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Differential comparison of degradation efficiencies in urban environmental waters and effluents and with and without nanoparticles

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Abstract:

DOM is an important component of water bodies and provides unimaginable vitality to the entire water body. This paper employed a filter configuration method to extract dissolved organic matter and sewage. In the control group, nanoparticles are added to set up a control group. The degradation efficiency of urban water bodies and sewage and their degradation efficiency in the presence or absence of nanoparticles was compared using a UV spectrophotometer and a photochemical reaction meter. By analyzing the degradation efficiency of DOC, we observed that the degradation efficiency of urban water is much higher than that of wastewater, and nanoparticles can increase the reaction rate. This effect is particularly pronounced in pond water, which can provide a reference for the standard of wastewater discharge and urban water management.

Keywords: DOM, Urban water, Sewage, TiO2 nanoparticles, Photochemical reaction, Degradation

1 Introduction

The research field of this paper is urban environmental water bodies and sewage and the effect of nanoparticles on the light reaction. This experiment aims to study urban water bodies and sewage and compare their degradation efficiency in the presence of different nanoparticles. The principle of the experiment involves the extraction of dissolved organic matter from lakes, rivers, ponds, and other urban bodies, as well as the configuration of urban sewage with soluble organic matter in aqueous solution as a sample. A set of parallel groups was prepared, with nanoparticles added to one set. The light reaction apparatus was used to get the results.

In 2014, the Journal of Environmental Science published a study comparing microbial degradation of dissolved organic matter from sources such as lake grass and algae[1]. Another study, published on July 7, 2023, investigated the photochemical activity and constitutive relationship of dissolved organic matter in lake water, focusing on lakes with different degrees of urbanization in five watersheds of Wuhan (Townsend Lake, East Lake, Houguan Lake, Yanxi Lake, and Yandong Lake) [2]. The research on photochemical/microbial degradation of colored dissolved organic matter (DOM) from different sources was conducted by the Key Laboratory of Ground Surface System and Environmental Carrying Capacity of Northwest University (NWU) and the School of Geography, Earth and Environmental Sciences of the University of Birmingham (U.K.). This study examined the relationship between colored soluble organic matter emitted from nonpoint source pollution and microbial activity [7].

At the same time, against the background of the "double first-class" construction initiative, research on the new material of TiO2 was initiated. TiO2 is an inorganic material known for its high surface activity, large surface area, good light absorption, strong oxidizing ability, and low cost, making it a common catalyst. Studies have revealed that when light waves irradiate the semiconductor photocatalyst, the energy is sufficient to create conduction band photogenerated electrons (e-) and leave photogenerated holes (h+) in the valence band. Semiconductor photocatalytic oxidation ability depends mainly on the highly active electron-hole pairs, leading to redox reactions with adsorbed -OH, H2O, and O2, resulting in the generation of hydroxyl radicals (-OH) and superoxide radicals (-O2-), thereby facilitating the oxidative degradation of organic pollutants and degradation of virtually non-selective substances (Fig1) [3]. The basic principle of TiO2 nanoparticles affecting the rate of photocatalysis is consistent with the concept applied in this experiment, which also contributes to wastewater treatment [4]. In this study, TiO2 is employed as a control group to further explore its catalytic performance. We aim to extend previous research by focusing on the urban water and sewage degradation rate in Nanjing and comparing it with the findings from studies conducted in Wuhan. Additionally, we will investigate the impact of nanoparticles on water samples, further building upon our understanding of TiO2 as a new material in this domain.

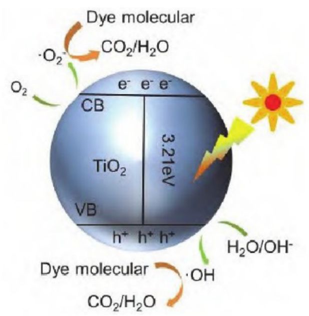


Figure1: Degradation Mechanism[3]

2 Method

2.1 Experimental materials

The experimental materials used in this experiment include buckets, sample bottles, vacuum pumps, filter flasks, test tubes, beakers, magnetic stirrers, pipette guns, syringes, filter tips, precision balances, waste tanks, cuvettes, UV spectrophotometers, centrifuge racks, centrifugal tubes, photochemical reactors, and weighing paper.

