International Journal of Research in Science & Engineering
ISSN: 2394-8299
Vol: 02, No. 04, June-July 2022
http://journal.hmjournals.com/index.php/IJRISE
DOI: https://doi.org/10.55529/ijrise.24.38.46

Investigating the Antibacterial Properties of ZnO-NPs

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Received: 05 April 2022 **Accepted:** 18 June 2022 **Published:** 30 July 2022

***Abstract:** The size range of several hundred nanometers to several of micrometers contains a lot of microorganisms. The aim of the current report was to study the antibacterial properties of ZnO-NPs through a theoretical review of the most important findings in previous studies. The study found the most important antibacterial properties of ZnO-NPs, including: Strong antibacterial results can be achieved by enhancing variables such as UV light, zinc oxide particle size, concentration, shape, and surface modification, which affect many different toxicological processes. One of the main properties of ZnO-NPs is the production of intracellular ROS formation, as well as the mechanical damage of the cell wall due to the release of Zn2+ ion and its attachment to the cell membrane.*

***Keywords:** Bacteria, ZnO-NPs, Antibacterial Activity, Antibacterial Properties of ZnO-NPs.*

1. INTRODUCTION

Nanotechnology has unique properties that allow it to enter numerous sectors and applications, and interest in it has grown recently. They entered the pharmaceutical and medical fields as well as the mechanical, chemical, and technology industries (kadhi, 2019). Among the most well-liked areas for contemporary research and improvement in essentially all technical disciplines is the field of nanotechnology (Paul & Robeson, 2008). High surface area, small size, superior chemical reactivity, greater control over the light spectrum, lighter weight, higher strength, and multilateral chemistry (Kadhim et al., 2019). Zinc oxide, one of the most popular nanomaterials, has attracted a lot of interest from the scientific and medical sectors due to its significant applications. The scientific and medical sectors are becoming more interested in ZnO for biomedical and antibacterial applications, in large part because of the physical and chemical characteristics of these nanomaterials (Noor et al., 2017). For example, a wide spectrum of radiation absorption, strong photostability, high electrochemical coupling coefficient, and high chemical stability (Kołodziejczak-Radzimska & Jesionowski, 2014).

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In several industries, including optoelectronic display technologies, Among the most often used semiconductors is zinc oxide. Zinc oxide has multiple properties and is suitable for high technology such as solar cells, electromagnetism, etc. due to their high chemical and thermal stability, electronic, photoelectric, and piezoelectric properties (Hahn, 2011).

The use of nano-zinc oxide was not restricted to these fields; rather, it was a crucial component in the medical field, particularly in recent years, which saw a remarkable advancement in the application of nanotechnology in medicine. Because nanoparticles can now be manufactured in the shape and size required for a given purpose, it is now possible to develop novel approaches for treating diseases that were previously difficult to target because of size limitations. Given that the majority of biological activities occur at the nanoscale, combining the efforts of nanotechnology with biology can address significant biomedical issues. Metal oxides, particularly zinc oxide, are among the semiconductors that are most effective and safe for biological use. Due to its resistance to hostile settings and the fact that zinc compounds are GRAS-listed, or generally recognized as safe by the Food and Drug Administration, zinc oxide has recently drawn increased attention. Zinc oxide is also inexpensive, non-toxic, and very effective against pathogenic bacteria. Zinc oxide nanoparticles (ZnO-NPs) are used in a variety of medical industrial industries in the United States, including pharmaceuticals and cosmetics (Wahab, et al., 2012; Mirzaei & Darroudi, 2017). Because of their innate capacity to absorb UV rays, they are also frequently utilized to treat a variety of various skin conditions. They are used to block UV rays. Sunscreens, antimicrobials, and other medical devices all employ ultraviolet light. Additionally, research has demonstrated that ZnO-NPs nanoparticles can be extremely hazardous to leukemia cells, bacteria, and cancer cells. ZnO-NP nanoparticles have also been researched as biosensing, drug, and gene-delivery vehicles to combat cancer (Zhang, et al., 2013).

