International Journal of Information Technology and Management
Vol. 18, Issue No. 2, August-2023, ISSN 2249-4510

DOI: https://doi.org/10.29070/q72xx108

Nanocomposite photocatalyst facile fabrication with efficient photocatalytic activity under visible light

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Abstract: A precipitation-deposition mixture of manganese dioxide and lead sulphide was produced with lead sulphide concentrations ranging from half a milligramme (0.5 PbS) to one and a half milligrammes (1.5 PbS). Testing the metal with different instruments was the next stage. Some of the methods that were used include photoluminescence spectroscopy, SEM, ED-X-ray spectrometry, BET-surface area, and UV-visible diffuse reflectance spectra. Testing the photocatalytic activity using methylene blue dye revealed that 1% PbS/MoS2 outperformed both 0.5% and 1.5% PbS/MoS2. We looked at the photocatalytic activity as a function of pH and catalyst dose, among other factors. Light activates the PbS-MoS2 combination, which effectively breaks down methylene blue (MB) dye.

Keywords: PbS/MoS2 nanocomposite, Visible light, Photocatalysis, Methylene Blue

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INTRODUCTION

Lately, natural contamination has turned into a squeezing worldwide issue, with natural pollutants presenting huge dangers to biological systems and human wellbeing. Conventional remediation techniques frequently miss the mark in productively eliminating these poisons. Be that as it may, nanocomposites have arisen as a promising answer for photocatalytic corruption of natural pollutants under noticeable light. This article investigates the blend, portrayal, and assessment of nanocomposites in this specific circumstance, featuring their true capacity in tending to ecological difficulties.

Nanocomposites hold tremendous potential for photocatalytic debasement of natural pollutants under apparent light, offering upgraded execution contrasted with conventional impetuses. The amalgamation interaction considers exact command over nanocomposite properties, while portrayal procedures give bits of knowledge into their design and piece. Through assessment tests, nanocomposites show surprising productivity in debasing different natural contaminations, featuring their relevance in ecological remediation. Be that as it may, difficulties like versatility, cost-adequacy, and long haul solidness should be tended to for inescapable arrangement of nanocomposites. Proceeded with research endeavors pointed toward upgrading blend strategies, upgrading portrayal procedures, and further developing impetus execution will additionally push the field of nanocomposite-based photocatalysis towards maintainable answers for ecological contamination alleviation.

Nanotechnology, in its broadest sense, refers to the use of technological means for the purpose of creating and executing nanostructures and nanomaterial applications. Material dimensions (grain size, layer thickness, and materials below 100 nm) that exhibit nanostructures are largely responsible for the growing fascination with nanotechnology (Hornyak et al. 2009). Nanomaterials are unique in their peculiar characteristics due to the size of these particles. According to Chattopadhyay et al. (2009), materials that have a dimension smaller than 100 nm are considered nanomaterials. The chemical, physical, and biological domains are all rich in potential uses for nanotechnology and nanomaterials.

During the 1959 American Physical Society annual meeting, Richard Feynman delivered his now-iconic speech titled "There is a plenty of room at the bottom," marking the beginning of nanotechnology. During the previous twenty years, there have been numerous advancements in the field of nanomaterial manufacturing, including new discoveries and technologies. New theoretical and experimental synthesis methods and processes for the discovery of new materials open up vast opportunities for the development of innovative nanostructured materials with a wide range of dimensions and properties. As a result of this breakthrough, new fields of research and technology are opened up.

Research on the photocatalytic properties and potential applications of pure PbS in waste treatment has already taken place. But no one has documented the photocatalytic activity of a PbS/MoS2 hybrid that we are aware of. Using a combination of the precipitation-deposition process and varying concentrations of Pb (0.5, 1, and 1.5 percent), this unique PbS/MoS2 hybrid material was created. When exposed to visible light, we want to know how well it decomposes MB solutions. The visible light water-breaking capabilities and stability of the 1% PbS-MoS2 heterostructure are much superior to those of pure PbS.

