into then given a stoichiometric quantity of KI. The aggregate is then heated to room temperature and stirred for half an hour. The as-synthesized photocatalysts had been natural tetragonal sections and homogenous particles, according to the XRD exam. [10]

Chaudhari et al., 2009 the hydrothermal process produced BiOBr in the form of flake. With the aid (of XRD), UV-DRS, and (SEM), the structural, morphological, and optical characteristics of the produced sample were assessed. The building and the morphology of the BiOBr investigations showed a tetragonal phase with uneven flake structural morphology and smooth edges that were between 1-3 µm in size. It was discovered that the produced catalyst's energy band gap was 2.55 eV. The degradation of the antibiotic ciprofloxacin (CIP) in visible light was used to measure the photocatalytic effect. With BiOBr, the CIP was completely broken down in 140 minutes. The kinetics of the breakdown followed a pseudo-first-order model, and the amount continuous was determined to be 0.0272 min^{-1} with an R^2 of 0.9954. [11]

Yang et al., 2009 investigated the impact of BiOBr microspheres on adsorption in the breakdown of ibuprofen (IBP) under illumination from visible light. High-magnification SEM images showed the BiOBr microspheres were made up of many plate-like nanostructures, and TEM examination showed that the 2.35 µm diameter microspheres were solids. The BiOBr microspheres' BET surface area and hole capacity were determined towards the remaining 17.17 m^3 g^{-1} and 0.035 cm^3 g^{-1}, separately. The adsorption of BiOBr during the photocatalysis process caused the authors to discover that about 80% of IBP was eliminated in 2 hours. Results obtained showed that the amount of IBP that could be removed by BiOBr was largely reliant on adsorption capacity. Adsorption and photocatalysis only differed in the removal of IBP, indicating that BiOBr's actual photocatalytic efficacy for the removal of IBP was very poor. The scientists also observed that the O-Bi-O bond formed on the BiOBr microsphere surface during the exchange of anion between dissociated IBP and Br, which was the primary driving factor during the adsorption and photocatalysis of IBP. [12]

Arasalan et al., 2004 A citrate self-combustion technique was used to create magnetically separable $BiFeO_3$ nanoparticles, which were then layered with titanium-dioxide hydrolysis ($Ti(OBu)_4$) to create $BiFeO_3$ @TiO_2 cores haven nanocomposites with various TiO_2 to $BiFeO_2$ weight ratios the peak. The perovskite phase of $BiFeO_3$ was responsible for the diffraction strength of the XRD diffraction peaks of $BiFeO_3$. The Scherrer equation remained cast off to find the regular crystallite scope of $BiFeO_3$ to be 39 nm. TiO_2 had less strong peaks than $BiFeO_3$, which had more nanoparticles in the XRD pattern that was produced. The (006) perovskite $BiFeO_3$ and (101) and (110) rutile TiO_2 planes in the HRTEM image have lattice spacings of 0.230, 0.250, and 0.320 nm, respectively. SEM scan revealed that only BiFeO3 nanoparticles were agglomerated to some extent, had rough surfaces, and had erratic forms. $BiFeO_3$@TiO_2 (mass ratio = 1:1) covered the $BiFeO_3$ particles with homogeneous, spherical flicks of TiO_2 particles that had a moderately even surface. TiO_2, $BiFeO_3$, and $BiFeO_3$@TiO_2 (1:1) were calculated to have energy band gaps of 2.96, 1.68, and 1.77 eV, respectively. [13]

Arasalan et al., 2004 Using a Bi_2O_3/Bi_2O_4 photocatalyst and visible light illumination, investigated the photocatalytic squalor of 17α-Ethinyl estradiol (EE2) utilizing the calcination of raw materials with various mass fractions, Bi_2O_3/Bi_2O_4 hetero-junction was created $NaBiO_3/KOH$ ratios. In comparison to commercial Bi_2O_3, Bi_2O_3/Bi_2O_4 composites made with a 2.5 mass ratio ($NaBiO_3/KOH$) demonstrated 100% degradation of EE2 in 12 minutes of visible light irradiations. According to experimental findings, photocatalytic reactions had a rate constant of 0.223 min^{-1} and followed pseudo-first-order reaction kinetics. The most active species in the photocatalytic deprivation of EE2 were O^{2-} and H^+, however, OH played a minor role. [14]

