

REVIEW OF THE SYNTHESIS CHARACTERIZATION AND PHOTOCATALYTIC ACTIVITIES OF GRAPHENE OXIDE/METAL OXIDE NANOCOMPOSITES

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ABSTRACT

Numerous studies show that sustainable water processing strategies may enhance water quality. Photocatalytic technology, among other methods, has shown impressive promise as a low-cost, ecologically friendly, and sustainable technology in recent years. The ideal photocatalyst must have high photocatalytic activity, a large specific surface area, collect sunlight, and exhibit recyclability; this is the greatest hurdle to the commercialization of photocatalyst technology. With this in mind, this review focused on the methods used to create graphene/metal oxide nanocomposite, how it is characterised, and its most important applications in photocatalysis. Rate-limiting factors that were discussed include photocatalyst loading, photocatalyst structure, temperature, pH, oxidising species' influence, and light wavelength. Intermediates formed during photo-oxidation of organic contaminants by these photocatalysts are also explored. Graphene-based materials were summarised in terms of their significance in the context of this study's ultimate goal, which was to examine the efficacy of their use in the context of pollution control. At the end, a high-level summary of the issues and potential solutions is provided.

Keywords: *graphene oxide, metal oxide, photocatalyst, zinc oxide nanocomposite, titanium oxide nanocomposite.*

INTRODUCTION

To maintain good health, people need access to clean water. In order to maintain human health, water must be free of harmful contaminants such heavy metals, chemicals known to cause cancer, and infectious pathogens. Authorities and civil society all across the globe have had to respond quickly to the pressing needs posed by the world's rapid industrialization and population growth. By 2050, the United Nations Water Development Report 2020 predicts that the global population would be 748 million people short of clean drinking water, and that industrial water use will have increased by a staggering 400 percent. In areas where harmful metal ions and industrial waste are not effectively removed, potable water is a serious issue. This results in a significant risk to human health from a wide variety of toxic organic and inorganic substances found in the water supplies. An improved wastewater treatment method is urgently needed to deal with problems of this kind. Natural aerobic procedures, coagulation,

precipitation, membrane diagnostics, photocatalysis, Fenton reactions, microbial fuel cells, and adsorptions have all received significant attention in recent years. However, several obstacles prevented their widespread use, including the length and complexity of the required methods, the high cost of operations and the chemicals used, and the difficulty in producing aggregate loam and separating it. However, modern oxidation techniques, which use photocatalytic heterogeneous and homogeneous oxidation of various organic pollutants, are seen as among the most promising approaches to efficient wastewater treatment in light of all these limitations. Any chemical reaction that takes place in the presence of light and a photocatalyst is said to be a photocatalytic reaction. Environmental safety, complete degradation of pollutants, and the absence of secondary contamination are only a few of the benefits of this technique. Providing a light energy from an external source is necessary for a large variety of possible photocatalysts since they can only be used with UV radiation. This is especially true given that solar light only contains 5% UV radiation. A number of metal oxides have been investigated for their potential as heterogeneous photocatalysts in the treatment of wastewater. Iron (III) oxide, zinc oxide (ZnO), titanium dioxide (TiO₂), tungsten trioxide (WO₃), vanadium oxide (V₂O₅), and zirconia are just a few examples.

The most well-known photocatalysts for wastewater treatment are zinc oxide (ZnO) and titanium dioxide (TiO₂). Due to its many desirable qualities, including low price, high oxidation capacity, strong photosensitivity, bio consistency, acceptable photocatalytic performance, high chemical stability, outstanding pyroelectric and piezoelectric properties, and acceptable photocatalytic performance, ZnO has shown great promise in recent years. When exposed to ultraviolet light, ZnO's large definite surface area (i.e., highly acute regions) generates photogenerated charge carriers and reactive oxygen species (ROS) such hydroxyl radicals, facilitating the adsorption and mineralization of pollutants. The quick recombination and poor resistance to corrosion limit the practical utilisation of electron-hole pairs, and the relatively broad bandgap (about 3.37 eV) necessitates UV light for the process to take place. Numerous methods, including as metal loading, ion doping, connection with semiconductor, composite loading, enhanced structural design, etc., have been used to date to boost ZnO's performance. The most promising of these methods is the employment of carbon-based material to either manufacture visible-light-active photocatalysts or to extend the lifetime of photo-generated electron-hole pairs. It is true that ZnO has been used in conjunction with more traditional carbon-based materials, but graphene and its analogues are among the most promising candidates for this use. These materials excel in a wide variety of electrical, thermal, chemical, and adsorption areas, demonstrating remarkable surface features. Due to its surface functionality of hydroxyl/carboxyl groups and its potential for charge separation capabilities, graphene oxide (GO) is a promising choice for ZnO-based integrated photocatalysts.