REVIEW OF LITERATURE

Aa, et al., (2023) Fusion of ecologically benign nanoparticles (NPs) has lately supplanted compound approaches as the gold standard for wastewater and pollution cleanup. Many other semiconductor photocatalysts, including TiO2, WO3, SnO2, CeO2, ZnO, Bi2O3, Ag, Na2SeO3, ZnCr2O4, Nb2O5, and countless more, have been successfully synthesised using green combination techniques. One promising new approach to water purification is photocatalytic degradation, which uses various nano-semiconductor photocatalysts to photooxidize various environmental contaminants. Due to its accessibility, low cost, and positive impact on the environment, plant waste has the potential to be an excellent component of environmentally friendly metal nanoparticle (NP) combinations. This review primarily focusses on the incorporation of plant components into nano-photocatalyst mixtures. This review compiles all of the research on the use of light to facilitate the photooxidation breakdown of naturally occurring pollutants. One inexpensive and environmentally friendly way to make nanoparticles that are effective in cleaning up water pollution is to use garbage plants in the green mix of nano-photocatalysts. The fundamental objective of this research is to find eco-friendly new applications for plant waste that include financial photocatalysts. New developments in this region are being bolstered by this.

Jasim, et al., (2022) Porous materials known as metal-organic frameworks (MOFs) have already found widespread use and great potential in research and development in areas such as medicine. There is a constant flux in them as well. This study primarily focusses on the basic mixing techniques for ZnMOFs and current research on the use of Zn MOF-based photocatalysts to remove natural contaminants, such as natural colours, from water.Photocatalysis using MOFs is the primary emphasis. Due to its porous structure and massive surface area, this nanomaterial is an excellent wastewater cleaner. The distributions showed debasement of more than 90%. These findings demonstrate the significant ability of Zn-MOFs to alter the aforementioned pollutants. Results demonstrated that the Zn-MOF nanostructure is quite powerful and continues breaking down a lot of contaminants even after being employed numerous times, indicating a high reusability rate. This audit primarily targets composites containing Zn-MOFs. We will demonstrate how to mix and express these combinations in the first phase. Now I know how to employ these mixtures to degrade light-sensitive contaminants of various colours.

Shume, (2020) Even while photocatalytic processes are a promising new technique to eliminate these dangerous compounds, not all commercially available photocatalysts are sunlight-sensitive enough to comprehend their breakdown. The majority of scientists believe that metal oxide nanoparticles perform admirably as photocatalysts when exposed to visible light. The green built course, which incorporates nanostructured silver oxide and other eco-friendly materials and technologies, is an affordable and eco-conscious option. The most effective Ag2O NPs were produced by minimising the impacts of pH, concentration, metal particle attachment, and contact duration. Our written review states that we used various methods, including SEM, TEM, X-ray diffraction, EDS, X-ray photoelectron spectroscopy, FTIR, a UV-visible spectrophotometer, and scanning electron microscopy, to study the design, shape, crystallinity, size, cleanliness, and optical properties of the Ag2O NPs. Using mixed nanocrystalline Ag2O as a catalyst, this review examines the photocatalytic degradation of natural hues under visible light conditions. Scientists have previously shown that when exposed to visible light, green mixed Ag2O NPs completely degrade natural hues and pollutants.

Kumar, & Pandey, (2017) Crucial to the photocatalytic framework's oxidation rates and efficacy are a number of functional constraints that restrict the photodegradation of the natural atom. The function boundary was recently defined in a report. Several fundamental components control the rate of photodegradation. Many factors must be taken into account, such as substrate convergence, activity measurement, pH of the arrangement, temperature of the reaction medium, light intensity, surface area of the photocatalyst, nature of the substrate and photocatalyst, construction of the substrate and photocatalyst, doping of metal and non-metal particles, and many more. Optimal conditions for photodegradation of organic compounds have been identified by a small number of researchers. Low centralisation of the natural substrate with an optimal concentration of photocatalyst was shown to provide the most intense photodegradation of natural mixes. A natural substrate's rate of photodegradation is also affected by the arrangement's pH. Photodegradation is more severe at low pH, which makes sense given that titania exhibits its maximum adsorption at low pH. If you want to know how natural substrates degrade when exposed to light, you need to know the surface area. By expanding the photocatalyst's surface area, we can improve the photodegradation of organic substrates. One possible explanation is that the phenomena was caused by an increase in the number of dynamic sites as a function of surface area. For the photocatalysis cycle to proceed, it is necessary to determine the amount of photocatalyst. When considering the dosage of photocatalysts, what is the limit? Excessive use will significantly reduce photodegradation, whilst insufficient use would have the reverse impact. The amount of metal and non-metal particles in a naturally occurring substrate determines how quickly it degrades when exposed to light. Since metal particles increase the positive charge on the photocatalyst's surface, they are necessary. Factors like light intensity and temperature determine whether organic materials can be photodegraded. Operating the photocatalytic process at room temperature or just slightly over 80°C allows for the most efficient photodegradation. If you want to transfer electrons from the valence band to the conduction band or even to a band hole energy level, you need use light.

