Antimicrobial property of zinc based nanoparticles

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\textbf{Abstract.} Pathogen bacteria strains with wide spectrum can cause serious infections with drastic damages on humans. There are studies reflecting antibacterial effect of nanoparticles type metal or metal oxides as an alternative or concurrent treatment to the diseases caused by infectious agents. Synthesised nanoparticles using different methods like sol-gel, hydrothermal or plant extraction were tested following well-established protocols with the regard to their antimicrobial activity. It was found that zinc based nanoparticles possess strong synergistic effect with commonly used antibiotics on infection tratment.

1. Introduction

Last years a lot of serious health issues was caused by the increasing resistance of pathogen agents towards antibiotics. Researches could reveal novel application of metals as intrinsic antimicrobial activity by combining advanced technologies of material science and material science respectively (Figure 1).

According to the reports, metal and metal oxide nanoparticles represent a group of materials which were investigated in respect to their antimicrobial effects. In present study, our attention was focused on the recent discoveries concerning antimicrobial activity of metal and metal oxide nanoparticles together with their mechanism of action. Results showed that the particle size was the essential parameter which determined the antimicrobial effectiveness of the metal nanoparticles. By combining classical therapy with metal based nanoparticles might be an important choice to overcome the current bacterial resistance to antibiotics\cite{1}.

Zinc oxide type nanoparticles proved to have bactericidal effects on Gram-positive and Gram-negative bacteria as well as the spores which are resistant to high temperature and high pressure \cite{2}.
2. Materials and methods

In recent years biologically synthesized nanomaterial has become a major field of nanotechnology. A leaf aqueous extract of Azadirachta indica (L.) was used to obtain ZnO based nanoparticles and their antimicrobial activity was investigated. Results described an increase antimicrobial activities due to the increase of H2O2 concentration from the surface of ZnO which depended on concentration of ZnO nanoparticles (50, 100, 200 $\mu$g/mL). Furthermore, zinc oxide nanoparticles exhibited an interesting antibacterial effect on both Gram positive and Gram negative bacteria at micromolar concentration [3].

Zinc oxide nanoparticles (ZnO NPs) were also synthesized using a simple and eco-friendly method based on leaf extract of Moringa oleifera. Wurtzite hexagonal structure and presence of functional groups of both leaf extract and ZnO NPs were revealed using XRD and FT-IR patterns. FE-SEM and EDX technique used for textural characteristics highlighting showed their particles size, morphology and topography, intense and narrow width of zinc and oxygen with high purity and crystalline respectively. Studies results of antibacterial activity (Figure 2) revealed that intense area of inhibition was observed Gram positive bacteria followed by the Gram negative bacteria and fungal at concentration of 200 $\mu$g/mL of ZnO NPs [4].

Figure 2. Antimicrobial activity of ZnO nanoparticles form Moringa oleifera leaf extract [4]

Another biological process using V. trifolia plant leaf extract was developed to synthesize zinc oxide nanoparticles presented in figure 3. Physical-chemical characterization by X-ray diffraction FT-IR spectroscopy, SEM-EDX assessment showed small crystalline size at higher volume of extract, functional groups present from the leaf extract such as alcohols, phenols, 10 amines, aromatic and aliphatic amines and the presence of pure aspect zinc and oxygen without a different impurity peaks.
It was shown that green synthesized zinc oxide nanoparticles are more useful in both environmental purification and clinical laboratory [5]. Antimicrobial efficacy of ZnO has been investigated against Escherichia coli in simple model systems and in typical topical products containing antioxidants, chelating agents, electrolytes, titanium dioxide pigment resulting that antibacterial activity of zinc oxide nanoparticles was partially inhibited by NaCl and MgSO4 salts.

By adding ZnO in complex formulations, microbiological quality was significantly improved in spite of the presence of other ingredients that influenced antimicrobial activity [6].

![Figure 3. Zones of inhibition (mm) of various human pathogenic microorganism effects of various antimicrobial agents and its equivalent bar diagram and Gas Chromatogram of leaf sample of Vitex trifolia.](image)

Other researches used zinc oxide nanoparticles with hexagonal, spherical shape with particle size smaller than 100 nm from Murraya koenigii leaf extract. Results showed that zinc based nanoparticles had intense activities on Staphylococcus aureus (14.0±0.50mm) and Bacillus subtilis (13.8±0.76mm) at concentration of 200 μg/mL [7].