We used buckets and sample bottles for urban water sampling during the sample preparation stage. Filters and vacuum pumps were employed to carry out the filtration process to extract soluble organic matter. Markers were used to label the sample and transfer it to test tubes. A precision balance was used to measure the appropriate amount of material in solution configuration. After returning the sample to the photochemical reactor for the reaction, it was removed using a pipette gun, needle, and filter head at specific intervals. The sampled material was then transferred to centrifuge tubes, labeled with markers, and subjected to the final data measurement using a UV spectrophotometer.

2.2 Sampling

Three different water bodies in the city were sampled, namely lakes (Xuanwu Lake in Nanjing), rivers (Pearl River near Xuanwu Lake in Nanjing), and lakes (Soil Research Institute at No. 73, East Beijing Road, Nanjing). The buckets used for the collection were rinsed three times before sampling. Then the containers containing the samples were rinsed three times and placed into the sample bottles for preservation, awaiting the next processing step.

2.3 Filtration

The definition of soluble organic matter refers to organic matter with a diameter of less than 0.45mm. When an organic matter is smaller than 0.45mm, it is considered soluble and can be filtered out from the urban water samples through physical changes in the system. Vacuum pumping filters and membranes are selected to obtain the solution, as the required soluble organic matter is less than 0.45mm. The reason for using vacuum pumping filters is to speed up the filtration rate by utilizing the principle of air pressure difference. The area below the filter membrane experiences a decrease in pressure due to the vacuum machine. In contrast, the air pressure above the filter membrane remains higher, thus causing the liquid to be filtered towards the lower pressure area below the filter membrane, resulting in rapid filtration. In the experiment, if a large amount of filter residue appeared on the membrane, it indicated the need to change the membrane, which may lead to clogging. Once all the filtrate is obtained, it should be transferred to other containers to facilitate subsequent light experiment sampling.

2.4 Configuring the solution

Our experimental study aimed to investigate the degradation effects of urban environmental water bodies and sewage on natural water bodies. We selected three types of sewage to cover point source pollution and surface source pollution. These included domestic sewage, aquaculture sewage, printing and dyeing sewage. We focused on domestic sewage.

2.5 Colloidal particles

The Tyndall effect refers to the scattering phenomenon of nanoparticles/colloidal particles by light. In our experiment, many nanoparticles/colloidal particles remained in the water. Our experiment aimed to compare the degradation rate of municipal water and sewage with and without nanoparticles. We configured six municipal water bodies and sewage samples to create parallel samples, adding nanoparticles to study their effect on the photochemical degradation reaction.

We used titanium dioxide nanoparticles in this experiment. Titanium dioxide nanoparticles are widely used in photocatalytic reactions, with photocatalytic hydrolysis and photocatalytic degradation of organic pollutants being the most common applications. The special properties of titanium dioxide nanoparticles enable them to change the rate of photocatalytic reactions. We compared the results by adding nanoparticles to different samples.

2.6 Light experiments

We utilized the photochemical reactor to simulate real sunlight for a photochemical degradation reaction of the solution. We selected the visible wavelength of ultraviolet light as our experimental wavelength. We chose a 500w mercury lamp as the light source for this experiment. This reactor was equipped with a stable and professional light source and magnetic stirring system to ensure uniform and equal irradiation of each tube, thus reducing errors. It is important to note that the instrument emitted strong ultraviolet light energy, which could pose a risk of damage to the human body. Long-term exposure to this light could lead to skin cancer. Therefore, it is advised to turn on the power supply of the illumination lamp only after the instrument has been turned off. The instrument featured an observation window through which the effect of light and the reaction could be monitored promptly. The instrument's stable professional light source and magnetic stirring system ensured uniform and equal irradiation of each tube, reducing the risk of error.

2.7 Ultraviolet spectrophotometer

We eventually measured the results of our experiments to get our final degradation results using a UV spectrophotometer, which operated based on the principle that almost all living things are composed of molecules and atoms. These molecules and atoms can absorb the energy of some wavelengths of incident light, resulting in molecular vibrational energy level jumps and electronic energy level transitions. The UV spectrophotometer was designed by this principle. Since the molecules and atoms comprising each substance are different, the amount of energy absorbed by each substance varies. This disparity in energy absorption creates distinct characteristics for each substance. The UV spectrophotometer capitalizes on these unique characteristics, forming the basis for substance testing. Each substance has its own fixed absorption spectrum curve, which serves as the foundation for qualitative and quantitative analysis in spectrophotometry. Spectrophotometric analysis is an effective method for studying substances' composition, structure, and interactions based on their absorption spectra. Ultraviolet-visible spectrophotometry (UV-VIS) mainly utilizes the absorption effect of molecules or ions of substances absorbing light within a certain wavelength range. It then conducts qualitative and quantitative analysis and structural analysis of the sample based on the absorption spectra produced by molecules or ions absorbing light of a specific wavelength in the incident light. Absorption spectra are produced by the absorption of a specific wavelength of incident light by a molecule or ion. The Lambert-Beer law, also known as the law of light absorption, is the basis for quantitative analysis by spectrophotometry. When the wavelength of the incident light is fixed, the absorbance A of the solution is a function of the concentration of the absorbing substance C and the thickness of the absorbing medium l (absorption range) [5].

