

Dhaka University Nanotechnology Centre (DUNC)

University of Dhaka

Dhaka 1000, Bangladesh

Inception Report

On

Enhanced Removal of Cationic and Anionic Dyes Simultaneously by ZnO/Functionalized Nanocellulose Composite from Industrial Wastewater

Project Duration

01 December 2025 – 30 April 2026 (5 Months)

Project Supervisor

Name of the Student

Dr. Muhammed Shah Miran

Md. Sajib

Professor

Research Fellow

Department of Chemistry

Dhaka University Nanotechnology Centre

University of Dhaka

University of Dhaka

Dhaka-1000


Dhaka-1000

Email: shahmiran@du.ac.bd

Email: sajibchemdu@gmail.com

Contact No.: 01818441345

Contact No.: 01742754175

Received

19/12/25
Dhaka University Nanotechnology Centre (DUNC)
University of Dhaka
Dhaka-1000, Bangladesh

1. Title of the Proposed Research Project:

Enhanced Removal of Cationic and Anionic Dyes Simultaneously by ZnO/Functionalized Nanocellulose Composite from Industrial Wastewater

2. Name of the Project Supervisor with Affiliation:

Name: Dr. Muhammed Shah Miran

Designation: Professor

Department/Institute: Chemistry

Website (if any): https://www.du.ac.bd/faculty/faculty_details/CHM/116

E-mail Address: shahmiran@du.ac.bd

Contact No.: 01818441345

Academic Qualification: PhD

Number of Journal Articles and Books: 49 and 04

Google Scholar/ResearchGate ID/link (if any):

<https://scholar.google.com/citations?hl=en&user=SSCStKEAAAAJ>

https://www.researchgate.net/profile/Muhammed_Miran

3. Place where the work will be performed:

Material Chemistry Research Lab (MCRL), Physical Chemistry, Department of Chemistry, University of Dhaka, Dhaka-1000, Bangladesh.

4. Outline of the project with background information:

4.1. Background

The pure accessible surface water is limited and deliberately polluted by wastewater disposed of from many industries, which contains highly toxic organic and inorganic chemicals. Regular release of toxic organic pollutants as a form of industrial wastewater has continuously increased as a result of industrialization and urbanization. These organic molecules are resistant to natural degradation and are called persistent organic pollutants (POPs). They remain in the water for hundreds of thousands of years and spread toxicity. Consumption of these toxic substances causes serious health issues, which could cause millions of deaths every year throughout the world (1). These pollutants not only pollute surface freshwater but also pollute the reserve underground



water, rendering it unusable. The primary source of water pollution is the direct release of industrial and municipal wastes into uncontaminated natural water sources. Although major industries employ wastewater treatment, smaller industries and factories often cannot afford to install their own wastewater treatment plants. However, wastewater treatment plants have inefficient and expensive methods for purifying wastewater, facing challenges in removing POPs (2, 3, 4). Many conventional techniques have been developed, but they are not very effective in removing these toxic organic molecules from wastewater.

Advanced oxidation processes (AOPs) have the potential to completely remove organic molecules from wastewater by using high-potential hydroxyl radicals. These radicals break down the toxic organic molecules and convert them into nontoxic molecules such as CO₂ and H₂O. It is often called mineralization. The photocatalytic method uses a catalyst that produces hydroxyl radicals by the irradiation of UV-visible radiation. ZnO is a photocatalyst that breaks down the organic molecules by the irradiation of UV light. However, the efficiency is not very good due to the lower surface area, large particle sizes, lower dispersibility or high aggregation behavior, and lower adsorption capability. These limitations can be overcome by the introduction of matrix materials such as cellulose, which allow them to be better dispersion, increase the surface area by producing the nano-scale material, and enhance the adsorption capacity of both cationic and anionic dyes.

Cellulose, the most abundant natural polymer on Earth, derived from sources like wood, cotton, agricultural residues, and bacterial fermentation, serves as an excellent base for adsorbents due to its renewability, biodegradability, low cost, and abundance of hydroxyl groups that can be functionalized for improved dye affinity (5). These materials are particularly effective at removing organic dyes from wastewater through mechanisms such as electrostatic interactions, hydrogen bonding, ion exchange, and π - π stacking. Commercial cellulose consists of fibers about 20-50 μ m in diameter. Creating cellulose nanoparticles exposes the inner surface, which increases the total surface area of the particles.