These days, GO-based ZnO nanoparticles are widely used in photocatalytic applications owing to their excellent physicochemical and photo-electrical properties. Structure-wise, GO-based nanocatalysts may significantly improve ZnO's photocatalytic activity because to the high electronic mobility shown by the p- conjugated structure. The GO/ZnO combination enhances visible-range light energy harvesting by increasing the spacing of electron-hole pairs on the

surface of ZnO. Their high specific surface, abundance of active sites, and sturdy sustaining qualities all contribute to their impressive efficacy.

As a photocatalyst, TiO₂ is among the most promising materials. TiO₂'s photocatalytic potential has been studied for a variety of applications, including as the destruction of organic contaminants and the purification of air, among others. On the other hand, photocatalysts as a whole have certain drawbacks, including a lack of efficiency, a high recombination rate, and a need for ultraviolet light. TiO₂ has 1) superior stability, 2) cheap cost and low toxicity, and 3) increased photocatalytic activity in comparison to other semiconductor materials, all of which make it a popular photocatalyst in research on wastewater treatment. Because of this, photocatalytic activity can only occur in the visible part of the Sun's spectrum. Additionally, TiO₂ has a higher rate of electron and hole recombination. These problems may be solved by the fabrication of photocatalysts based on a TiO₂ composite and graphene derivatives. In the case of graphene, the electron mobility is higher, which enhances electron transport and decreases recombination of electron and hole. TiO₂ aggregation can be avoided, leading to a larger surface area and more active sites for pollutant degradation, which might be a significant advantage of using a graphene-TiO₂ composite. Using less of the graphene-TiO₂ composite photocatalyst also improves the pollutant degradation rates. Graphene's electrical and photonic properties make it a promising material for boosting TiO₂ photoactivities. Graphene has a high heat conductivity, increased load carrier's mobility, and higher mechanical strength (Yaqoob et al., 2021). Since graphene-TiO₂ absorbs more visible light and has a strong affinity with other organic materials, its photoactivity has also been enhanced. This article discusses the properties, production, and crucial function in photo-degradation of ZnO and TiO₂-GO nanocomposites. This article discusses the properties of zinc oxide, titanium dioxide, and hydroxyapatite (GO), as well as the methods for synthesising GO/metal oxide nanocomposites, the photocatalytic mechanism for degradation, the factors affecting the efficiencies of the photocatalyst, the existing difficulties, and the recommendations for future works.

SIGNIFICANCE OF GRAPHENE DERIVATIVES FOR PHOTOCATALYSIS

Graphite, diamond, and amorphous carbon are all categorised differently based on their atomic structure and properties. Graphene is an atomically thin, two-dimensional (2D) carbon material. Since graphene is a primary component of nanomaterials, they have a direct bearing on this extraordinary material. Besides its use as a photocatalyst, graphene has emerged as a leading material in a vast number of other fields as well, such as energy conversion and storage. Figures 1A-D show the diversity of graphene and its usage in the production of heterogeneity across a variety of industries and fields. Its enormous surface and catalytic, optical, and electric features also make it a promising candidate for the development of redox vibrating media and water purification catalysts. Carbon-based nanoparticles are very porous, and their surface area keeps growing, both of which contribute to their potent adsorption capabilities, which in turn make them useful in a number of wastewater treatment applications.

