Functionalization of Cerium Oxide Nanoparticles (CeO_2) for Applications in Diagnostic Hydrogels

Wound infections pose a serious health issue that can lead to dangerous complications, such as chronic inflammation or sepsis. Early detection of infections is crucial for effective treatment; however, currently used diagnostic methods, such as microbiological testing, are time-consuming, costly, and require specialized equipment and trained personnel. The lack of rapid, easy-to-use, and accessible diagnostic solutions limits the ability to provide timely intervention, especially in home care settings. Addressing these needs, this research project focuses on developing an innovative diagnostic tool capable of detecting infections quickly through a visual color change.

The primary aim of this project is to develop an innovative hydrogel-based material that will function as a disposable diagnostic sensor. Hydrogels are water-rich gels characterized by their flexibility and biocompatibility, making them a promising material for biomedical applications. In this project, the hydrogel will be enhanced with cerium oxide (CeO_2) nanoparticles, known for their unique physicochemical properties, and a color indicator, bromothymol blue (BTB).

The designed diagnostic system will respond to pH changes in wounds, which are key indicators of infection. During an infection, the pH of a wound shifts to a more alkaline range, causing the hydrogel to change color from yellow to blue, providing a simple and visual signal for the need for medical intervention.

In the first phase, a hydrogel matrix based on chitosan—a naturally derived polysaccharide with antibacterial and biocompatible properties—will be developed and thoroughly characterized. During the second stage, cerium oxide nanoparticles will be synthesized in situ directly on the hydrogel surface. This process will ensure the uniform distribution of nanoparticles and their stable embedding within the material's structure. The nanoparticles will subsequently be functionalized with thiol ligands, which will provide stability in the dynamic environment of a wound and enable interactions with the color indicator.

The next step will involve integrating bromothymol blue (BTB) into the hydrogel to create the final diagnostic system. This system will then be analyzed for its stability, biological safety, and diagnostic effectiveness. The final stage of the project will focus on developing a theoretical model of the material’s functionality to optimize its future production.

This research initiative arises from the urgent need to develop innovative diagnostic tools that are fast, simple, and accessible. Current diagnostic solutions are often too complex to be applied directly at the wound site. Delayed diagnosis, on the other hand, can lead to severe health complications. The proposed diagnostic hydrogel has the potential to revolutionize healthcare by serving as a tool that patients or caregivers can easily use in their daily practice.

The most important expected outcome of the project is the development of an innovative, disposable diagnostic system that will enable rapid and intuitive wound assessment. Another key result will be the acquisition of new scientific knowledge regarding the physical and chemical processes occurring within complex biomaterial systems. The findings will not only lead to the development of a practical medical solution but will also advance understanding of hydrogel-nanoparticle integration and their mechanisms of action in biological environments.

The diagnostic hydrogel developed through this project may find broad applications in medicine, particularly in wound care and home-based healthcare. Due to its intuitive and easy-to-use design, the developed material has the potential to become an invaluable tool for both patients and healthcare providers, significantly improving quality of life and enhancing safety in infection diagnostics. This project has the potential to open new perspectives in medical diagnostics, exemplifying a modern approach to the application of nanotechnology in biomedicine.