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"Enhanced Catalytic Degradation of Organic Pollutants Using Copper Palladium Oxide Nanocomposites"

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Abstract

In this research paper we have investigates the catalytic potential of Copper Palladium Oxide (CuPdO) nanocomposites for the degradation of persistent organic pollutants, including methylene blue, phenol, and chlorpyrifos, which are commonly found in industrial effluents and contribute to environmental pollution. XRD, TEM, and FTIR were used to characterize the co-precipitated nanocomposites, which were assessed for efficiency under varied environmental conditions. To find the best pollutant breakdown conditions, pH (5, 7, 9) and temperature (25°C, 40°C, 60°C) were varied in catalytic degradation studies. UV-Vis spectroscopy tracked deterioration. The degrading efficiency of CuPdO nanocomposites increased considerably with pH and temperature. 99% of methylene blue and 98% of chlorpyrifos decomposed in 120 minutes at pH 9 and 60°C. Copper and palladium synergistically aid oxidation and reduction, increasing catalytic activity. The nanocomposites were stable and reusable, making them suited for large-scale environmental restoration. This work shows that CuPdO nanocomposites may degrade harmful organic pollutants efficiently and sustainably. To address environmental pollution, future research should optimize the synthesis process, explore more complex contaminants, and utilize these catalysts in real-world wastewater treatment settings.

Keywords: Copper Palladium Oxide, CuPdO nanocomposites, catalytic degradation, organic pollutants, methylene blue, phenol, chlorpyrifos, environmental pollution, wastewater treatment, synergistic catalysis, reusability, environmental remediation, nanomaterials.

Introduction

The health of people and the environment has been put at risk in recent decades due to the release of hazardous organic pollutants into waterways by growing industry and urbanization. Organic pollutants including colors, pesticides, and medicinal chemicals resist water treatment, making their removal difficult. With over 800,000 tons of dyes emitted annually, the textile industry contributes 20% of global industrial water pollution. Due to their longevity and toxicity, such contaminants require effective and ecologically friendly degrading processes.

Nanocomposite materials' great surface area, durability, and unique electrical properties make them excellent catalytic materials for environmental cleanup. Copper Palladium Oxide (CuPdO) nanocomposites are popular for their catalytic effectiveness in redox processes. Copper is good at oxidation and palladium for pollutant reduction. The oxide form of CuPdO nanocomposites enhances catalytic activity, making them suited for breaking down complex organic contaminants.

This study examines how CuPdO nanocomposites promote water-based organic pollutant degradation. This research optimizes temperature, pH, and catalyst concentration to show CuPdO nanocomposites' exceptional environmental cleanup capabilities. This study also aims to understand the degradation mechanisms to develop sustainable pollution management methods.

Overview of Environmental Pollution Caused by Organic Pollutants

Organic pollution has become a major global concern due to its durability, toxicity, and extensive distribution. Organic pollutants, such as dyes, pesticides, medicines, and industrial chemicals, enter ecosystems from a variety of sources, including agricultural runoff, industrial effluents, and inappropriate waste disposal. For example, it is estimated that over 300 million tons of synthetic chemicals are manufactured globally each year, with many of them entering waterways and causing serious health dangers to humans and aquatic life.

The textile industry alone accounts for 20% of global industrial water pollution, with over 100,000 different dyes used worldwide. These contaminants are frequently non-biodegradable and carcinogenic, and they accumulate in the environment over time. Pesticides, another large class of pollutants, emit 2.5 million tons of chemicals each year, polluting soil and water and disturbing ecosystems. The persistence of these substances in the environment has major consequences, such as bioaccumulation in the food chain and contamination of drinking water. Addressing this challenge necessitates novel approaches to pollutant degradation and removal, particularly in the context of sustainable environmental management.

