

The Effects of ZnO Colloidal Particles on Photochemical Decomposition of DOM in Water Bodies

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Abstract:

Dissolved organic matters, abbreviated as DOM, are indispensable parts in every water bodies, and are a main cause of most pollutions. In this research, UV-Vis spectrometry is used to measure the change in absorbance of the water samples collected from Sanhe Lake, Yunliang River and a pond(all in Nanjing) with different concentrations of ZnO colloids under the 300 W mercury light, and therefore use the absorbance calculated out to determine the rate and efficiency of photochemical decomposition to find out the extent of catalyzing effect of ZnO colloids on decomposing such DOM. After a series of experiments, we found out that ZnO works as a great catalyst in decomposing DOM. Its effect will differ a little bit depending on the type of water body. We think it can be taken as an effective way of tackling organic contamination issues.

Keywords: Dissolved organic matter, ZnO colloids, Photodegradation

1. Introduction:

1.1 Research background

Ponds, lakes, and rivers are ubiquitous natural water bodies categorized by a variety of hydro-ecological features, including flow dynamics, depth, and disturbance levels. These differences can affect their physicochemical and biological processes in a large extent, as Brönmark & Hansson stated in their book in 2017 that the physical structure, especially depth and exposure to wind, fundamentally dictates the thermal and chemical stratification of water bodies^[1].

Colloidal particles (1 nm – 1 µm) are widespread

reactive interfaces in aquatic systems. Their high surface area and reactivity allow them to influence the transport and transformation of aquatic organic matters through adsorption and aggregation. It is discovered earlier that different kinds of interactions happens, which can be categorized into adsorption, bridging flocculation and steric stabilization just as M. A. Schlautman and J. J. Morgan mentioned in their research^[2], between colloidal particles and natural aquatic organic matter, a core component organic cycle. Colloids can change the molecular state and environmental exposure of organic matter, therefore regulating its rate of decomposition and the water bodies' capacity of purification.

Increasing pollution in cities due to the growing populations has made the need for effective water remediation strategies more and more urgent. According to some previous research, the amount of anthropogenic phosphorus, which is a common type of aquatic organic matter, in water bodies has doubled from the amount in 2010[3]. Functional colloidal materials, like metal oxide nanoparticles, have remarkable potentials. Zinc oxide (ZnO) colloids is a good example, and it can catalyze the degradation of organic pollutants through photocatalytic processes through surface combinations and reactive oxygen species generation.

However, the efficacy of the catalyzing effect of this type of colloidal particle is quite dependent on the types of water bodies. Key properties of ponds, lakes, and rivers—such as ion concentrations, water speed, and dissolved organic matter composition—directly impact colloidal particles' stability and aggregation states, which both diminishes its catalytic performances. Therefore, the same colloidal material may exhibit different effects on the decomposition of aquatic organic matters in different types of water bodies.

1.2 Literature review and research gaps

Based on previous studies, we have gained a lot of understanding and insights into the relationship and interaction between DOM (Dissolved Organic Matter) and organic pollutants in lakes. We have learned that DOM is a complex organic mixture, consisting of both pollutants and non-pollutants. Therefore, DOM contains organic pollutants and can be regarded as one of the indicators for measuring organic pollutants^[4]. Additionally, sunlight has a certain promoting effect on the degradation of organic pollutants. Sunlight can break down organic pollutants in lakes into hydroxyl compounds and biologically available monosaccharides and amino acids, which clearly shows that sunlight can decompose organic pollutants into some harmless or even beneficial chemical substances for the environment^[5]. Besides, the adsorption of zinc oxide on pollutants is also a significant achievement. Zinc oxide can treat water with nutrient-rich phosphorus and other substances, but the treatment efficiency is affected by variables such as water pH and DOM concentration^[6]. From these research directions, we can see that there are some research gaps in each of them. In this paper, we will use sunlight as a helper and use the change in DOM concentration to determine the effect. We will conduct a systematic and detailed exploration of the impact of zinc oxide colloidal particles on the degradation of organic matter in environmental water bodies. Meanwhile, in previous measurement studies, there was no targeted and detailed

investigation of the water pollution situation in the lakes in the Nanjing area. In this paper, we will conduct a more careful and targeted investigation of the organic pollutants in the ponds, rivers and lakes in the Nanjing area. Specific situations will be analyzed specifically. The measurement of the impact of zinc oxide colloidal particles on the water bodies in Nanjing is also the core focus of this experiment.

