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Innovative Applications of Nanotechnology in Water Treatment and Pollution Control

With rapid industrialization and urbanization, water pollution has become a pressing global issue, involving organic contaminants, heavy metals, pathogenic microorganisms, and persistent chemicals. These pollutants not only threaten ecological health but also pose direct risks to human drinking water safety. Traditional water treatment methods, such as sedimentation, filtration, disinfection, and activated carbon adsorption, while effective under specific conditions, have limitations in terms of efficiency, selectivity, and long-term sustainability. Recently, nanotechnology has emerged as a promising approach, offering innovative solutions for water treatment and pollution control due to its unique physical, chemical, and biological properties.

Nanomaterials exhibit high surface area, tunable surface functionalities, and excellent catalytic properties, enabling effective removal, disinfection, and degradation of pollutants. For example, nanoscale zero-valent iron (nZVI) can reduce heavy metals and organic pollutants, titanium dioxide (TiO_2) nanoparticles can degrade persistent organic compounds under photocatalysis, and silver or copper nanoparticles demonstrate strong antibacterial activity. Functionalized nanomaterials can achieve selective adsorption of specific contaminants, improving treatment efficiency while minimizing secondary pollution risks.

Applications of nanotechnology in water treatment are expanding beyond laboratory research into practical engineering. Nanofiltration and reverse osmosis membranes enhanced with nanomaterials show improved flux and selectivity, photocatalytic nanocomposites enable solar-driven green degradation processes, and integrated nano-adsorbents and nanocomposites demonstrate potential in advanced wastewater treatment and water reuse. Concurrently, studies on the environmental behavior and safety of nanomaterials are essential to ensure that their application does not introduce new ecological or health risks.

This study aims to review the innovative applications of nanotechnology in water treatment and pollution control, focusing on the removal mechanisms, application scenarios, and engineering potential of various nanomaterials. It will also examine environmental safety, economic feasibility, and future development trends, providing theoretical and technical guidance for the advancement of sustainable water treatment technologies.