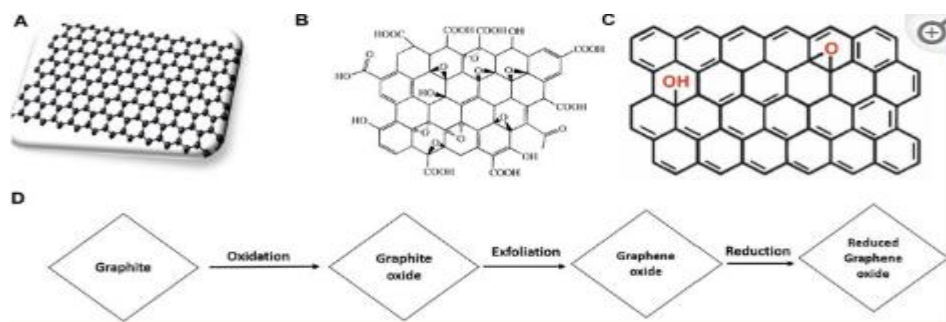


Figure 1. Structure of (A) single layer graphene, (B) graphene oxide (GO) (C) reduced graphene oxide (rGO) and (D) the synthesis route of rGO through GO reduction.

GO, which is created when graphite oxide is exfoliated, is a versatile material with several potential uses. The first attempt at synthesising GO was carried out by Benjamin C. Brodie (1859), an Oxford University chemist, and L. In 1898, Staudenmaier made his name in the scientific community. Subsequently, Hummers et al. continued their study of the material by conducting the chemical reaction in graphite using potassium and nitric acid. G. Offeman and Hummers attempted it later with some tweaks, as shown in Figure 1D, which involves mixing 100 g of graphite powder in sulfuric acid with 50 g of sodium nitrate at first. To ensure that no impurities are present, we cool the mixture in an ice bath. Third, graphite starts to oxidise in a combination of 300 g of potassium permanganate and agitation, requiring a very thorough and small amount of potassium permanganate to keep the suspension temperature below 20°C. In the fourth place, after 20 minutes of mixing, the combined solution becomes a brownish-grey paste with a little amount of gas generated. Fifth, the paste is left to run for 30 minutes before being gently mixed with deionized water to produce a bright sparkling wave at 98°C. Sixth, after the paste has become brown after being diluted, it may be kept for another 15 minutes. Seventh, hydrogen peroxide is used to get rid of the remaining manganese dioxide and additional deionized water is added to boost the dilution. When peroxide is added, the suspension quickly becomes a bright yellow colour. As a result, step eight involves filtering a suspension of overflowers and rinsing the resulting yellow-brown filter a couple of times. Tenth, the filtered products' heated powder is 40 degrees Celsius. At long last, GO has been reduced to a single sheet of atoms.

Carboxyl, hydroxyl, and epoxy groups mix with important functionality components such polymeric materials and metal oxides in the formation of graphene semi-continuous composites with tuneable textural and surface chemical characteristics. Graphene-based nanocomposites provide a fertile research ground for the improvement and development of water purification technologies. To add insult to injury, utilising commercial graphene as a photocatalyst is very costly. As a result, the synthesis of graphene from waste material by the hummer approach may be the most cost-effective alternative. In order to generate the GO, which may then be doped with metal oxide to serve as a photocatalyst, several initiatives are now underway to make use of agro-waste material, biomass, paper, etc. As a result, this measure has the potential to improve the technique's dependability and efficiency.

GRAPHENE OXIDE/METAL OXIDE NANOCOMPOSITE SYNTHESIS METHODS

The nanocomposites GO/ZnO and GO/TiO₂ have attracted a lot of attention in the field of photocatalysis because of their small size and advantageous optoelectronic properties. For the ZnO and TiO₂ photo catalyst, it will be crucial to reduce the recombination process and enhance its resistance to photo-corrosion. High stability is achieved by including ZnO and TiO₂ nanoparticles into the GO surface, which prevents the joining of graphene-based layers owing to the strong van der Waals forces between graphene layers. The following are some of the most common methods used in the field of material science to synthesise novel and improved graphene oxide/metal oxide nanocomposites.

Sol-Gel Method

Among the many potential methods for producing composites, sol-gel has been employed since the late 1980s in the synthesis of nanocomposites. As shown in Figure 2, the sol-gel method is a multi-step process based on the progressive hydrolysis of metal precursors to achieve metal hydroxide resolution, followed by immediate condensation to produce a 3D gel.