1.3 Research objectives

In this study, we hope to understand what kind of impact the zinc oxide in its colloidal particle state can have on the degradation of organic matter in environmental water bodies. This will help us further clarify whether zinc oxide can exert a stronger adsorption effect in this state compared to other states. Through clear answers to these questions, we can have a deeper understanding of the role and position of zinc oxide in preventing water pollution and finding more suitable materials in the future. At the same time, in this paper, we can fill the gap in the field of water pollution prevention and control in Nanjing. By studying the water bodies in Nanjing, we can have a more targeted and specific approach to the prevention and control of water pollution in Nanjing. This will help promote the prevention and control of sewage in the Nanjing area. In this regard, we hope to find a material that is more suitable for the treatment of sewage in Nanjing, so that the material can degrade some specific organic substances in Nanjing to achieve a specific analysis based on the specific situation.

2. Materials and Methods

2.1 Water Sample Collection

To investigate the differences in the catalytic performance of ZnO colloidal particles across various water bodies as said in introduction, water samples (1.5 L each) were collected from three sources: a pond, a lake, and a river. The sampling sites were the central pond in Qilin Park, Sanhe Lake, and Yunliang River. (All the water sources are in Jiangning district, Nanjing)

Clear differences among the water bodies can be observed in terms of color (ranging from green to transparent) and the presence of aquatic vegetations.

The main instruments used in the experiments included a diaphragm vacuum pump, a pipette, 0.45 μm cellulose acetate filter membranes, glass sampling bottles, test tubes, and a photochemical reactor (implemented in subsequent photochemical tests).

2.2 Water sampling

We conducted sampling in Jiangning District, Nanjing City. We selected one pond, one river and one lake for the sampling process, namely: the central pond of Qilin Park, the Yunchang River and Sanhe Lake. We used bottles made of high-density polyethylene material for sampling. The samples were sealed immediately after collection and were quickly transported back to the laboratory for pre-treatment. We aimed to maintain the initial state conditions of the water samples as much as possible and minimize the influence of strong light and microbial factors on the pollutants in the water bodies.

2.3 Water sample pretreatment

Next, we come to the crucial step: water sample pretreatment. In this experiment, we will use the vacuum filtration method to filter the water sample. First, we need to set up the experimental apparatus. The acetate cellulose filter membrane with a pore size of 45 micrometers is placed flatly on the middle of the cleaned sand core. This filter membrane has a very small pore size and has an efficient filtering ability for most particles that cannot dissolve in water. Moreover, its chemical properties are relatively stable and are very unlikely to undergo chemical reactions with the filtered water and its impurities. Then, the funnel is placed on top of the middle of the sand core. Using the sand core to tightly fix the connection between the middle of the sand core and the sand core funnel, ensure that the filtration system has good sealing performance during the experiment. On this basis, the tube on the diaphragm vacuum pump is connected to the cylindrical protrusion at the middle of the sand core. After turning on the diaphragm vacuum pump, continuously extract the air in the filtration device to create a pressure difference between the inside and outside of the filter membrane, making the external pressure greater than the internal pressure. Utilizing the atmospheric pressure, the water sample can be filtered more quickly. During this process, the insoluble impurities larger than 0.45 micrometers in the water sample can be efficiently removed, obtaining a clean and clear water sample, reducing interference in the subsequent research. This enables the research to focus more on the degradation of controllable pollutants in water bodies under the action of photocatalysis, effectively avoiding interference caused by some particles to absorbance, ZnO surface adsorption, etc.

2.4 Photocatalytic experiment

In order to conduct a more systematic study on the role of granular colloidal ZnO in the degradation of soluble impurities in water under photocatalytic conditions, we divided

the pre-treated water into three equal parts and added different concentrations of ZnO to each part. The first group served as the control group and was configured with a 0 g/L ZnO solution; the second group was configured with a 0.03 g/L oxidative solution as the low-concentration experimental group; the third group was configured with a 0.3 g/L ZnO solution as the high-concentration experimental group. The blank control group was used as the condition without colloidal ZnO particles as the catalyst, where the degradation effect was achieved solely through ultraviolet light irradiation. The results were used to provide a visual reference for evaluating the contribution of ZnO to photocatalysis. The other two groups could be used to explore the influence of catalyst concentration on the degradation rate, serving as important data for studying the degradation kinetics.