Since nanotechnology has been heavily utilized in the field of medicine, which has made it possible to treat diseases that were previously difficult to focus on due to size restrictions, zinc oxide nanoparticles (ZnO-NPs) have attracted the attention of many researchers due to their antibacterial properties. Due to the fact that most biological activities occur at the nanoscale, it is now possible to develop new forms of safe and affordable antibiotics to eradicate and manage diseases. Based on the above, the research problem can be formulated with the following question:

What are the Antibacterial Properties of Zinc Oxide-NPs?
Therefore, the research aims to study the antibacterial characteristics of zinc oxide-NPs. To achieve the desired goal, we will discuss in this report the following points:

- Concept of Zinc Oxide Nanoparticles.
- The concept of bacteria and the effect of NPs.
- Antibacterial activity.
- antibacterial properties of zinc oxide-NPs.

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Concept of Zinc Oxide Nanoparticles

ZnO is a versatile, useful, strategic, and adaptable inorganic material with a wide range of applications. It is known as an II-VI semiconductor because Zn and O are categorized into groups 2 and 6, respectively, of the periodic table. Unique optical, semiconducting, chemical sensing, electric conductivity, and piezoelectric capabilities are held by ZnO (Fan & Lu, 2005). Its distinctive characteristics include an inherent n-type electrical conductivity, a relatively wide band gap of 3.3 eV in the near-UV spectrum, and a significant excitonic binding energy of 60 meV at room temperature. (Schmidt-Mende & MacManus, 2007). These qualities allow ZnO to have exceptional applicability in a variety of domains (Wang & Song, 2006). According to Janotti and Van (2009), the excited emission can last longer at room temperature in addition to the conductivity rises, when ZnO is doped with additional metals. ZnO has a weak covalent bond, but Zn-O has a very strong ionic bond in comparison to organic and inorganic materials, it is more heat resistant, more selective, and more durable. (Padmavathy & Vijayaraghavan, 2008). The production of ZnO-NPs, which exhibit remarkable antibacterial and antifungal properties in addition to possessing potent catalytic and high photochemical activity, has sparked research into ZnO's potential as a novel antibacterial agent. ZnO, which aids in the antibacterial response and is employed as a UV protector in cosmetics, exhibits strong optical absorption in the UVA (315-400 nm) and UVB (280-315 nm) regions (Song et al., 2011).

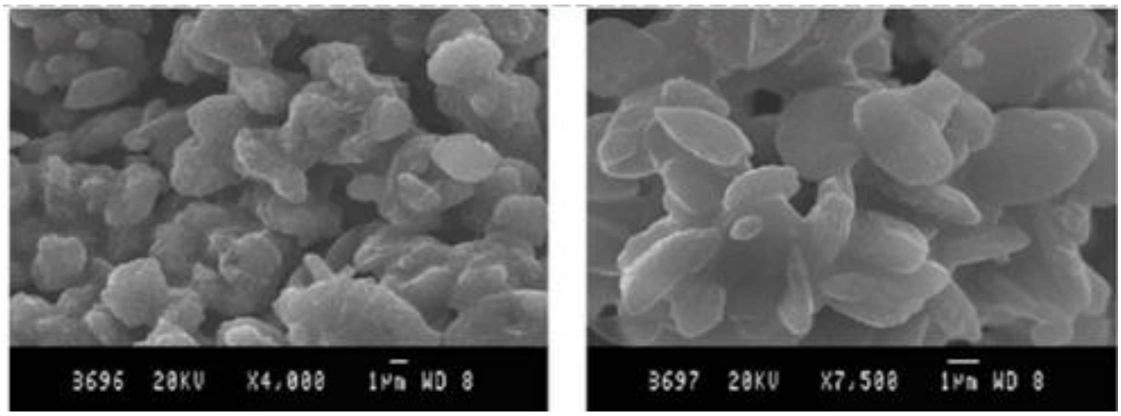

Figure 1: A scanning electron microscope (SEM) image of ZnO-NPs (source: B.V.Kumar et al, 2011)

The Concept of Bacteria and the Effect of NPs

Cell walls, cytoplasm, and cell membranes serve as the hallmarks of bacteria. The majority of the cell wall, which is made up of a homogenous peptidoglycan layer made of amino acids and sugars, is located outside the cell membrane. The osmotic pressure in the cytoplasm and the distinctive cell shape are both maintained by the cell wall. Gram-positive bacteria have a thicker cell wall (20–80 nm) and a single cytoplasmic membrane covered in many layers of peptidoglycan polymer. Contrarily, the cell wall of gram-negative bacteria is composed of two membranes: an outer membrane and a plasma membrane that is covered with a peptidoglycan layer that is 7-8 nm thick (Fu et al., 2005). Typical bacteria cell architectures are depicted in Figure 2.