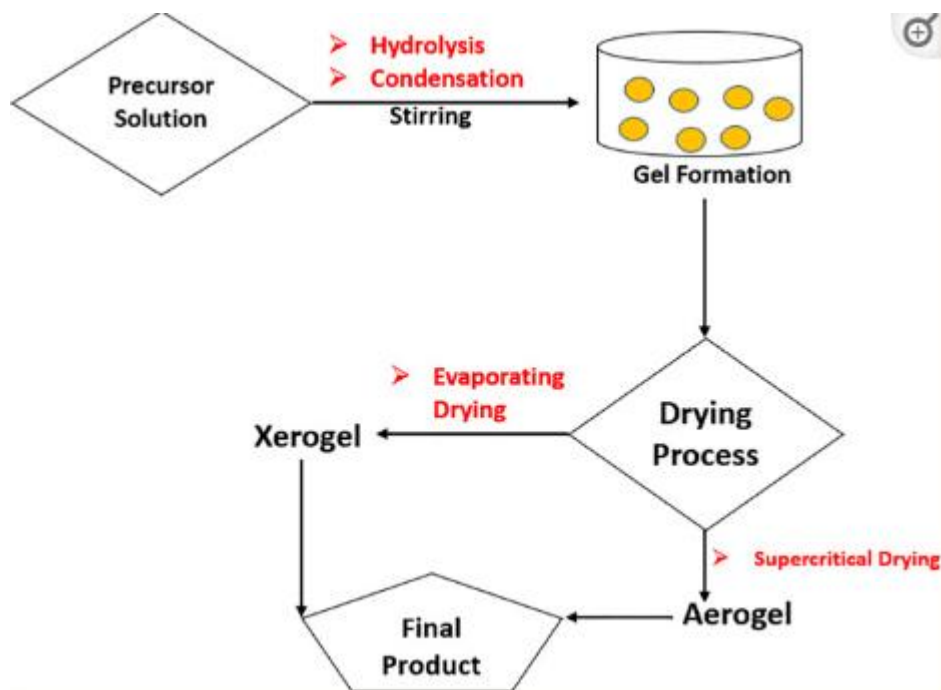


Figure 2 Graphic presentation of sol-gel technique (Reproduced from Yaqoob et al., 2020 with MDPI permission)

Direct Growth of Metal Oxide Nanoparticles on the Surface of Graphene Oxide

Nanocomposite with optimum ratio of ZnO and TiO₂/GO synthesis. ZnO NPs were prepared by first depositing Zn²⁺ ions uniformly over the surface of GO, and then treating the mixture with NaOH and NaBH₄ at 150°C. After graphene oxide was converted to graphene, ZnO/graphene was the final product. ZnO NPs have matured to a size where their average physical size is between 10 and 20 nm, and their dispersion on the surface of graphene layers is very fine. The simple in-situ approach for making ZnO/graphene nanocomposite was disclosed by Chang et al. To begin, a combination of ZnO quantum dots and graphene was created by combining the two materials at a predetermined ratio. ZnO/graphene thin films were produced by casting the resulting combination onto various substrates, such as polyethylene terephthalate, quartz, glass, and SiO₂/n-Si. Then, the films were hardened by evaporation at 100 °C while trapped in a zinc nitrate solution, which was employed to in situ elevate ZnO quantum rods into ZnO nanorods for usage in ZnO/graphene nanocomposites. Increasing substrate adherence was the goal of these reactions. Finally, the nanocomposite was rinsed many times to get rid of any remaining contaminants in the ZnO nanorods. In his study, Feng et al. reported on the investigation of a novel simple approach to synthesise ZnO nanosphere/rGO nanocomposites using a hydrothermal assisted in-situ gelatin method and described the ZnO dispersion impact on rGO. The results show that ZnO/rGO nanocomposite was made by adding Zn (Ac)₂. 2H₂O and GO to a gelatin solution in various proportions. This reaction took place at room temperature while being continually stirred. Concurrently, the previously obtained mixture was pH-adjusted to a range of 9.0-10.0 by adding NH₃.H₂O at a concentration of 25 wt% and swirling it constantly with a magnetic rod for a period of 30 minutes. After that, the material was transferred to autoclaves made of stainless steel and Teflon (25 ml in size) for a reaction lasting the same length of time as ZnO production. The last process included washing the final product with water and drying it in a vacuum at 80 degrees Celsius. The photocatalytic reaction of the nanocomposite was enhanced thanks to the RGO compounds' efficient electron transportation and enhanced well surface area. It was also reported by Sahatiya and Badhulika that a single graphene in-situ synthesis process employing electrospinning that was doped with zinc oxide (GO-ZnO) was as simple as one step.