Due to the fact that the diameter of the ZnO powder particles used is only 40-80 nanometers, they tend to aggregate in water due to intermolecular forces such as van der Waals forces, making the distribution in water uneven and resulting in unsatisfactory catalytic degradation effects. To make the ZnO colloidal particles more uniformly dispersed in water, before the light irradiation experiment, the two groups configured with ZnO colloidal particles were subjected to ultrasonic treatment. The solution was placed in an ultrasonic cleaner (model KH-300) and dispersed for twenty minutes. The vibration of the ultrasonic waves can generate strong local jets and shock waves in the solution, during which the intermolecular forces between the ZnO particles will be overcome, enabling the ZnO particles to be uniformly dispersed in water, thereby maximizing the catalytic effect.

The photocatalytic reaction will be carried out in a photochemical reactor, with a mercury lamp of rated power 300 W as the core, which will emit ultraviolet wavelengths to simulate sunlight.

In order to conduct a more meticulous and rigorous study on the kinetic trend of the concentration attenuation of soluble pollutants after the addition of ZnO particles in the photocatalytic process, we set seven key time points for sampling and analysis in the experiment, which are the time of the start of light irradiation (0 minutes), 30 minutes, 1 hour, 2 hours, 3 hours, 18 hours, and 23 hours. At each time point, an appropriate amount of reaction liquid was extracted and preserved for subsequent experimental data analysis.

2.5 Collecting UV light absorbance data

After all the sample collections at various time points were completed, we began to collect the absorbance data of the samples. Since most of the dissolved organic matter

has a strong absorbance at the 254-nanometer wavelength of ultraviolet light, we will use a 254-nanometer ultraviolet-visible spectrophotometer to measure the absorbance of each sample at each time point. First, we will pour an appropriate amount of pure water into the cuvette to calibrate the instrument to read the absorbance of the cuvette, which will serve as the zero point. Then, after placing the sample solution in the quartz cuvette, we will close the cover of the ultraviolet-visible spectrophotometer and start the measurement. Once the reading stabilizes, we will record the absorbance value corresponding to each sample one by one to ensure the accuracy of the data and its

traceability. Before each measurement, the light surface of the cuvette needs to be dried to ensure that the absorbance data measured when the ultraviolet light passes through the cuvette is not affected by external water stains. After each sample measurement, the cuvette needs to be rinsed with pure water to ensure that there is no residual liquid in the internal space of the cuvette before the next sample is poured into it.

3. Experiment results

3.1 Pond experiment results

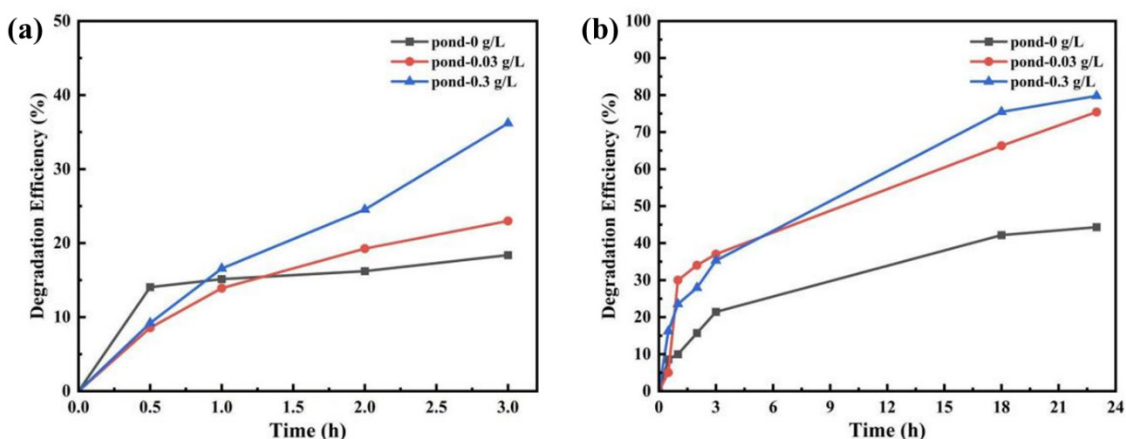


Fig 1. The DOM degradation efficiency of pond water sample at 254 nm with different ZnO concentrations during photodegradation process, (a) shows the first 3 h, (b) shows the whole 23 h