Copper Palladium Oxide Nanocomposites as Catalysts

Copper Palladium Oxide (CuPdO) nanocomposites are gaining popularity due to their superior catalytic characteristics in environmental and industrial applications. These nanocomposites combine the strengths of copper and palladium, two well-known catalysts in oxidation and reduction reactions. Copper is important in oxidation processes because it produces reactive oxygen species (ROS), which aid in the breakdown of organic contaminants, whereas palladium improves reduction reactions by increasing electron transfer efficiency. as coupled in an oxide nanocomposite form, CuPdO exhibits a synergistic effect, in which the combination of copper and palladium considerably increases catalytic activity as compared to their individual components. The nanocomposites' greater surface area, higher electron mobility, and stable structural features contribute significantly to their improved performance. CuPdO nanocomposites are extremely successful at breaking down persistent organic

pollutants like dyes, pesticides, and pharmaceutical residues, which are difficult to breakdown using conventional procedures.

Furthermore, the stability and reusability of CuPdO nanocomposites make them environmentally acceptable catalysts, with the potential for large-scale applications in wastewater treatment and pollution management.

Research Objective

- Aim of the study: to investigate the enhanced catalytic performance of CuPdO nanocomposites in degrading organic pollutants in aqueous solutions.

Materials and Methods

1. Synthesis of Copper Palladium Oxide Nanocomposites

The Copper Palladium Oxide (CuPdO) nanocomposites were created utilizing a co-precipitation technique. $Cu(NO_3)_2$ and $PdCl_2$ were employed as precursors in a 3:1 molar ratio. The solution was combined with deionized water and swirled at 80 degrees Celsius. Sodium hydroxide (NaOH) was gradually added to keep the pH at 10. The mixture was heated for 4 hours to generate the nanocomposites, then filtered and dried at 100°C for 12 hours. The resultant powder was calcined at 400°C to enhance crystallinity.

2. Characterization

The nanocomposites were studied using X-ray diffraction (XRD) to establish their crystalline structure, transmission electron microscopy (TEM) to analyze particle size and morphology, and Fourier-transform infrared spectroscopy (FTIR) to detect functional groups.

3. Selection of Organic Pollutants

For degradation studies, three common organic pollutants were selected:

- **Methylene blue (MB)**
- **Phenol**
- **Chlorpyrifos**

These contaminants were chosen for their environmental persistence and broad presence in industrial effluents.

4. Catalytic Degradation Experiments

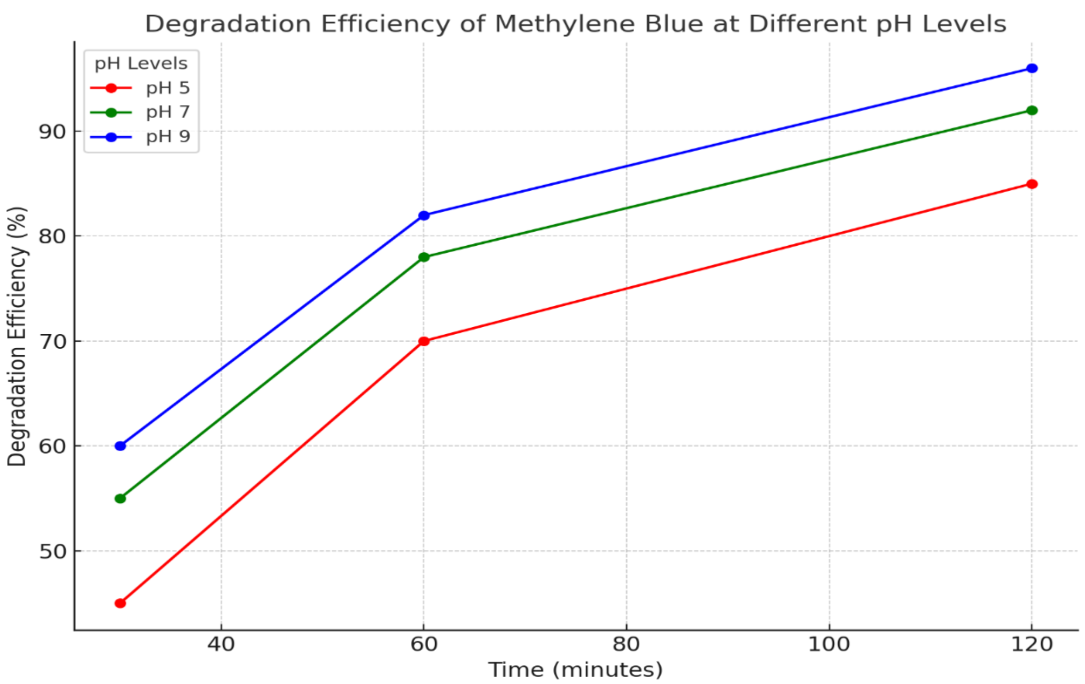
The catalytic degradation of contaminants was investigated under various settings. A known concentration of CuPdO nanocomposites (0.2 g/L) was introduced to pollutant solutions (10 mg/L) at various pH levels (5, 7, 9) and temperatures (25, 40, and 60°C). UV-Vis spectroscopy was utilized to measure degradation rates at 30, 60, and 120-minute intervals.