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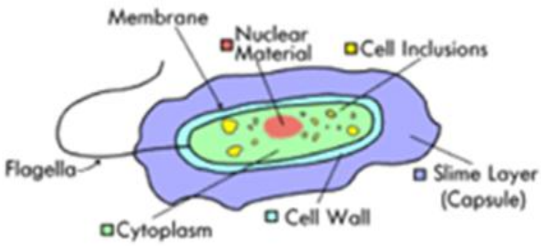

Figure 2: bacterial cell structures (Source: Edwards et al.)

These sizes allow NPs to easily pass through the peptidoglycan, making them extremely prone to damage. All cellular components aside from the nucleus are housed in the cytoplasm, a jelly-like fluid that makes up a cell. This organelle is responsible for carrying out growth, metabolism, and replication. As a result, the cytoplasm contains water (80%), salts, ions, proteins, carbohydrates, and nucleic acids. This composition affects the cellular structure's ability to conduct electricity. Cell walls of bacteria have a net negative charge.

Antibacterial Activity

The American Heritage Medical Dictionary from 2007 defines antibacterial activity as the process that kills or inhibits bacterial growth. The surface area in touch with the microorganisms is another way to characterize it (Wahab, et al., 2010). Antibacterial medicines, however, are selectively concentrated medications that can injure or impede bacterial development without harming the host. To cure or prevent bacterial infections, these substances function as chemotherapeutic agents. If an antibacterial agent kills bacteria, it is referred to as bactericidal; if it prevents germs from growing, it is referred to as bacteriostatic.

Antibacterial Properties of Zinc Oxide-NPs

High Photocatalytic Efficiency

In comparison to TiO2, ZnO is proven to have a higher photocatalytic efficacy to have the highest biocompatibility of all inorganic photocatalytic materials. (Zhang, 2011). ZnO responds better to UV light and can dramatically increase its contact with bacteria since it can absorb UV light to a big extent (Nirmala et al., 2010). This significantly improves its conductivity. It nevertheless exhibits photoconductivity even after the UV light has been switched off, which has been attributed to a surface electron depletion zone that is closely associated to negatively charged oxygen species (O2, O2) surface-adsorbed substance. UV light immediately causes this surface-attached oxygen to desorb from its loosely bound state. According to Bao et al. (2011), this results in a smaller surface electron depletion zone, which improves photoconductivity. According to Baruah, et al., (2010), a sort of photo-induced oxidation known as photocatalysis can be harmful and incapacitate living beings. ZnO-NPs in aqueous solution have a phototoxic effect when exposed to UV light, which may cause the generation of ROS like superoxide ions (O2) and hydrogen peroxide (H2O2). These species are important for bioapplications, according to Zhang et al. (2011). The newly developed active species can enter cells and either kill or prevent bacterial growth. The use of ZnO-NPs for photocatalysis in bionanotechnology and bionanomedicine has been used in several

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antibacterial applications as a result of this method. As a result of ZnO's ability to absorb UV light, it was postulated that the resulting free radicals would boost its bioactivity (Seil et al., 2009).