Direct Growth of Metal Oxide Nanoparticles on the Surface of Graphene Oxide

Characteristically produced nanocomposite of ZnO and TiO₂/GO. A uniform layer of Zn²⁺ ions was placed on the surface of GO, and then, after heating with NaOH and NaBH₄ to 150°C, the GO was transformed into ZnO NPs. After graphene oxide was converted into graphene, ZnO/graphene was the final product of the process. ZnO NPs have typically grown to be between 10 and 20 nm in size, with a very finely dispersed particle physical size. A simple in-situ approach for generating ZnO/graphene nanocomposite was disclosed by Chang et al. To initiate the process, a combination of ZnO quantum dots and graphene was prepared by combining the two materials at a predetermined ratio. The combination was then cast onto several substrates, including PET, quartz, glass, and SiO₂/n-Si, to produce ZnO/graphene thin films. The films were then hardened by evaporating them at 100°C while encased in a zinc nitrate solution, where the quantum rods were in situ elevated to nanorods and then employed

to create ZnO/graphene nanocomposites. The purpose of these reactions was to strengthen the bond between the substrate and the substrate. And last, the contaminants from the ZnO nanorods were washed off by repeatedly washing the nanocomposite. In their study, Feng et al. not only described the influence of ZnO dispersion on rGO, but also reported on the discovery of a novel, simple approach for synthesising ZnO nanosphere/rGO nanocomposites using a hydrothermal assisted in-situ gelatin method. The results showed that ZnO/rGO nanocomposite was created by adding Zn (Ac)₂ · 2H₂O and GO to a gelatin solution in various proportions. At room temperature, this reaction was carried out while being continually stirred. Simultaneously, the previously obtained mixture was pH-adjusted to a range of 9.0-10.0 by adding NH₃·H₂O at a concentration of 25 wt% and swirling it constantly with a magnetic rod for a period of 30 minutes. The produced product was then transferred to stainless steel-based autoclaves that had been lined with Teflon (25 ml in capacity) and subjected to the same reaction time as in ZnO synthesis. Finally, the final product was cleaned with water and dried in a vacuum at 80 degrees Celsius. Enhanced photocatalytic activity of the nanocomposite was achieved thanks to the RGO compounds' high electron transport and expanded well surface area. The electrospinning of a single layer of graphene doped with zinc oxide (GO-ZnO) nanocomposite was also reported by Sahatiya and Badhulika.

FACTOR AFFECTING THE PHOTOCATALYSIS PROCESS

Photocatalysis's ability to breakdown and decolorize contaminants in water resources is influenced by a number of variables. Here we highlight the importance of a few of the most prominent to demonstrate their role in photocatalysis.

Photocatalyst Loading

Particularly for ZnO and TiO₂ doped photocatalysts, the loading effect has a sizeable bearing on photocatalytic behaviour performance. The influence of loading on the overall efficacy of pollutant degradation has been studied using a variety of photocatalysts. An exhaustive literature search led to the following conclusion: the rate of photodegradation is proportional to the amount of catalyst loaded, up to the point when the catalyst is at its most active. This behaviour is in line with the high photocatalyst amount that increases both the total number of active reaction sites and the ZnO/GO photocatalyst's surface area. An increase in the production of superoxide radicals and hydroxyl as a result makes it possible for contaminants to be broken down. There was thus less of a decline in degradation percentage. Although, screening effects and UV-light scattering impact cause a decrease in the photodegradation percentage at high concentration loadings of the catalyst when the dosage is adjusted. To add insult to injury, using too much of a photocatalyst may increase agglomeration contact, which in turn can decrease the surface area available for catalysis. This exposed surface area may be absorbed by UV rays or adsorbed by chemicals, reducing the catalytic efficiency. Also, the turbidity of the solution tends to rise with increased catalyst loading. As a result of this singularity, light cannot travel through any intervening media. With less volume, photo-activated suspensions degrade at a slower pace. In order to prevent using an excessive amount of catalyst and to

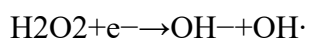
guarantee a supreme photons absorption, it has been suggested that the optimal photocatalyst mass be examined in light of this phenomenon.