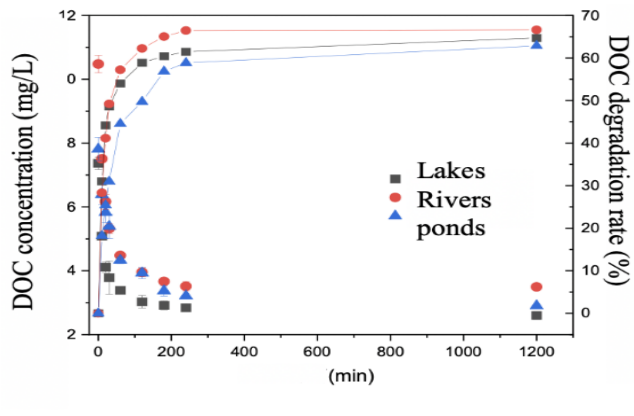
3 Analysis

3.1 Sample Sampling and Processing

A good sample was taken and transferred into the test tube. The initial state of the solution was extracted into the centrifuge tube using a pipette, and the test tube was marked with a marker pen before being placed into the photochemical reaction apparatus. The photochemical reaction apparatus utilized a 500w mercury lamp as a light source. After waiting for ten minutes, the sample was removed, and the sampling process was repeated. Once sampling was complete, the test tube was transferred back to the photochemical reaction apparatus, and the waiting process was repeated. After each repetition, a sample was extracted for analysis. Once all samples were obtained, the data were graphed using a UV spectrophotometer for the measurements.

3.2 Analysis of Results

Changes in dissolved organic carbon (DOC) concentration and degradation efficiency in different water bodies during the photodegradation process



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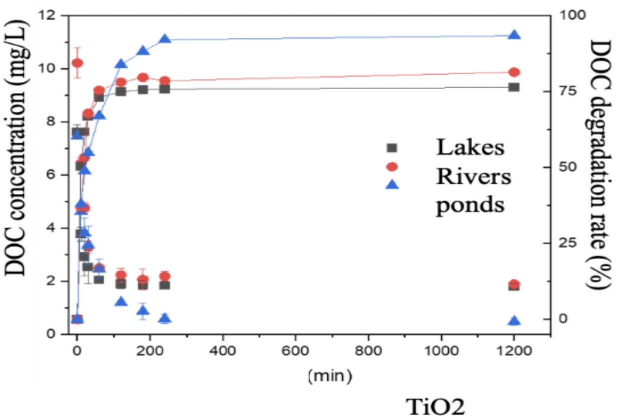