Various Morphologies of ZnO-NPs

According to Espitia et al. (2012), controlling variables such as solvents, precursor types, and physicochemical conditions such as pH and temperature, along with shape-directing agents, may lead to the production of ZnO-NPs with the structural characteristics required for the best antibacterial response. Surface activity also governs surface morphology in conditions of poorly regulated growth. NP is capable of holding a large number of active facets using synthesis and growth techniques. In contrast to ZnO rod structures, which contain (111) and (100) facets, spherical nanostructures mostly have (100) facets. With (111) facets, high-atom-density facets have more antibacterial action (Pal et al., 2007). This is supported by the ease with which rods and wires permeate bacterial cell walls as opposed to spherical ZnO-NPs (Yang et al., 2009), which is proof that ZnO nanostructures can change how they internalize depending on their shape. But flower-shaped ZnO-NPs outperform spherical and rod-shaped ZnO-NPs in terms of their biocidal efficacy against S. aureus and E. coli (Talebian et al., 2013). When assessing the contribution of ZnO nanostructured's polar facets to antibacterial activity, It has been shown that more polar surfaces have more oxygen vacancies in addition to having increased internalization. It is widely known that oxygen vacancies encourage the development of ROS, which in turn inhibits ZnO's ability to photocatalyze (Li et al., 2008). Currently, According to research by Tong et al. (2013), heavily exposed polar facets with a (0 0 0 1)-Zn termination on ZnO morphologies are more effective at inhibiting the growth of bacteria (Tong et al., 2013).

Thermal Annealing for Surface Modification

ZnO surfaces with added functionality have the strongest antibacterial effects. ZnO powder is annealed to significantly increase the inhibition. According to the research done by Ann et al. (2014), during oxygen annealing, a sizable number of oxygen atoms were absorbed onto the ZnO surface, enhancing the antibacterial response by increasing the amount of ROS produced in the suspension, which in turn caused the bacteria to experience severe oxidative stress. By annealing ZnO nanorods in air and oxygen to encourage the development of nanoholes on the surface, Mamat et al. (2011) found that increasing the surface area led to increase oxygen molecule uptake and diffusion onto the surface in response to UV light exposure, which in turn contributed to the production of more ROS on the surface. Increased generation of ROS and the ionization of Zn^{2+} ions would both result from changing the ZnO-NPs surface area.

Size and Concentration of ZnO Particles

The concentration and size of ZnO-NPs have a big impact on how antibacterial they are. The fraction of antibacterial activity of ZnO-NPs to their concentration. Similar to how size influences activity, NP concentration also has an impact on this reliance. The greater surface area and higher concentration of ZnO-NPs are thought to be the cause of their antibacterial activity (Zhang et al., 2007). The efficiency of ZnO-NPs' antibacterial activities is increased

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because smaller ZnO-NPs can easily pass because of the size of their interfacial area, across bacterial membranes.

Surface Defects

Surface flaws and surface charges also play significant functions in the mechanism because ZnO-NP surfaces have many edges and corners that could be reactive surface sites. Despite having a straightforward chemical structure, ZnO exhibits extremely complex a chemical flaw, which is connected to its microbiological resistance. ZnO's toxicity is highly impacted by surface imperfections. For example, The antibacterial activity of ZnO-NPs, according to Padmavathy and Vijayaraghavan (2008), is related to membrane damage caused by flaws like edges and corners, which come from the abrasive surface of ZnO. ZnO-NPs can be used in innovative ways by managing the flaws, impurities, and associated charge carriers. The features of the IV and the grain boundary are significantly altered by defects (Schmidt-Mende & MacManus, 2007).

2. CONCLUSIONS

The goal of the current report was to investigate ZnO-NPs' antibacterial activities. ZnO-NPs' bactericidal properties and various influences on the activity were the main topics of discussion. Strong antibacterial results would primarily be attained by enhancing variables such as UV light, ZnO particle size, concentration, shape, and surface modification. These variables affect several different toxicity processes. One of ZnO-NPs' main properties is the production of intracellular ROS formation, which has the potential to result in death. The cell wall is mechanically damaged as a result of Zn2+ ion release and adherence to the cell membrane.

Due to the well-known antibacterial capabilities of ZnO-NPs, a wide range of antimicrobial applications have been initiated. ZnO-NPs has a remarkable stability and a long life when compared to cleaners made of organic materials, which has promoted its use as a bacterial inhibitor. Due to their favorable surface-to-volume ratio and potential for use as novel antibacterial agents, ZnO-NPs have emerged as a promising a potential choice among metal oxides. Due to other distinctive qualities, particularly in the areas of biomedicine and catalysis, ZnO-NP usage are anticipated to rise.

ZnO-NPs have the potential to be an effective alternative to antibiotics as well as a cunning weapon against multidrug-resistant microbes. Through studies and scientific papers, the toxicological impact of ZnO-NPs should be assessed to ascertain the effects of employing these NPs in health-related issues.

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