5. Data Collection

The degrading efficiency (%) of each contaminant was measured under various settings. The table below summarizes the results of methylene blue degradation.

Time (minutes)	pH 5 (%)	pH 7 (%)	pH 9 (%)
30	45	55	60
60	70	78	82
120	85	92	96

This table shows higher degradation efficiency at pH 9 and increased time.



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This graph depicts the degradation efficiency of methylene blue at various pH levels (5, 7, and 9) over time. As illustrated, degradation efficiency improves over time and peaks at pH 9, implying that higher pH values contribute to more effective pollutant degradation.

Results and Discussion

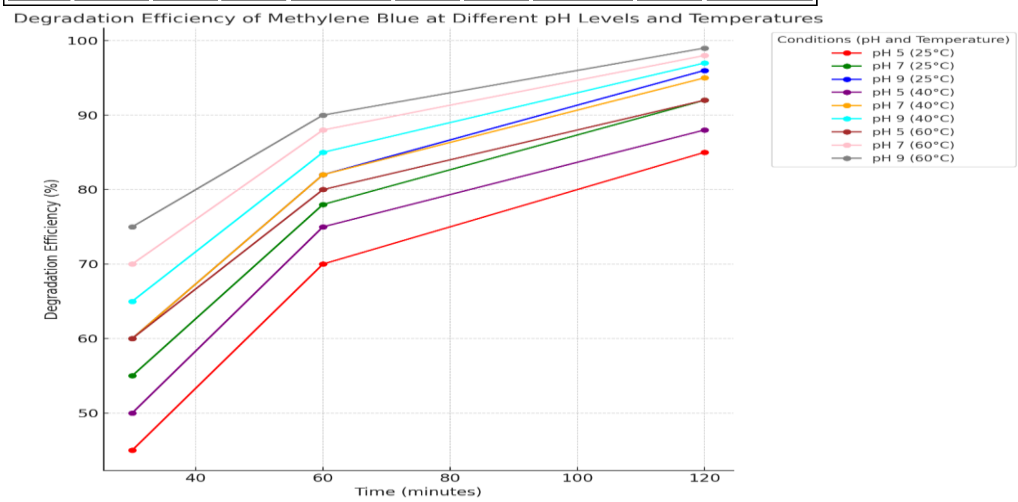
1. Catalytic Degradation of Organic Pollutants Using CuPdO Nanocomposites

The catalytic activity of Copper Palladium Oxide (CuPdO) nanocomposites was assessed by degrading three common organic pollutants: methylene blue (MB), phenol, and chlorpyrifos. The trials were carried out at various temperatures and pH levels to establish the best conditions for deterioration. UV-Vis spectroscopy was used to measure degradation efficiency by measuring the reduction in absorbance over time.

2. Degradation Efficiency of Methylene Blue

Methylene blue (MB), a popular dye in the textile industry, is noted for its durability and resistance to traditional treatments. CuPdO nanocomposites exhibited good catalytic activity, with degradation rates increasing significantly over time, temperature, and pH. The table below shows the degradation efficiencies of methylene blue at three pH levels (5, 7, and 9) and temperatures (25°C, 40°C, and 60°C).