Table 1. The degradation rates of pond water samples with 0g/L, 0.03g/L, and 0.3g/L ZnO colloids and photosynthetic reactions

	Pond-0g/L	Pond-0.03g/L	Pond-0.3g/L
K	0.0283	0.0612	0.0635
R ²	0.9066	0.8899	0.9226

According to the data shown in the Figure 1, the efficiency and initial rate of the photochemical decomposition of DOM in pond all increase significantly with the increase in concentration of ZnO colloidal particles. In the first period of reaction (0-3h), the ranking of the efficiency of decomposition of DOM under different concentrations of ZnO colloidal particles can be listed as: 0.3 g/L > 0.03 g/L > 0 g/L. At the 3-hour time point, the decomposition efficiency of DOM was 18% without ZnO colloidal particles (which may be caused by excessive DOM produced by different plants in the pond), 23% at 0.03 g/L, and

36% at 0.3 g/L. This indicates that the addition of colloid largely catalyzes the initial photocatalytic decomposition process. At the 24-hour reaction time point, the final decomposition efficiency of DOM was 45% without the addition of ZnO colloids. After adding 0.03 g/L zinc oxide colloid, the final decomposition efficiency increased to 76%, which improves 31%. At a high concentration of 0.3 g/L, the final decomposition efficiency further increased to 81%, showing an increase of 36%. These results indicate that higher colloid concentration can lead to a greater improvement in final degradation efficiency, which further

suggests that the photochemical decomposition efficiency of DOM is quite dependent on the concentration of ZnO colloids. From the decomposition kinetic parameters, the rate of photochemical decomposition constant (k) under colloid-free conditions was 0.0283, which is the lowest among the three groups, $R^2 = 0.9066$. This indicates that the decomposition process was slow under ZnO-free conditions and the fitting was moderate. After adding 0.03 g/L zinc oxide colloid, the k value increased significantly to 0.0612 with $R^2 = 0.9946$, showing that the decomposition was markedly accelerated and the fitting was excellent. At 0.3 g/L, the k value further rose to 0.0737 with $R^2 = 0.9826$, further supporting the enhancing effect of high-concentration ZnO colloids on the rate of photochemical decomposition.

Overall, ZnO colloids work as a good catalyst effect on the photochemical decomposition of DOM in pond water. Under the influence of high concentration of ZnO, the degradation rate constant k increased by more than 100% compared to the control group, demonstrating extremely strong catalytic efficiency. The rise in final decomposition efficiency increases with the increase in ZnO colloid concentration, and the colloid-free group shows the lowest initial rate of decomposition. Variations in kinetic parameters further stabilize the indispensable role of ZnO in enhancing both decomposition efficiency and rate.

3.2 River experiment results

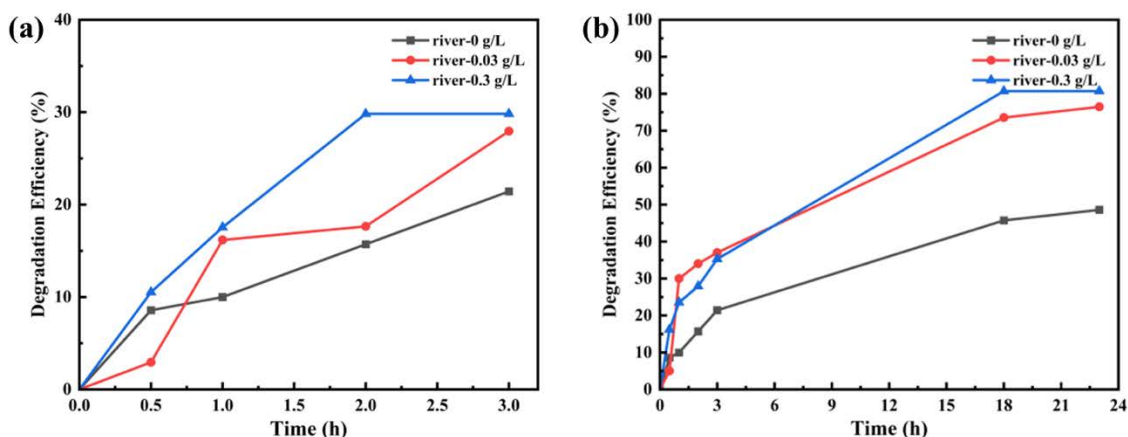


Fig 2. The DOM degradation efficiency of river water sample at 254nm with different ZnO concentrations during photodegradation process, (a) shows the first 3 h, (b) shows the whole 23 h