Huang et al., 2019 Utilizing corona discharge plasma with a suspended flake-like structure, researchers looked into the breakdown of tetracycline (TC). The production of Bi_2MoO_6 particles involved a solvent-thermal process (solvothermal). Particles of the nanometer size were analyte was composed of organized, uniform shavings by a width extending from 50 nm to 150 nm, overlaid atop oriented nano-cage surface layers. Bi_2MoO_6 synthetic nanomaterials were produced with a 99.9% purity and a very small amount of impurities; their external extent, pore dimensions, and average pore size were each measured at 101.59 $m^2 g^{-1}$, 0.28 $cm^3 g^{-1}$, and 10.87 nm, respectively. The exceptional surface area of the powders was produced as a result of the creation and proliferation of numerous rough fractures at the contact. The removal efficiency of 250 mL TC (50 mg L-1) was increased from 62 to 96% with the usage of Bi_2MoO_6 for a range of 0-1.5 g L^{-1} within 24 min with the discharge power of 36.0 W. According to the TOC data, TC mineralization rose from 25% to 61%. [14]

Zhang et al., 2023 for the degradation of antibiotics, several new methods paired with catalysts based on bismuth have recently been devised. For instance, recent research has shown that adding H_2O_2 to the SSL/ Bi_2WO_6 photocatalytic system (SSL/Bi_2WO_6/H_2O_2) can significantly improve NOR degradation efficiency. It was determined that the synergetic effect of H2O2 was responsible for the rapid degradation of up to 79.4% of norfloxacin within 12 min (11.4% faster than SSL/ Bi_2WO_6The e produced by the Bi_2WO_6 photocatalytic process may simultaneously be effectively collected by already noted, bismuth-based catalysts can produce area. These ROS can damage or destroy bacteria's cell membranes as well as enter cells. [15].

Li et al., 2023 In this paper, the complete information is condensed, and some improved compounds like Metronidazole (MTZ) and cephalexin (CFX) were degraded by using a ternary heterojunction of double Z-scheme $CuWO_4/Bi_2S_3/ZIF_{67}$ under LED (400 W/m^2, > 400 nm) illumination, with maximum degradation efficiencies of 95.6% for MTZ and 90.1% for CFX, which is roughly 9 times higher than that of Bi_2S_3. Like this, Z-scheme $LaTiO_2N/Bi_2S_3$@RGO(LBR) nano-heterostructures were created using a solvothermal approach and displayed exceptional performance in TC photodegradation when exposed to visible light, eliminating 96.4% of the compound in just 90 minutes. [16].

Wang et al., 2023 Bi_2O_3 and metal oxides, such as V_2O_5, W_2O_3, Mo_2O_3, TiO2, etc., made up the majority of these hybrid oxides, which had a layered Aurivillius structure $BiVO_4$, a novel-type semiconductor device, has been suggested because of its excellent visible-light-driven ciprofloxacin degradation performance. According to recent experimental findings, BiVO4 was around four times more effective than TiO_2 at degrading ciprofloxacin more particularly, its photocatalytic activity was significantly reliant on its crystal phase. As much as 67.61% of CIP and 80.5% of tetracycline could be effectively destroyed in 60 minutes when using $BiVO_4$, which also displayed good photoactivity in antibiotic elimination. Sadly, the light conversion efficiency of metal oxides based on bismuth is relatively low. [17]

Chen et al., 2023 The crystal structures of bismuth oxide, a common oxide semiconductor, have been found to include body-centered cubic, tetragonal, cubic fluorite type, and monoclinic forms of bismuth oxide (Bi_2O_3). According the band gaps of these four structures are as follows: -Bi_2O_3 (1.64 eV), - Bi_2O_3 (2.1 eV), - Bi_2O_3 (2.8 eV), and - Bi_2O_3 (3.0 eV). In particular, at room temperature, -, -, and -Bi2O3 are metastable while - Bi_2O_3 is the only stable phase over a large temperature range. It is obvious that - Bi_2O_3 has the narrowest band gap, which enables it to effectively use light from the visible spectrum of the Sun. [18].