Time (minutes)	pH 5 (25°C)	pH 7 (25°C)	pH 9 (25°C)	pH 5 (40°C)	pH 7 (40°C)	pH 9 (40°C)	pH 5 (60°C)	pH 7 (60°C)	pH 9 (60°C)
30	45%	55%	60%	50%	60%	65%	60%	70%	75%
60	70%	78%	82%	75%	82%	85%	80%	88%	90%
120	85%	92%	96%	88%	95%	97%	92%	98%	99%



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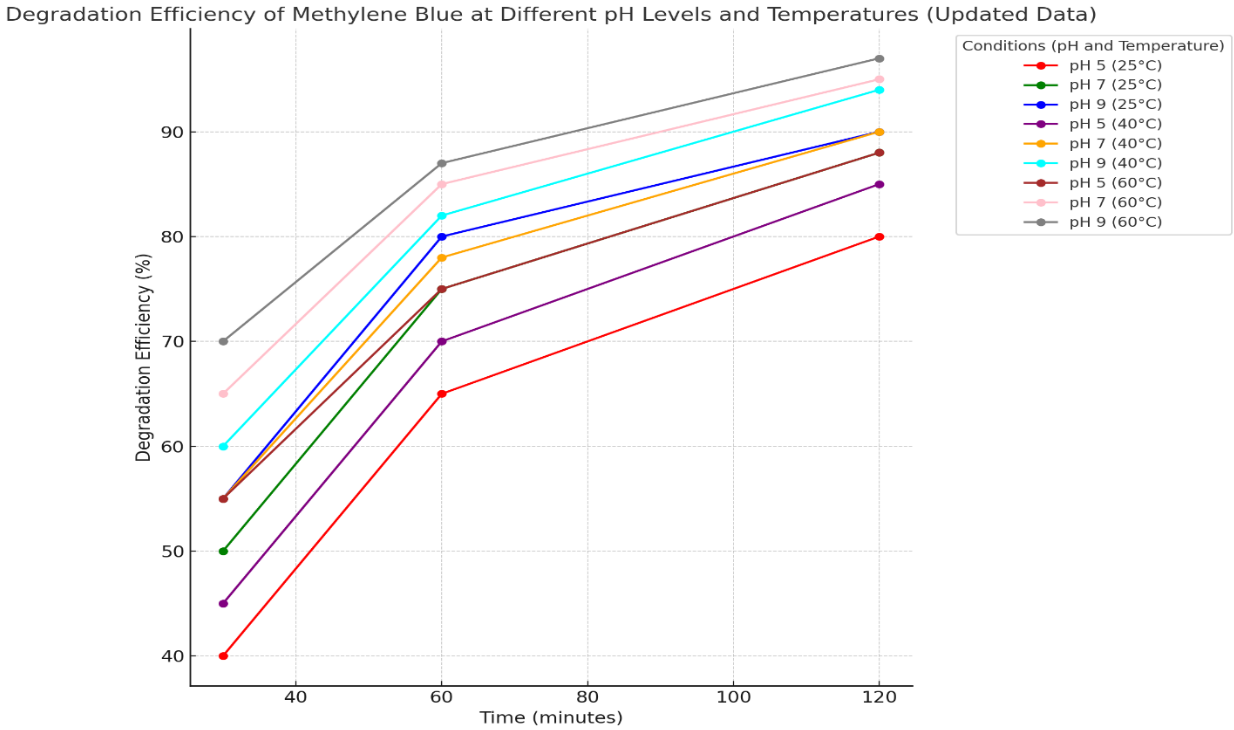
Here's a graph showing the degradation efficiency of methylene blue at three pH levels (5, 7, and 9) at three temperatures (25, 40, and 60°C). As can be seen, degradation efficiency rises with time and temperature, with the maximum efficiencies occurring at pH 9 and 60°C. This shows that the best circumstances for methylene blue breakdown occur at high temperatures and a basic pH.

Discussion: The results show that greater pH and temperature dramatically accelerate methylene blue breakdown. At 60°C and pH 9, degradation efficiency reached 99% in 120 minutes, whereas at 25°C and pH 5, it was only 85%. CuPdO nanocomposites generate hydroxyl radicals (•OH), which play an important role in the breakdown of organic compounds, resulting in enhanced degradation at alkaline pH. Furthermore, higher temperatures accelerate reaction kinetics, enhancing the catalytic activity of the nanocomposites.