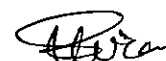
Cellulose contains numerous hydroxyl (-OH) groups on its surface, providing active sites for the adsorption of dye molecules. When cellulose disperses in water, deprotonation occurs at the surface hydroxyl groups. The hydrogen attached to the oxygen atom is released as H⁺, which is electrostatically attracted to the partially negatively charged oxygen in water, forming H₃O⁺ ions, leaving behind an anionic oxygen ion on the surface of the cellulose particles. Consequently, the overall surface charge of the cellulose particles becomes negative. Cationic dyes are attracted to the negatively charged surface and adsorb, while anionic dyes are repelled and tend to escape from

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the surface. Surface functionalization of nanocellulose enhances its ability to adsorb both cationic and anionic dyes, aiding in wastewater treatment (6). Melamine formaldehyde resin functionalizes the surface of the nanocellulose, where melamine resin molecules replace a fraction of the hydroxyl groups. After surface functionalization, the nanocellulose surface contains -NH₂ and -OH groups, which facilitate the adsorption of anionic and cationic dyes, respectively.

References

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4.2. Objective of this Project

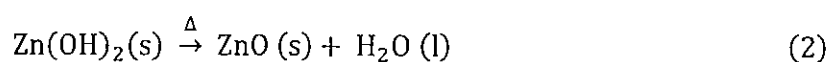
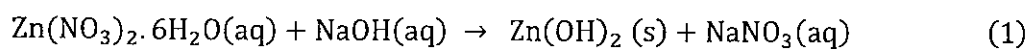
The primary objective of this research is to design a nanocomposite photocatalyst that is capable of simultaneously removing both cationic and anionic dyes from aqueous solutions. Specifically, the study aims to:

- i) Prepare the ZnO nanoparticles via the hydrothermal method
- ii) Optimize the reaction parameters involved in the acid hydrolysis of cellulose to enhance its surface area and improve adsorption efficiency.
- iii) Functionalize the nanocellulose to adsorb the cationic and anionic dyes simultaneously.
- iv) Preparation of ZnO/Nanocellulose and ZnO/functionalized nanocellulose composite to enhance the photocatalytic removal of organic dyes.
- v) Optimize the physicochemical parameters and evaluate the adsorption kinetics and mechanism.

4.3. Methodology

4.3.1. Preparation of ZnO Nanoparticles

ZnO nanoparticles will be prepared via hydrothermal method using zinc nitrate hexahydrate ($\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$) as a precursor. An appropriate amount of precursor will be dissolved in water, followed by the dropwise addition of 1M NaOH solution. After that, the mixture will be transferred to a Teflon-lined hydrothermal autoclave, and the autoclave will be shifted to an oven placed at 100 °C for 24 h. After 24 h, the residue of the nanoparticles will be recovered via filtration followed by several washes with water and ethanol. The residue will be dried in air and then in an oven at 60 °C for overnight.



4.3.2. Preparation of Nanocellulose

10 g of α -cellulose will be dispersed in 100 mL of 50% sulfuric acid. The dispersion will be heated to 40 °C with magnetic stirring at 700 rpm for 30 min to dissolve the amorphous region of α -cellulose. To stop the reaction, 400 mL of cold water will be added to this dispersion, and the beaker will be placed in an ice bath. After that, the byproduct sugar molecules and the unreacted acid molecules will be removed from the dispersion with repeated centrifugation at 9000 rpm for 30 min. The purified nanocellulose dispersion will be sonicated for 2 h. After that, the

nanocellulose will be dried in a fridge dryer and then stored in an air-tight vial labeled as NC. Figure 1 depicts the tentative synthesis procedure of the NC.