Structure of Photocatalyst

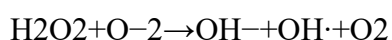
Altering the growth structure of ZnO and TiO₂ may boost their photodegradation efficiency. Due to their exceptional physicochemical characteristics and structural shape, ZnO or TiO₂ nano-based structures have recently attracted a great deal of interest in the research of photocatalysis. Nanoparticles (NPs) of ZnO or TiO₂ are commercially available in a wide variety of shapes and sizes, including sheets, belts, rods, dumbbells, wires, discs, flowers, and neotheropods. All of these distinct forms have their own unique set of characteristics and morphologies that aren't seen in ZnO or TiO₂ in bulk form. These nanostructured morphologies of ZnO and TiO₂ feature nano-sized particles with a large surface area. The physical and chemical characteristics of this huge surface area are exceptional. ZnO and TiO₂ at the nanoscale have distinctive surface and quantum effects. Research by Assi et al. looked at the use of ZnO nanorods in photocatalytic degradation of methylene blue (MB). According to the results of the research, ZnO nanorods with a larger surface area are more effective at photodegradation than those with a smaller one. For the photocatalytic destruction of Rhodamine B, a novel ZnO or TiO₂ nano range sheet was developed. Yet the 3D fleecy-based structure suggests several reaction active sites and a sizable operating surface area. The maximised surface area and improved separation ability for holes and electrons in the nanostructure catalysts resulted in a greater rate of photodegradation while removing Rhodamine B through photocatalytic reaction.

Oxidizing Species

It is usual practise to boost the photo-oxidation rate by adding good oxidising species, such as potassium peroxydisulfate (K₂S₂O₈) and hydrogen peroxide (H₂O₂), to a solution of ZnO/TiO₂. As part of the photocatalytic degradation process, hydrogen peroxide is also thought to serve many purposes. Hydrogen peroxide, for instance, produces hydroxyl radicals (Eqs. 12, 13) and may cause charge separation by drawing electrons out of the conduction band.



(12)



(13)

Hydrogen peroxide may be reactive towards ZnO/TiO₂, generating peroxy groups that are unfavourable to the photocatalytic activity, when its concentration is above the concentration essential. It is possible that K₂S₂O₈ is more efficient at degrading pollutants than H₂O₂, although Bizani et al. reported that adding an oxidant like H₂O₂ was more successful in the lab. However, it has been shown that K₂S₂O₈ is more effective in degrading organic pollutants

than the photocatalysis approach. It includes hydrogen peroxide, which is indicative of effective toxin elimination, and organic carbon that has been partially dissolved (DOC).

pH

Degradation of organic molecules during photocatalytic reaction is also influenced by the pH level. Catalyst surface charge, contamination hydrolysis, oxidant concentration, and contamination ionisation degree are all significantly affected by pH. Adsorption characteristics of the cationic or anionic organic pollutant differed depending on whether the photocatalyst was charged negatively or positively on its surface. Moreover, the major oxidation species is demonstrated to be influenced by the pH of the solution, with holes and hydroxyl radicals being the most prominent oxidative species at lower and higher pH values, respectively. The point of zero charge (pzc) is another critical factor to understand; it describes the pH value at which the net surface charges of a catalyst are neutral. The pzc value is used to calculate the surface charge of catalysts, which is positive below pzc and negative above it. As a result, the success of the catalysts in degradation may depend on the pH setting that is found to be optimal.