MATERIAL AND METHODS

Synthesis of PbS Nanoparticles

First, the PbS nanoparticles were synthesized by dissolving the appropriate amounts of $Pb(NO_3)_2$ and Na_2S in 100 mL of distilled water. The solution was stirred continuously for 30 minutes until it became transparent. Next, NaOH (0.2 M) was added to adjust the pH to 9. The resulting mixture was then vigorously stirred for an additional two hours. After filtration, the filtered product was dried in an oven at 110°C, yielding nanocrystalline lead sulfide. Finally, the dried material underwent calcination at 400°C for 2 hours to complete the synthesis.

Synthesis of MoS_2 Nanoparticles

MoS_2 nanoparticles were prepared using a conventional procedure where 2 millimoles of ammonium molybdate and 10 millimoles of thiourea were dissolved in 60 mL of distilled water under continuous stirring. The solution (80 cc) was transferred into a Teflon-lined stainless steel autoclave, which was then sealed and maintained at 200°C for 24 hours. After cooling to room temperature, the black precipitate was isolated by centrifugation and washed three times with ethanol and distilled water. The final product was dried in an oven at 80 °C for 12 hours.

Synthesis of PbS/MoS_2 Nanocomposites

The nanocomposites were synthesized by first mixing 200 mL of distilled water with 0.2345 M ammonium molybdate and 0.5% $Pb(NO_3)_2$, ensuring that both PbS and MoS_2 were present in the mixture. After an initial 4 hours of stirring, a 0.5 M thiourea solution was added gradually while maintaining continuous stirring for an additional 3 hours. The precipitate was then separated by filtration and washed with a mixture of ethanol and deionized water to remove any residual impurities. The final step involved drying the material at 80°C for 24 hours. A similar procedure was followed to prepare nanocomposites with 1.5% MoS_2 and 1% PbS.

Evaluation of Photocatalytic Activity

The photocatalytic performance was evaluated by monitoring the photodegradation of methylene blue (MB). Once the degradation process was complete, the chemical oxygen demand (COD) was determined using the dichromate oxidation method.

RESULT AND DISCUSSION

Characterization by UV-Vis DRS

Figure 1 illustrates the UV-Vis diffuse reflectance spectra (DRS) for PbS, MoS_2, and the PbS/MoS_2 nanocomposites with varying ratios (0.5%, 1%, and 1.5%). Notably, after converting the spectra to their respective absorption edges, the nanocomposites exhibited a slight red shift compared to the individual materials.

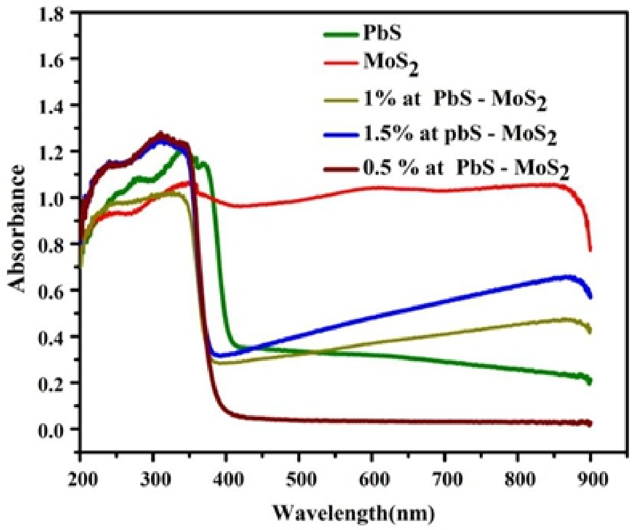

Figure 1: UV-Vis DRS spectra for PbS, MoS_2, and PbS/MoS_2 nanocomposites (0.5%, 1%, 1.5%)

Optimization of Reaction Parameters

Effect of pH on Photodegradation Efficiency

As shown in Figure 2, the highest degradation efficiency (83%) was observed at pH 11.5. At higher pH levels, the catalyst surface becomes more negatively charged, enhancing the adsorption of the positively charged MB molecules via electrostatic attraction.

