APPLICATION OF GREEN TECHNOLOGIES AND NANOPARTICLE - MODIFIED ELECTRODES

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Introduction

The modern development of pharmaceutical analysis and medical diagnostics requires the implementation of environmentally safe, sustainable, and highly sensitive analytical methods. In this context, the principles of green chemistry have gained significant importance, as they aim to reduce reagent toxicity, minimize energy consumption, and decrease environmental impact.

One of the most promising approaches is the use of nanoparticle-modified electrodes, which significantly enhance the sensitivity and selectivity of electrochemical sensors. The combination of green synthesis technologies for nanoparticles with electrochemical analytical methods opens new opportunities for the determination of pharmaceutical compounds, biologically active substances, and pharmaceutical pollutants.

The aim of this study is to analyze the potential application of green-synthesized nanoparticles for electrode surface modification in order to improve the efficiency of electrochemical pharmaceutical analysis.

Methods

In this study, metal and metal oxide nanoparticles (Ag, Cu, ZnO, TiO_2, Fe_3O_4) synthesized using green chemistry approaches were employed. Particular attention was given to biological synthesis methods, including:

synthesis using plant extracts (ginger, green tea, aloe vera), where polyphenols and flavonoids act as reducing and stabilizing agents;

biosynthesis involving microorganisms and enzymes;

synthesis in aqueous media at low temperatures without the use of toxic solvents.

The synthesized nanoparticles were used to modify electrode surfaces either individually or as part of hybrid nanocomposites with biopolymers (chitosan, starch, polyvinyl alcohol). The performance of the modified electrodes was evaluated using electrochemical methods for the determination of model pharmaceutical compounds.

Results

The results demonstrated that the application of green-synthesized nanoparticles significantly improves the electrochemical properties of electrodes. In particular:

the electron transfer rate at the electrode surface increased;

the signal-to-noise ratio was enhanced;

the limit of detection (LOD) of analytes was substantially reduced;

measurement stability and reproducibility were improved.

The modified electrodes exhibited high efficiency in the determination of pharmaceutical compounds such as ibuprofen, paracetamol, diclofenac, and caffeine. It was shown that hybrid nanocomposites enable the simultaneous detection of multiple components in complex analytical systems.

In addition, biosynthesized nanoparticles demonstrated high biocompatibility, allowing their application in *in vitro* biosensors and analytical systems.

Discussion

The obtained results confirm the high potential of integrating green chemistry principles into electrochemical pharmaceutical analysis. Compared to conventional nanoparticle synthesis methods, green technologies provide environmental safety, reduced energy consumption, and cost effectiveness.

The use of nanoparticles as electrode modifiers enables the development of highly sensitive and selective sensor systems that meet modern sustainability requirements. These approaches are particularly relevant in the context of the transition of the pharmaceutical industry toward green and digital laboratory technologies.

Further research should focus on expanding the range of nanomaterials and analytical targets, as well as adapting the developed sensor systems for practical applications in clinical diagnostics and environmental monitoring.

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