Table 2. The degradation rates of river water samples with 0g/L, 0.03g/L, and 0.3g/L ZnO colloids and photosynthetic reactions

	River-0g/L	River-0.03g/L	River-0.3g/L
K	0.032	0.068	0.080
R^2	0.95	0.99	0.98

Figure 2(a) shows the changes in the photodegradation efficiency of the grain transportation water body over the first 3 hours under different colloid concentrations under photocatalytic action. Figure 2(b) shows the changes in the photodegradation efficiency of the grain transportation water body over the first 23 hours under different colloid concentrations under photocatalytic action. From the figures, it can be seen that, overall, the degradation efficiency of the water gradually increases with time, and from the 18th hour, the degradation efficiency reaches a balance,

with no significant increase. Meanwhile, within a certain range, ZnO colloid particles can significantly promote the degradation of the water, and this increase is with the increase of colloid concentration. Without adding colloid, the degradation efficiency of the water within 3 hours is approximately 21.43%, and within 23 hours, it is approximately 48.57%; under the condition of ZnO concentration of 0.03g/L, the degradation efficiency of the water within 3 hours is approximately 27.94%, and within 23 hours, it is approximately 76.47%; under the condition of ZnO

concentration of 0.3g/L, the degradation efficiency of the water within 3 hours is approximately 29.82%, and within 23 hours, it is approximately 80.70%. According to table 2, in the three ZnO colloid particle concentrations, R^2 is all greater than 0.90, indicating that the three variables all conform to the first-order degradation kinetics. The deg-

radation kinetics constants of the three concentrations of 0.3g/L ZnO ($K=0.080$) are greater than those of 0.03g/L ZnO ($K=0.068$) and 0g/L ZnO ($K=0.032$).

3.3 Lake experiment results

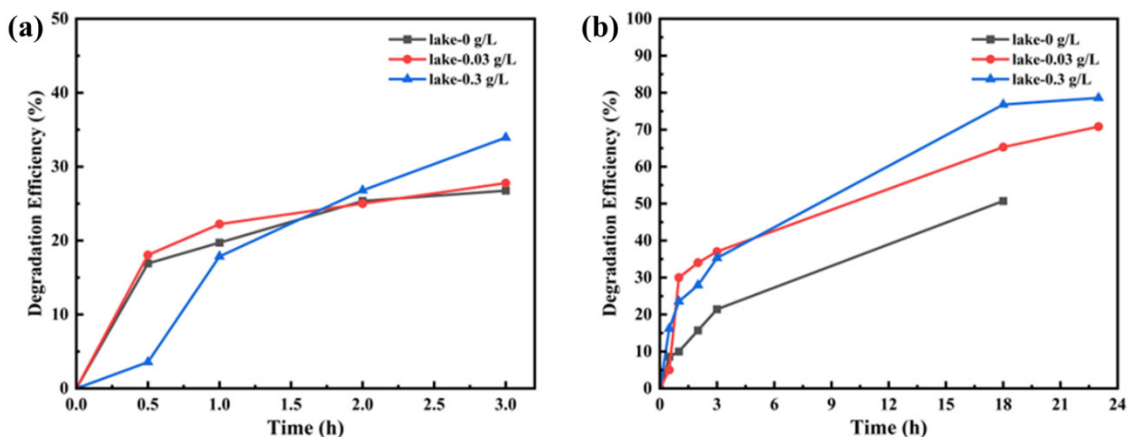


Fig 3. The DOM degradation efficiency of lake water sample at 254nm with different ZnO concentrations during photodegradation process, (a) shows the first 3 h, (b) shows the whole 23 h

Table 3. The degradation rates of river water samples with 0g/L, 0.03g/L, and 0.3g/L ZnO colloids and photosynthetic reactions