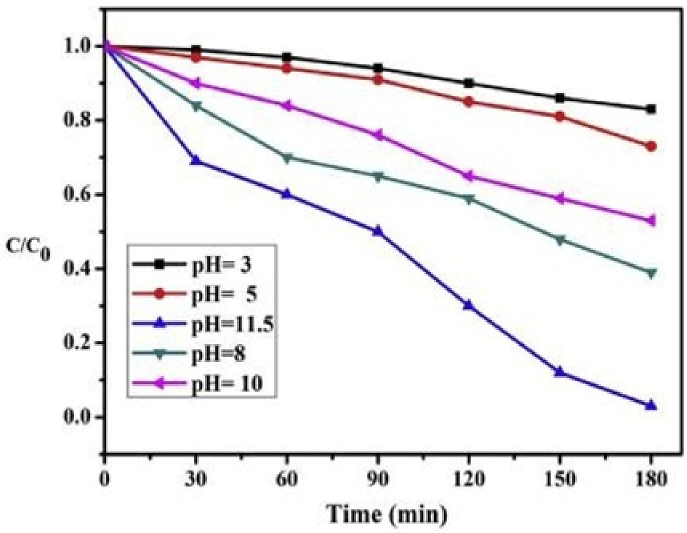

Figure 2: Influence of pH on MB photodegradation efficiency

Effect of Catalyst Dosage

This was attributed to excessive catalyst leading to aggregation, light scattering, and diminished penetration of the light source, ultimately decreasing the number of active sites available for photocatalysis (see Figure 3).

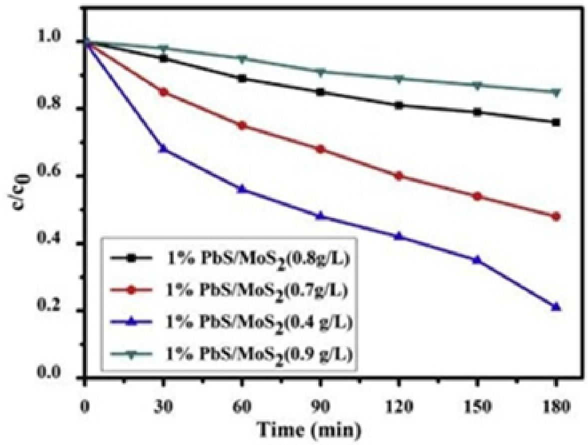

Figure 3: Impact of catalyst dosage on MB photodegradation

Kinetics of MB Photodegradation

Our results show that compared to other modified and their naked catalysts, the rate constant of 1% PbS/MoS_2 nanocomposites is much higher.

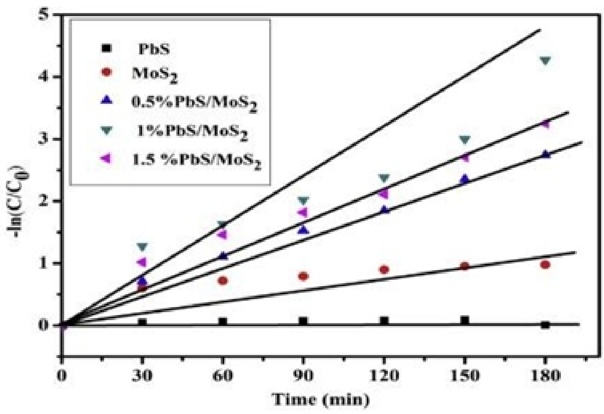

Figure 4: Kinetic profile for the photocatalytic degradation of MB

CONCLUSION

In summary, we successfully synthesized PbS/MoS_2 nanocomposites with varying molar ratios using a precipitation-deposition method. XRD analysis confirmed the formation of tetragonal PbS and hexagonal MoS_2 phases, while SEM images revealed a characteristic sheet-like morphology. EDX analysis further verified that the nanocomposites were composed solely of lead, molybdenum, and sulfur. The photocatalytic tests demonstrated that the 1% PbS/MoS_2 nanocomposite exhibited enhanced activity, attributed to its favorable structural and optical properties.

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