3. Experimental part

Clear waters is a primary need for human health. Recycling naturally waters is not enough for population and undrinkable according to standard parameters. Presently, pathogenic bacteria significantly contaminate most of the natural waters. Globally, approximate 700 million peoples are facing huge scarcity of water, predicting nearly about 1.8 billion people face water scarcity problem in 2025 [8]. Annually, around 12 million people die because of water borne disease (WHO 2012) [9] and majority of these diseases occurring in underdeveloped countries is due to the ingestion of contaminated waters [10]. Advanced nanotechnology and nano material applications respectively open the opportunities to improve the waste water treatment methods including decontamination of the nano- and mycro- contaminants due to their reactive surface inducing coating on pollutant decreasing the toxicity of compounds and destroying pathogen agents. Antimicrobial activity of zinc based nanomaterials makes them useful in antibiotic simultaneous treatment to significantly improve healing [11]. Several synthesis methods are available for the preparation of pure and doped ZnO nanomaterials, like hydrothermal, hydrolysis, sol–gel, vapor condensation, spray pyrolysis and organic precursor flame decomposition [12–17].

Generaly metal nanomaterials like silver, gold and zinc exhibited important antimicrobial activities [18–20]. Bacteria resistance developing against antibiotics and metals creates health problems, leading to inability of classical medicine to treat efficient several diseases [21]. For human welfare there has been a special attention for stable antimicrobial metal nanoparticles development [22]. Nanomaterial based antimicrobial medicines especially zinc oxides are more efficient in hard conditions [23].

Nowadays, researchers focussed on antibacterial effect and stability of ZnO nanoparticles also known to be safe materials for human and ecosystem [24, 25]. More over, zinc oxide nanoparticles were dopped in wallpaper of hospitals to prevent microbial load on walls and nosocomial infection respectively [26]. An enhanced antimicrobial activity of ZnO nanoparticles and other metal oxides like Al2O3, SiO2 and TiO2 was due to the presence of water molecules on its surface being capable to generate free radicals of hydroxyl and oxygen species responsible for oxidative stress in treated bacterial cells of Escherichia coli, B. subtilis and Pseudomonas sp.
4. Results and discussions
Chemically synthesized cobalt doped ZnO nanoparticles were found to be crystalline with a single phase as confirmed by XRD (Figure 4) and SEM (Figure 5) features.

![X-ray diffraction pattern of ZnO and Co doped ZnO](image)

**Figure 4.** X-ray diffraction pattern of 0% pure ZnO, 1% of Co doped ZnO, 3% of Co doped ZnO and 5% of Co doped ZnO.

It was found that increasing the percentage of Co from 0% to 5% in ZnO, leads to an enhanced crystallite size from 20.5 to 25.7 nm. also experienced a colour change, but of a smaller value ($\Delta E_{ab}^* = 7.06$), in comparison with that of C2 area, where $\Delta E_{ab}^* = 9.58$.

SEM images revealed that, after treatment, Co doped nanoparticles morphology changed from rod to spherical shaped. Cobalt doped zinc oxide nanomaterials were tested as a bactericidal agent resulting that this treatment and exposure of sunlight enhanced the antibacterial activity against Escherichia coli and Vibrio cholerae at 50 $\mu$g concentration [27].

![SEM images of ZnO and Co doped ZnO nanoparticles](image)

**Figure 5.** Doping analysis of ZnO and Co doped ZnO nanoparticles by SEM coupled with energy dispersive X-ray spectroscopy, here, pure ZnO (1 and a), 1% Co doped ZnO (2 and b).

Antimicrobial activity of zinc oxide powders was investigated on the five microbial strains of Escherichia coli; Staphylococcus aureus; Pseudomonas aeruginosa; Candida albicans; Aspergillus brasiliensis in order to assessed relationships between the structural parameters and physicochemical characteristics of zinc oxide particles and their antimicrobial activity.
Zinc oxide particles with interesting textures as small size, large specific area and high porosity exhibit higher antibacterial effect according to their action mechanisms [28]. Antimicrobial activity against various bacterial and fungal strains is represented by zinc ions (Zn2+) since zinc oxide nanoparticles releases Zn2+ ions in aqueous solution contributing to the antimicrobial effectiveness of ZnO as shown in figure 6.

Researchers studied the contribution of the soluble zinc species regarding antimicrobial activity of ZnO on microbial cultures in broth medium. The Zn2+ released in the broth significantly contributed to the overall antibacterial effect of zinc oxide nanoparticle. Soluble zinc species and ZnO powders possessing larger specific area showed specificity with respect to the microbial strains. [29].

![Figure 6. Action mecanism of Zn\(^{2+}\) on microbial cell](image)

5. Conclusions

Interdisciplinary researches that include nanotechnology, pharmacology, physiology, physics, chemistry and medicine represent nowadays a key direction for nanoparticles development in order to prevent or treat serious diseases caused by dangerous infectious agents. Antibacterial activity of zinc based nanoparticles is enhanced by their morphological characteristics and physicochemical properties mostly due to the positive surface charge of metal that binds to the negatively charged surface of tested bacteria. Regardless of the used synthesis method, zinc oxide or cobalt doped ZnO nanostructures with low toxicity have shown an important antibacterial effect and can be used as a suitable alternative in pharmaceutical industries.

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