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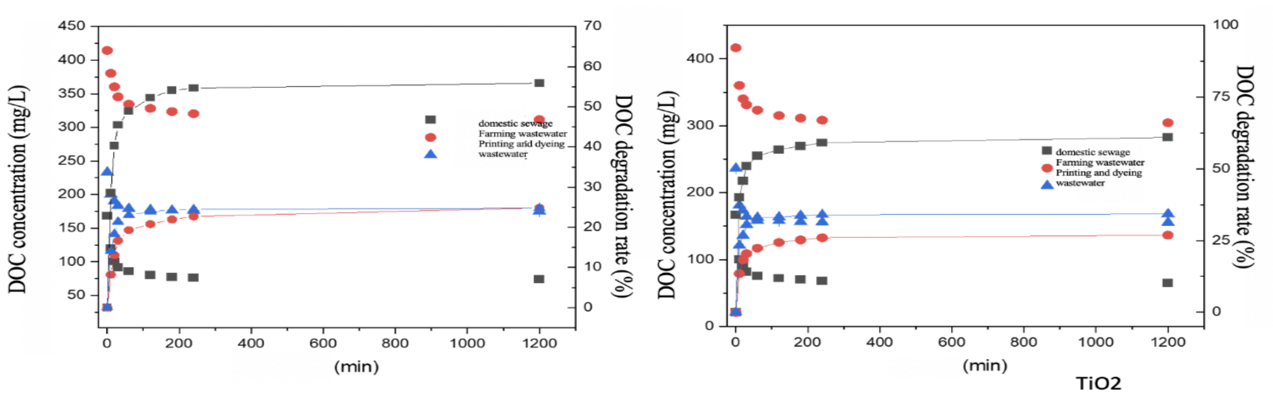
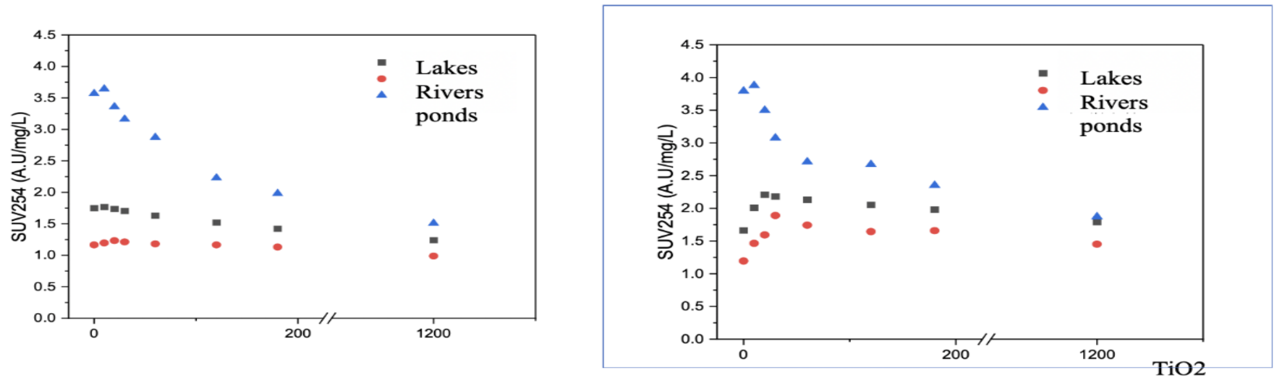


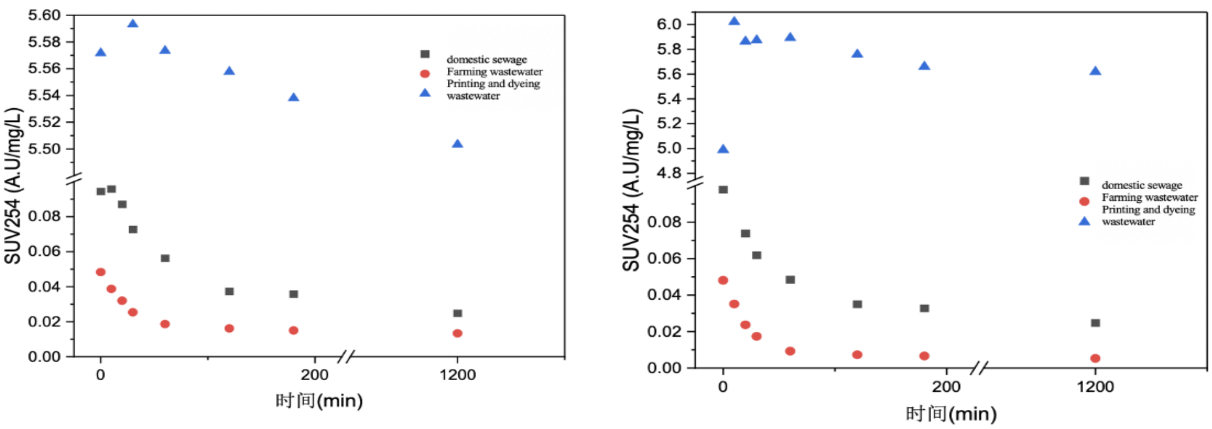
(c) (d)

Figure 2: Changes in dissolved organic carbon (DOC) concentration and degradation efficiency in different water bodies during the photodegradation process

Figure 2 above shows each solution's concentration change and degradation rate in terms of DOC. On the left are the samples without added TiO2 nanoparticles, while on the right are the solutions with added TiO2 nanoparticles. The images show that the photodegradation rate of urban water without added TiO2 nanoparticles increases slowly over time and eventually stabilizes between 60% and 70%. The degradation rate of the river water body is the highest, followed by lakes and ponds, which exhibit the lowest degradation rates.

