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Thesis Abstract

Synthesis and Analysis of Nanomaterials with Applications in Controlled Drug Delivery

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Synthesis and Analysis of Nanomaterials with Applications in Controlled Drug Delivery

This thesis, structured in two main parts, explores the potential applications of nanoparticles both in the medical field, particularly in oncology treatments, as well as in the environmental protection, focusing on the removal of organic pollutants from water. The topic is highly relevant, considering the growing interest in nanomaterials and their wide range of applications.

The first part of the paper presents the fundamental theoretical concepts related to nanomaterials, emphasizing the key characteristics that distinguish them from conventional materials. Due to their large specific surface area, unique structures, and behaviors at the nanoscale, nanoparticles exhibit distinct physicochemical, optical, electrical, and magnetic properties that can be leveraged in various applications. The work offers a detailed analysis of the main categories of nanoparticles, including metallic nanoparticles, metal oxide-based particles, carbon-based nanoparticles, polymeric variants, and composite materials. Each category has its specific advantages and limitations, with the choice of the most suitable type depending on the intended application. For example, metallic nanoparticles are known for their high reactivity and remarkable optical properties; magnetic nanoparticles are extensively used in biomedicine due to their responsiveness to external magnetic fields; while polymeric nanoparticles are favored for their capacity to enable controlled drug release.

The thesis also addresses the various synthesis methods employed for these types of nanoparticles, ranging from traditional chemical and physical techniques to modern, environmentally friendly approaches, including green and bioinspired synthesis methods. Special attention is given to the physicochemical characterization techniques used to determine properties such as size, shape, crystalline structure, chemical composition, as well as optical and magnetic behaviors. These methods include transmission and scanning electron microscopy (TEM, SEM), X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), UV-Vis spectroscopy, Fourier-transform infrared spectroscopy (FTIR), and advanced techniques such as fiber optic-based surface plasmon resonance (FO-SPR).

In the chapter dedicated to medical applications, the advantages of employing nanoparticles in cancer treatments are highlighted. The concept of magnetic hyperthermia is

examined an innovative technique whereby nanoparticles are injected directly into tumors and then selectively heated through the application of an alternating magnetic field, leading to the localized destruction of cancerous cells. The issue of controlled drug delivery is also discussed, emphasizing the importance of designing systems capable of protecting the active substance during circulation in the bloodstream and ensuring its targeted release at the desired site. In this context, the thesis provides detailed insights into the materials used, with particular focus on magnetite (Fe_3O_4) due to its outstanding magnetic properties, chemical stability, and proven biocompatibility in numerous previous studies.

Doxorubicin (Dox) was selected as the model drug because of its well-established efficacy in oncology, being a widely used cytostatic agent for the treatment of various types of cancer. However, its significant toxicity and adverse effects on healthy tissues highlight the need for innovative delivery systems that can improve its pharmacological profile. This thesis describes the development of nanoparticle-based systems specifically designed to enhance Dox delivery, thereby optimizing therapeutic outcomes, while reducing systemic toxicity.

The second part of the thesis presents the author's experimental contributions, which involved the synthesis, characterization, and testing of various types of nanoparticles with potential applications in oncology and environmental remediation. Magnetic nanoparticles coated with silica were developed to improve stability and prevent aggregation in biological environments. Furthermore, nanoparticles functionalized with L-cysteine, an amino acid that facilitates efficient doxorubicin binding and enhances interactions with tumor cells, were synthesized to promote rapid uptake by targeted cells. Nanoparticles functionalized with citric acid demonstrated their ability to stabilize colloidal systems and facilitate the controlled release of the active compound. All these types of nanoparticles were characterized in terms of morphology, chemical composition, magnetic properties, and biological interactions using specialized analytical techniques. The interactions between nanoparticles and Dox were monitored through FO-SPR, UV-Vis, and FTIR spectroscopy, confirming the systems' ability to retain and release the drug in a controlled manner.

In vitro biological tests were conducted on melanoma tumor cell lines (A375 and B16F10), evaluating the efficacy of Dox-loaded nanoparticles through cell viability assays (MTS), IC50 determination, fluorescence microscopy, and flow cytometry. The results demonstrated that these nanoparticles enhance the cytotoxic effectiveness of Dox, allowing lower concentrations to achieve the desired therapeutic effect. Moreover, these systems were shown to induce apoptosis

in tumor cells, a crucial mechanism for inhibiting uncontrolled proliferation. Another investigated aspect was the impact of these treatments on cellular signaling pathways, particularly the activation of ERK (*extracelular signal-regulated kinase*), a kinase involved in cell survival and proliferation. The findings revealed the inhibition of this pathway following treatment.

Another system explored within this research was based on PLGA (*poly(lactic-co-glycolic acid*))-PVA (*poly(vinyl alcohol*)) polymeric nanoparticles, recognized for their favorable properties in controlled drug delivery due to their stability and tunable release profiles. These nanoparticles were structurally and functionally characterized, and their ability to penetrate tumor cells and induce apoptosis proved superior compared to the free form of the drug.

A complementary research direction focused on the use of nanoparticles in environmental protection, specifically targeting the degradation of organic pollutants. In this regard, the degradation of Dox classified as an emerging pharmaceutical pollutant, was investigated using catalytic systems based on laccase enzyme and Tempo radicals, a combination known for its effectiveness in breaking down aromatic compounds *via* oxidative mechanisms. The results confirmed the system's efficiency in reducing residual Dox concentrations, contributing to ecosystem protection.

Additionally, hybrid nanoparticles based on TiO_2 and gold were developed for photocatalytic applications and tested for their efficiency in degrading methylene blue dye, a common pollutant in the textile industry. Experiments conducted under UV irradiation demonstrated the enhanced effectiveness of these systems in rapidly degrading the dye, confirming the potential of these nanomaterials for environmental applications.

In conclusion, the findings of this thesis demonstrate that the developed nanoparticles exhibit promising features for both innovative cancer treatments and environmental remediation, offering effective solutions for the removal of organic pollutants. The precise control of nanoparticle size, stability, and chemical functionalization, along with their integration into complex systems, allows for the creation of versatile materials capable of addressing real societal needs. This research supports the idea that nanotechnology could play a pivotal role in the future of personalized medicine and environmental protection, contributing significantly to the development of safer and more effective therapies and to the safeguarding of natural resources.