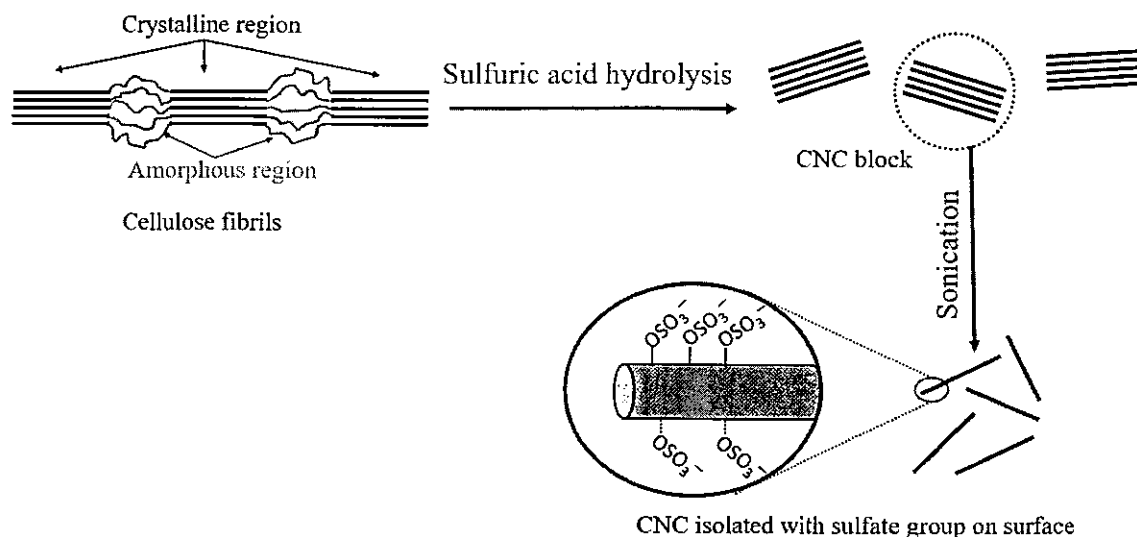


Figure 1. Preparation of nanocellulose from cellulose fiber with sulfuric acid hydrolysis

4.3.3. Surface Functionalization of Nanocellulose

Melamine formaldehyde solvent will be prepared by dispersing 2.2 g of melamine powder in 10 mL of water, followed by the addition of 4 mL of formaldehyde. The milky-white dispersion will be heated to 80 °C with continuous stirring for 30 min. After that, a clear solution of melamine formaldehyde resin solvent will form. After that, 1 g of NC will be dispersed in the clear solution of melamine-formaldehyde resin. The dispersion will then be heated to 80 °C with continuous stirring for 2 h. After 2 h, the solution will be cooled to room temperature, followed by washing several times with water and drying with a fridge dryer. A melamine-formaldehyde functionalized nanocellulose will be formed, which stored in a vial with labeled MF-NC.

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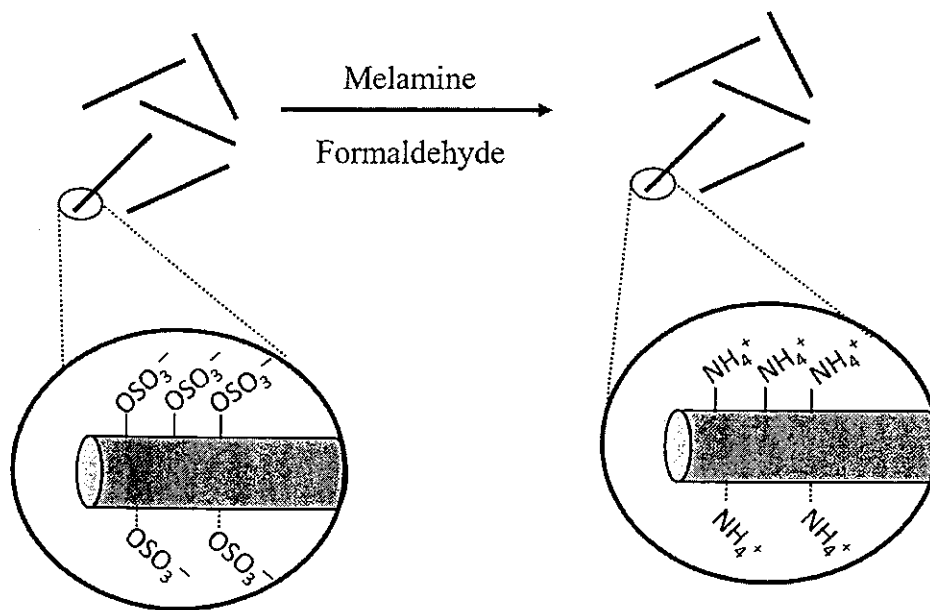


Figure 2. Surface functionalization of nanocellulose by melamine formaldehyde resin.

4.3.4. Preparation of ZnO/Functionalized Nanocellulose

A calculated amount of functionalized nanocellulose will be dispersed into water. To this dispersion, the calculated amount of $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ will be dissolved, followed by the dropwise addition of NaOH solution. After that, this will be transferred to a Teflon-linked hydrothermal autoclave, which will be shifted to an oven maintained at $100\text{ }^\circ\text{C}$ for 24 h. After 24 h. After that, the residue of the nanocomposite will be recovered via filtration, followed by several washes with water and ethanol. The residue will be dried in air and then in an oven at $60\text{ }^\circ\text{C}$ for overnight.

4.4. Characterization

4.4.1. Functional Group Analysis

The surface functional groups of prepared composites will be determined by Fourier Transform Infrared (FTIR) spectroscopy.

4.4.2. Compositional Analysis

The compositional analysis of the prepared materials will be carried out using X-ray Photoelectron Spectroscopy (XPS) and Nuclear Magnetic Resonance (NMR).

