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АКТУАЛЬНІ ЗАДАЧІ ХІМІЇ: ДОСЛІДЖЕННЯ ТА ПЕРСПЕКТИВИ

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APPLICATION OF METAL NANOPARTICLES FOR WATER PURIFICATION

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Water purification is one of the key environmental problems of our time, which requires the introduction of innovative technologies to increase the efficiency of contaminant removal, including organic and inorganic pollutants, microbial pathogens and heavy metals. The use of metal nanoparticles in water treatment systems can significantly increase the level of purification due to their unique physical and chemical properties, including high catalytic activity, sorption capacity and antibacterial characteristics [6]. Nanoparticles of silver, iron, copper, titanium and their oxides are widely used to remove specific groups of pollutants due to their ability to photocatalyse, reduce and adsorb. For example, zero-valent iron nanoparticles demonstrate high efficiency in the reduction of toxic heavy metal ions, and TiO_2 nanoparticles are actively used for the photocatalytic oxidation of organic pollutants under UV radiation. In addition, in recent years, there has been a growing interest in combined nanomaterials that combine several functional properties, such as magnetic nanoparticles coated with photocatalytic layers, which provide effective reduction and destruction of toxic substances.

The use of nanoparticles in water treatment is of particular importance during wartime and post-war periods, when there is a significant disruption of critical infrastructure and deterioration in the quality of drinking water. The destruction of industrial facilities, oil storage facilities and wastewater treatment plants leads to the contamination of water resources with a wide range of toxic compounds, including oil products, heavy metals and organic toxicants. In such conditions, the use of autonomous purification systems based on nanotechnology is key to ensuring the vital activity of the population. Mobile nanofiltration plants can be deployed in areas of environmental disaster to quickly remove harmful compounds and disinfect water. In addition, it is promising to combine nanotechnology with traditional purification methods to increase their efficiency and economic viability. Modern developments also focus on the use of hybrid nanomaterials that combine photocatalytic and biocidal properties, which can be useful for water disinfection in crisis conditions [7].

Among the advanced areas of water treatment technology development is the synthesis of nanoparticles using ‘green’ methods based on the use of biogenic agents such as plant extracts, microorganisms or enzymes [1]. The use of such technologies eliminates the need for toxic reagents and minimises the environmental risks associated with the production of nanomaterials. Green synthesis not only helps to reduce the cost of nanoparticles, but also increases their biocompatibility, which reduces the risk of negative impact on aquatic ecosystems. In addition, the resulting nanoparticles may have improved physicochemical characteristics, such as increased surface activity and selective sorption of specific pollutants, making them particularly effective in removing organic trace contaminants and heavy metal ions [2].

The use of different types of nanoparticles in water treatment can achieve different goals depending on the nature of the contaminants. For example, titanium oxide (TiO_2) nanoparticles are widely used in photocatalytic systems because they are activated by ultraviolet radiation and are capable of decomposing organic compounds into safe products. Silver nanoparticles have powerful antimicrobial properties and are used to disinfect water from pathogens. Magnetic nanoparticles, such as magnetite (Fe_3O_4), are highly effective in removing heavy metals due to the ability to easily extract them from the medium using an external magnetic field. Zero-valent iron nanoparticles are used to remediate toxic pollutants such as arsenic or chromium (VI) by reducing them to less toxic forms. The combination of these nanomaterials in multi-component systems can provide a synergistic effect and increase the efficiency of water treatment even in difficult conditions [4].

From an economic point of view, the use of nanoparticles in water treatment technologies is cost-effective due to the reduction in reagent and energy costs compared to traditional treatment methods [3]. In particular, the introduction of nanotechnology can reduce the use of chemical coagulants and flocculants, as well as reduce the amount of secondary waste generated, which is an important aspect for industrial enterprises and municipal water supply systems. Analytical studies show that the combined use of nanoparticles with classical treatment methods can reduce operating costs by 30-50%, depending on the type of contaminants and operating conditions. At the same time, the need for further research into the safe extraction of nanoparticles after the cleaning process remains relevant, as the release of residual nanomaterials into the environment can cause undesirable ecotoxicological effects. Nanotechnology also opens up prospects for the implementation of smart water quality monitoring systems based on sensor platforms using nanomaterials [5].

Thus, the use of metal nanoparticles in water treatment technologies is a promising area that combines high efficiency, economic feasibility and environmental safety. Further development of this area requires a comprehensive approach, including optimisation of methods for obtaining nanomaterials, studying their long-term stability in water systems, and developing effective strategies for their disposal after use. Regulatory support is also an important aspect of the large-scale implementation of nanotechnology in water treatment processes, requiring the development of appropriate standards and assessment of potential risks to human health and the environment. Research in this area also focuses on developing new methods for recycling used nanoparticles and preventing their uncontrolled release into ecosystems.

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