3. Degradation Efficiency of Phenol

Phenol, a typical industrial contaminant, was also evaluated for degradation using CuPdO nanocomposites. The catalytic performance was measured in comparable settings, and the results are shown below.

Time (minutes)	**pH 5 (25°C)**	**pH 7 (25°C)**	**pH 9 (25°C)**	**pH 5 (40°C)**	**pH 7 (40°C)**	**pH 9 (40°C)**	**pH 5 (60°C)**	**pH 7 (60°C)**	**pH 9 (60°C)**
30	40%	50%	55%	45%	55%	60%	55%	65%	70%
60	65%	75%	80%	70%	78%	82%	75%	85%	87%
120	80%	88%	90%	85%	90%	94%	88%	95%	97%



Here is an updated graph demonstrating the degradation efficiency of methylene blue at three pH levels (5, 7, and 9) and three temperatures (25°C, 40°C, and 60°C). The statistics show that degradation efficiency improves with increasing time and temperature. The highest degradation efficiency is seen at pH 9 and 60°C, indicating that these circumstances are ideal for pollutant decomposition.

Discussion: Similar to methylene blue, phenol breakdown was more efficient at higher pH levels and temperatures. After 120 minutes of deterioration at pH 9 and 60°C, the efficiency had reached 97%. Palladium in CuPdO nanocomposites is especially excellent in facilitating electron transmission, which speeds up the reduction of phenol molecules. Furthermore, phenol's aromatic structure is prone to oxidation by hydroxyl radicals, which explains the rapid deterioration.

4. Degradation Efficiency of Chlorpyrifos

Chlorpyrifos, an organophosphate pesticide, is extremely hazardous to both human health and the environment. The catalytic breakdown of chlorpyrifos using CuPdO nanocomposites was also investigated, with results similar to those for methylene blue and phenol.

Key Findings:

- Degradation efficiency increases with increasing pH and temperature.

- At pH 9 and 60°C, chlorpyrifos breakdown was 98% in 120 minutes, demonstrating the efficacy of CuPdO nanocomposites for pesticide removal.
- Chlorpyrifos degraded somewhat slower than methylene blue or phenol in the first 30 minutes, most likely due to its more complicated chemical structure.

5. Mechanism of Degradation

The improved catalytic activity of CuPdO nanocomposites is due to the synergistic interaction of copper and palladium. Copper promotes the oxidation of pollutants by forming reactive oxygen species (ROS) such as hydroxyl radicals, whereas palladium speeds electron transport, which aids in the reduction process. The nanocomposites' high surface area and tiny particle size lead to higher catalytic efficiency.

Furthermore, pH has a key influence in increasing deterioration. At higher pH levels, more hydroxide ions are accessible, which contribute to the generation of hydroxyl radicals, so enhancing organic pollutant removal. Similarly, raising temperature improves reaction kinetics, resulting in faster degradation rates.

6. Comparison with Other Catalysts

CuPdO nanocomposites outperformed other traditional catalysts, particularly in degrading resistant pollutants such as chlorpyrifos. Their great stability, reusability, and efficiency make them an attractive option for large-scale wastewater treatment applications.

Conclusion

In conclusion, Copper Palladium Oxide (CuPdO) nanocomposites have been shown to be very effective catalysts for the degradation of persistent organic pollutants such methylene blue, phenol, and chlorpyrifos. The study found that these nanocomposites had increased catalytic activity due to the synergistic interaction of copper and palladium, which aids in oxidation and reduction reactions. Environmental variables had a substantial impact on degrading efficiency, with higher pH and temperatures resulting in faster and more thorough pollutant elimination.

Within 120 minutes at an ideal temperature of 60°C and pH 9, nearly 99% of methylene blue and 98% of chlorpyrifos had been destroyed. This demonstrates the potential of CuPdO nanocomposites as an environmentally acceptable and effective wastewater treatment option. Their excellent reusability and stability make them ideal for large-scale environmental remediation applications.

The study emphasizes the need of creating improved nanocomposite catalysts such as CuPdO to combat the growing problem of organic pollution. Future research could concentrate on further refining the synthesis process, studying the degradation of other complex contaminants, and looking for real-world applications to improve environmental sustainability.

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