Temperature

Since photonic activation has a direct influence on photocatalysis degradation progress, it may result in functionalities at optimal temperature and unique pressure. This is helpful since the heat phase, which is normally required for disinfecting water, may be skipped. Degradation of contaminants may be sped up generally by high reaction temperatures. In addition, it may decrease the adsorptive volumes of the reactant and liquified oxygen, indicating a poor photodegradation productivity. Therefore, increasing the effectiveness of ZnO/GO and TiO₂/GO composites as photocatalysts requires an optimum environment.

Light Wavelength

The effectiveness of the photocatalytic reaction is also directly influenced by the light's wavelength. In the context of ultraviolet (UV) radiation, this term designates the electromagnetic band that may be subdivided into three subbands—UV-A1, UV-A2, and UV-A3—based on the wavelengths of the radiation they generate. UV-A1 has a wavelength range of 315–400 nm (3.10–3.94 eV), whereas UV-A2 and UV-A3 have wavelength ranges of 280–315 nm (100–280 nm) and 280–315 nm. Studies indicated, however, that produced TiO₂ may degrade 1,8-diazabicyclo (5.4.0) undec-7-ene in the presence of UV-A1 radiation. The decreased dispersion capabilities of high energy photons at 254 nm boost the electron-hole pairs that are produced appropriately for hazardous pollutant decompositions, resulting in a photocatalyst with a high productivity.

PRESENT CHALLENGES AND FUTURE PERSPECTIVES

Graphene and its derivatives are being developed into a broad range of nanocomposites with metal oxides for usage in the photocatalysis area. Since researchers in this field are working to

break down technical and financial hurdles in order to make their work a reality, their efforts are continuing and growing. Problems with the current setup need to be fixed. In the first place, despite the vast range of potential applications, there are currently no low-cost, mass-production methods for making graphene derivatives. Second, studies have shown that these graphene-based nanocomposites may improve their photocatalytic efficacy by increasing their ability to absorb light, to partition and transport loads, and to remain functional for extended periods of time. According to this line of thinking, there are several limitations that must be addressed in order to solve the fundamental scientific and technological issues that hinder its widespread usage and render it inappropriate for tasks of significant economic significance. The success of photocatalysis will need future interdisciplinary work between researchers and engineers; for example, the synthesis and design of the novel graphene-based nanocomposites for photocatalyst still require integrated thinking. This method has the potential to solve issues with nanocomposites' durability, recycling, and reusability after revival. There is also the issue of photocatalyst stability, which is a major challenge because of the catalysts' short lifetimes and susceptibility to photocorrosion. In the case of photocatalysts based on ZnO or TiO₂, photocorrosion is even more important than chemical corrosion. Numerous studies have focused on increasing the photocorrosion resistance of photocatalysts based on ZnO or TiO₂, and this work should be expanded to other systems. In addition, bioinspiration is a viable method for developing cutting-edge light-trapping, pollution-absorbing designs. Synthesizing GO from waste materials is a great way to get around the synthesis issue.

CONCLUSION

In conclusion, research into graphene/ZnO and graphene/TiO₂ nanocomposites was conducted with an eye on developing cutting-edge photocatalysis materials. This article summarised research published on graphene/ZnO and graphene/TiO₂ nanocomposites between the years of 2010 and 2020. Various pollutants in water, including organic dyes, heavy metal ions, and viruses, may be destroyed by light thanks to the photocatalytic activity of metal oxide semiconductors, which is enhanced by the interaction between graphene and photoactive metal oxide. Graphene's exceptional properties, such as its high adsorption capacity, broader light absorption range, improved charge separation capabilities, and outstanding durability, are enhanced by the size-dependent properties of nanomaterials. The future of these composites and how environmentally friendly they become make the development of water treatment technologies based on graphene/metal oxide nanocomposites a fascinating but difficult problem for researchers. This is a major obstacle in the way of reuse and proper disposal of these used composites. Concurrently, plans will be established for the recycling and disposal of trash generated by residential water purification equipment. Finally, it can be concluded that the graphene/metal oxide nanocomposite has immense potential as an efficient photocatalyst, but that there are issues with these materials that must be resolved before they can be put to their full use. They have not been studied extensively enough to determine whether doing so would help in the development of a more effective photocatalyst. Extensive study into the optimization of the graphene content in the composite is required to optimise output from these composites.

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