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4.4.3. Degree of Crystallinity and Crystal Structure

The degree of crystallinity and the crystal structure of the nanomaterials will be determined by using the X-Ray Diffraction (XRD) method, and crystallite sizes of nanomaterials will be calculated by the Scherrer equation. The Scherrer equation is

$$D = \frac{k\lambda}{\beta \cos\theta} \quad (6)$$

Where D is crystallite size in nm, k is the Scherrer constant (0.98), λ is the wavelength of x-ray radiation (0.154nm), β is the full width half maximum (FWHM) of the most intense peak, and θ is the Bragg angle with respective FWHM position.

4.4.4. Elemental Analysis

The elements present in the prepared materials will be determined qualitatively and quantitatively by Energy Dispersive X-ray (EDX) spectroscopy and a CHNS-O analyzer.

4.4.5. Morphological Analysis

Morphology of the prepared nanoparticles, such as the size and porous nature of the nanoparticles, will be evaluated by Field Emission Scanning Electron Microscopy (FESEM) and High-Resolution Transmission Electron Microscopy (HRTEM).

4.4.6. Surface Area and Porosity

Surface area of the prepared nanomaterials will be determined by using the Brunauer-Emmett-Teller (BET) N_2 adsorption-desorption isotherm technique.

4.4.7. Surface Charge

The zero potential charge (ZPC) of the nanoparticles will be determined by a pH meter, followed by the predetermined procedure, and the zeta potential of the nanoparticles will be determined by a Dynamic Light Scattering (DLS) instrument.

4.4.8. Optical Properties

The optical properties of the prepared nanocomposites will be characterized by UV-visible diffuse reflectance spectroscopy (UV DRS). The band gap of the nanocomposites will be derived by the Kubelka-Munk(K-M) method.



4.5. Application

Enhanced Removal of Cationic and Anionic Dyes from Aqueous Solution


The dye removal performance of the prepared nanoparticles will be evaluated by taking two kinds of dyes, such as cationic dyes and anionic dyes. Methylene blue and Orange G will be used as model dyes of cationic and anionic dyes, respectively. These two kinds of dyes will be removed simultaneously from aqueous solution by the use of the prepared nanocomposite. The effect of pH, catalyst dose, and initial concentration of dyes will be studied in the dye removal experiments. The mechanism of the removal of dyes by nanocomposites will be determined.

5. Rationale of the Project and its Importance:

Water pollution is the key challenge for the whole world. Day by day, it becomes increasingly difficult to access fresh water, as it is polluted by various reasons, with industrial waste being the major source. It is a severe problem in Bangladesh because we are one of the leading textile exporters in the world. Not only textile industries but also other sectors, such as leather and agro-based industries, also spilled their waste in the river without proper treatment. Clean water and sanitation are associated with the Sustainable Development Goals (SDGs), especially SDG-6 to ensure safe water, management of wastewater. The present study is directly connected with this SDG. Furthermore, it would be helpful to accomplish other development goals, such as ADP, Vision 2041, FYP, etc.

6. Previous Experience of the Project Supervisor in the area of Nanotechnology:

The project supervisor has been working in the field of nanotechnology for more than twenty years. Metal oxide-based semiconductors such as ZnO, TiO₂, MnO₂, and NiO with tunable size and morphology were successfully synthesized with several techniques for various applications such as photocatalyst and electrode materials. Dissolution and regeneration of cellulose in protic ionic liquids were also completed to have a composite with metal oxides to enhance the surface area of the active photocatalysts. Now we aimed at developing nanomaterials for wide application under ambient conditions for the treatment of industrial wastewater, as well as for use as an electrocatalyst for oxygen reduction reactions.



7. Time required for completion of the project:

Activities	Months				
	1	2	3	4	5
Literature survey and design of the experiment	■	■			
Synthesis of nanomaterials		■	■	■	
Characterization of nanomaterials			■	■	■
Photocatalytic activity			■	■	■
Report writing and preparation of the manuscript					■

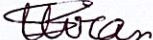
8. Requirement of funds as per the estimate under the headings:

Sl. NO.	Item	Quantity	Cost (BDT)
a	Research Fellowship	5	60,000
b	Accessories/Chemicals/ Analytical Services		3,000
	Total		63,000
	In words: Sixty-three thousand Tk. only		

9. Any financial assistance received/to be received from any other source for this project: No

Supervisor

Date: December 14, 2025

Signature: 

Dr. Muhammed Shah Miran
Professor
Department of Chemistry
University of Dhaka
Dhaka-1000, Bangladesh

Dr. Muhammed Shah Miran

Professor, Department of Chemistry

University of Dhaka, Dhaka-1000

Email: shahmiran@du.ac.bd

Contact No.: 01818441345