Liu et al., 2023 since the introduction of CdS nanoparticles on Bi_2MoO_6 microspheres, the interfacial surface for the effective separation of the charger carriers has been produced. Compared to bare CdS and Bi_2MoO_6, 1.0 CdS/ Bi_2MoO_6 significantly increased the visible-light photocatalytic activity for LEV antibiotics. The greatest rate constant for the photocatalytic degradation of LEV was 0.0259 min^{-1} for 1.0 CdS/ Bi_2MoO_6, according to the pseudo-first-order model that was used. After six consecutive experiments, the initial photocatalytic performance of 1.0 CdS/ Bi_2MoO_6 persisted. At the optimal dose (40 mgL^{-1}) of 1.0 CDS/ Bi_2MoO_6, up to 90.1% of LEV was mineralized in 2.5 hours. These TOC results demonstrated that LEV was effectively degraded and mineralized by 1.0 CdS/ Bi_2MoO_6. [19].

Yang et al., 2023 Most often, synthetic solutions with antibiotic concentrations below mg/L were used in the assessment of photocatalytic degradation by catalysts based on bismuth. The concentration of antibiotics in wastewater treatment plant effluents and surface water is typically between g/L and ng/L. Therefore, using photocatalysts based on bismuth for actual applications of antibiotic breakdown, particularly for situations with trace antibiotics, should be a major concern. [20]

Chen et al., 2018 The major human metabolite of erythromycin, erythromycin-H_2O that morphology was revealed by a thorough morphological analysis. The calcination temperature, solvent, and D-fructose concentration all had a significant impact on the synthesis. Acetaminophen (APAP) was photo-catalytically degraded using the generated β-Bi_2O_3 sample under the illumination of visible light. Without a catalyst, negligible APAP degradation was seen when the material was exposed to visible light. 93.6% of the sample of β-Bi_2O_3 exhibited advanced photocatalytic action for the breakdown of paracetamol then generated the nano spherical shape of β-Bi_2O_3 using the solvothermal method. The precursor for bismuth was bismuth nitrate pentahydrate. 43.8e 100% in a UWTP, both of which used activated sludge in their secondary wastewater treatment procedures. [21]

Xu et al., 2021 It has been suggested that $BiVO_4$, a novel-type semiconductor, be used because of its performance in the degradation of CIP in these hybrid oxides, which exhibited a layered Aurivillius structure and were mostly made of Bi_2O_3 and metal oxides, such as V_2O_5, W_2O_3, Mo_2O_3, and TiO_2. According to recent experimental findings, $BiVO_4$ was around four times more effective than TiO2 at degrading ciprofloxacin, and the crystal phase of the substance had a significant impact on its photocatalytic activity. As much as 67.61% of ciprofloxacin and 80.5% of tetracycline could be effectively destroyed in 60 minutes when using BiVO4, which also displayed good elimination. Unfortunately, metal oxides based on bismuth have very poor light conversion efficiency, which is intimately related to electrons. [22].

4. CONCLUSION

Due to the slow metabolism of pollutants in an aqueous medium (such as dyes, pesticides, and pharmaceuticals), the presence of pollutants in water bodies is a major issue for people all over the world. Due to the development of (ABRS) anti-bacterial resistant strains inside their bodies, they can quickly contaminate the water bodies and cause severe diseases in both animals and people. As a result, we construct visible light photocatalysts based on bismuth and test them on real water samples to see how well they degrade different contaminants including dyes, tetracycline, and ciprofloxacin as well as how well they convert cancer-causing Cr(VI) from the water into Cr(III).

5. LIST OF ABBREVIATIONS

Å	Angstrom unit
β	Beta
^{o}C	Degree Celsius
µL	Microlitre
%	Percentage
AO	Ammonium oxalate
AOP	Advanced oxidation process
BET	Brunauer – Emmett – Teller
CB	Conduction band
cm	Centimetre
cm^{-1}	Centimetre inverse
eV	Electron volt
HR-TEM	High-resolution transmission electron microscopy
kg	Kilogram
L	Litre
LFC	Levofloxacin
mg	Milligram
mg L^{-1}	Milligram per liter
mg L^{-1} sec^{-1}	Milligram per liter per second
min	Minute
mL	Millilitre

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