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Photocatalytic Applications of Metal Oxide Nanoparticles in Pharmaceutical Waste Degradation

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DESCRIPTION

Metal Oxide Nanoparticle (MONP) photocatalytic applications offer a possible solution to the expanding environmental issue of pharmaceutical waste pollution. Agricultural runoff, human waste and inappropriate disposal are common ways for pharmaceuticals that have been used or expired to enter aquatic systems. Antibiotic-resistant bacteria and hormone disruption in wildlife are only two of the negative consequences that these contaminants may have on aquatic ecosystems. Since pharmaceutical chemicals are frequently not efficiently broken down by conventional water treatment techniques, modern solutions like photocatalysis are being investigated. When exposed to light, metal oxide nanoparticles' distinct physicochemical characteristics have made them effective catalysts for the breakdown of persistent pharmaceutical contaminants.

Reactive Oxygen Species (ROS), such as hydroxyl radicals (•OH) and superoxide anions (O_2^{-}•), are produced when a photocatalyst absorbs light energy, usually in the visible or Ultraviolet (UV) range. This is the basic idea underlying photocatalysis. The large surface area, superior chemical stability and potent photocatalytic activity of metal oxide nanoparticles such as cerium oxide (CeO_2), zinc oxide (ZnO) and titanium dioxide (TiO_2) make them popular for this usage. Pharmaceutical pollutants are oxidized and broken down into less hazardous or biodegradable chemicals by ROS, which are created when these nanoparticles contact with water and oxygen to produce electron-hole pairs.

ZnO nanoparticles' high ROS production and similar band gap energy to TiO_2 make them important for photocatalytic degradation as well. Drugs like ibuprofen and diclofenac have been demonstrated to be efficiently broken down by ZnO nanoparticles. ZnO is less stable in wet conditions, though and frequently dissolves, which reduces its utility. Techniques including surface treatment with polymers or other stabilizing agents have been developed to improve ZnO nanoparticles' resilience and reusability in photocatalytic applications. Due to their redox activity and ability to store oxygen, CeO_2 nanoparticles have also been investigated for the breakdown of pharmaceutical waste. Continuous ROS generation during photocatalysis is made possible by their capacity to switch between the Ce_3^+ and Ce_4^+ oxidation states. CeO_2 nanoparticles are extremely effective in dissolving stubborn pharmacological molecules because of this characteristic. Additionally, it has been discovered that CeO_2 and other metal oxides, including TiO_2 or ZnO, can work in concert to improve photocatalytic activity when combined in composite nanostructures.

Composite metal oxide nanoparticle engineering and design have improved photocatalytic applications. For instance, TiO_2 has been shown to enhance photocatalytic activity by enhanced light absorption and charge separation when coupled with other metal oxides such as iron oxide (FeO_3) or tungsten oxide (WO_3). These hybrid systems take use of each component's capabilities, such as WO_3's visible light activity and TiO_2's strong ROS production capability, to produce improved pharmaceutical degradation. Using magnetic metal oxide nanoparticles, such iron oxide-based systems, which are easily separated and recovered from treated water using external magnetic fields, is another creative strategy. This characteristic reduces secondary pollutants linked to nanoparticle residues while also making it easier to reuse the catalyst. FeO_4-TiO_2 composites, for example, have demonstrated tremendous promise in the highly efficient and easily recoverable degradation of a variety of medicines, such as tetracycline and amoxicillin. For broad implementation, photocatalytic degradation must be integrated into the current wastewater treatment infrastructure in addition to technological developments. Comprehensive degradation of pharmaceutical contaminants has been demonstrated to be possible with hybrid systems that combine photocatalysis with traditional treatment techniques like biological therapy or sophisticated oxidation processes. For instance, combining membrane filtration with photocatalysis can improve pollutant removal while halting the leaching of nanoparticles.