Without adding TiO2 nanoparticles to domestic sewage, the degradation rate stabilizes between fifty-five percent and sixty percent. In contrast, printing dyeing and aquaculture degradation rates are very similar, at about twenty-four percent. The degradation rate of urban water with TiO2 nanoparticles increases significantly. The degradation efficiency of pond water is the highest, ranging between eighty-seven and a half percent to one hundred percent. The degradation efficiency of river water is the second fastest, ranging between seventy-five to eighty-seven and a half percent. The degradation efficiency of lake water is the slowest, at around seventy percent. In the case of TiO2 nanoparticles, the degradation rates of printing dye, ing, and aquaculture are very similar, at about twenty-four percent. The degradation rate of domestic sewage with TiO2 nanoparticles increases to about 62.5 percent, compared to the unadded 50 percent and 60 percent. The degradation rate of printing and dyeing wastewater increases by 37.5 percent compared to the unadded TiO2, reaching twenty-five percent, which shows little changes. Changes in dissolved organic carbon (DOC) concentration and degradation efficiency in different water bodies during the photodegradation process: The degradation efficiency of TiO2 nanoparticles is higher than that of the solution without TiO2 nanoparticles. The photodegradation efficiency of urban water without TiO2 nanoparticles is much higher than sewage's.





TiO2

Figure 3: Comparison of aromatic changes of dissolved organic matter in different environmental waters during photodegradation

The figure above depicts changes in solubility from the perspective of aroma. There are two main pathways of photodegradation. The first involves direct degradation, where large molecules break down into small ones. The second pathway is related to aroma. Research has shown that DOM in water can absorb a photon to enter an excited state. In this state, the lifespan of DOM is very short, leading to the release of hydrated electrons into the water. Dissolved oxygen then captures these electrons, forming superoxide anion radicals, which eventually convert to hydrogen peroxide and hydroxyl radicals. Additionally, fluorescence DOM release can generate singlet oxygen. Both types of radicals are highly oxidative(Fig4) [6]. These generated radicals then attack the double bond, reducing the number of benzene rings and reducing aroma. Similar to the DOC analysis mentioned earlier, the left side shows the solutions without TiO2 nanoparticles, and the right side shows the solutions with TiO2 nanoparticles. The general trend indicates that the degradation efficiency of solutions without TiO2 nanoparticles is lower than that of solutions with TiO2 nanoparticles, and the degradation efficiency of solutions in urban ambient water is higher than that of sewage.

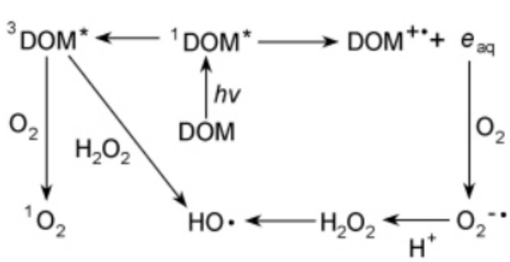


Figure 4: Schematic diagram of the change of dissolved organic matter into free radicals after light irradiation [6]

4 Conclusions

This experiment compared the water and sewage of Nanjing city with or without nanoparticles, using an ultraviolet spectrophotometer to measure the results and ultimately obtain the DOC concentration and fragrance. The findings revealed that the overall degradation efficiency of urban water was significantly higher than sewage's. In the absence of nanoparticles, the DOC degradation efficiency of the three kinds of water degradation efficiency was similar. Still, adding TiO2 nanoparticles led to a substantial increase in DOC degradation efficiency in pond water. The degradation efficiency of DOC in urban water without adding nanoparticles was similar to that of the three water bodies. However, after adding TiO2 nanoparticles, the degradation efficiency of DOC in pond water significantly increased. The degradation efficiency of domestic wastewater without TiO2 nanoparticles was higher than that of the other two types of point-source pollution. Additionally, the degradation efficiency of domestic and dyeing wastewater increased after adding TiO2 nanoparticles.

The experiment enabled the government to achieve more precise control over sewage discharges and facilitated better degradation and appropriate reduction of control. This allows natural water bodies to be restored to their optimal levels. Furthermore, appropriate amounts of nanoparticles can be added to manage water bodies within the city based on the water body's condition.

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