	Lake-0g/L	Lake-0.03g/L	Lake-0.3g/L
K	0.033	0.056	0.073
R^2	0.92	0.97	0.98

Figure 3(a) shows the changes in the photodegradation efficiency of the water body of Sanhe Lake under different colloid concentrations within the first 3 hours under photocatalytic action. Figure 3(b) shows the changes in the photodegradation efficiency of the water body of Sanhe Lake under different colloid concentrations within the first 23 hours under photocatalytic action. From the figures, it can be seen that, overall, the degradation efficiency of the lake water increases with time, and from the 18th hour, the degradation efficiency reaches a balance, with no significant increase. Meanwhile, within a certain range, ZnO colloid particles can significantly promote the degradation of river water, and this increase is with the increase of colloid concentration. Without adding ZnO colloid particles, the degradation efficiency of the lake water within 3 hours is approximately 26.76%, and within 23 hours is approximately 45.07%; under the condition of ZnO concentration of 0.03g/L, the degradation efficiency of the lake water

within 3 hours is approximately 27.78%, and within 23 hours is approximately 70.83%; under the condition of ZnO concentration of 0.3g/L, the degradation efficiency of the lake water within 3 hours is approximately 33.93%, and within 23 hours is approximately 78.57%. According to table 3, in the three ZnO colloid particle concentrations, R^2 is all greater than 0.90, indicating that the three variables all conform to the first-order degradation kinetics. The degradation kinetics constants of 0.3g/L ZnO ($K=0.073$) are greater than 0.03g/L ZnO ($K=0.056$) and 0g/L ZnO ($K=0.033$).

3.4 Experimental Data Analysis

From the above data, it can be seen that the photodegradation efficiency of all water bodies conforms to the first-order degradation kinetics. When comparing the photodegradation efficiency without adding ZnO colloid particles, it can be obtained that the lake water (26.76%) is

greater than the river water (21.43%) and the pond water (18.38%), which is in line with the field investigation situation. When collecting water samples in the field, the turbidity of the lake water is the lowest, followed by the river water, and the pond water is the highest. This is because the lake water is located in Sanhe Lake Park, where the water body is the confluence of the Yuliang River, Shangba River and Bai Water River, with strong water flow and the strongest self-purification ability, and it is regularly cleaned by staff to maintain the city appearance. The water body of the Yuliang River has relatively poor water flow and is a certain distance away from the residential area, and has not received special maintenance. The pond itself is not connected to any external water source, and the water body has almost no water flow, with the weakest self-purification ability. By observing the ZnO colloid concentration for the degradation efficiency, it can be seen that regardless of in the pond, river and lake, in the overall trend, as the ZnO concentration increases, the water body degradation efficiency increases and the degradation rate increases together. This indicates that ZnO has a promoting effect on the photodegradation efficiency and can be used as a catalyst in the photocatalytic oxidation degradation process.

4. Conclusion and discussion

In summary, this study systematically investigated the catalytic influence of ZnO colloidal particles on the photodegradation of dissolved organic matter (DOM) across three distinct aquatic environments: pond, lake, and river waters. The experimental results lead to the following key conclusions:

Firstly, ZnO colloids exhibit a powerful and consistent promoting effect on the photochemical decomposition of DOM. Quantitative analysis of the degradation rate constants (k) reveals that the introduction of ZnO can more than double the reaction speed. For instance, in pond water samples, the k value increased from 0.0283 in the control group to 0.0635 in the 0.3 g/L ZnO group—a remarkable enhancement of approximately 124%. Similar trends were observed in river and lake samples, where high-concentration ZnO treatment resulted in k values exceeding 0.06, representing a 1.0 to 1.5-fold increase compared to

natural conditions.

Secondly, the degradation efficiency demonstrates a clear dose-response relationship with ZnO concentration. The 0.3 g/L group consistently outperformed the 0.03 g/L group, suggesting that increasing the surface area of the photocatalyst effectively generates more reactive oxygen species (ROS) to oxidize organic pollutants.

Lastly, while the baseline degradation rates varied slightly due to the inherent hydro-ecological differences between ponds, lakes, and rivers, the catalytic superiority of ZnO remained stable across all water types. These findings provide compelling experimental evidence for the role of metal oxide colloids in enhancing the self-purification capacity of natural water bodies. Future research should further explore the long-term ecological impact of ZnO nanoparticles and their performance under natural sunlight to develop more sustainable strategies for aquatic organic remediation.

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