How to Cite:
Gurtu, G., Sharma, M., & Gargav, P. (2022). A preliminary review on antimicrobial property of zinc-based nanoflakes and its impact on wastewater purification. *International Journal of Health Sciences*, *6*(S1), 3099–3108. https://doi.org/10.53730/ijhs.v6nS1.5331

A Preliminary Review on Antimicrobial Property of Zinc-Based Nanoflakes and its Impact on Wastewater Purification

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***Abstract*---**Decreasing supply and increasing demand are among the factors causing global water scarcity. Existing water disinfection systems have limits, specifically the generation of disinfection by-products, prompting researchers to hunt for alternatives. Zinc oxide, an antibacterial compound used in the pharmaceutical and rubber industries, has aroused researchers' curiosity. Zinc oxide has indicated antimicrobial properties at the nanoscale, indicating broad application possibilities. This paper discusses zinc oxide, its antimicrobial properties, and its potential use in water disinfection.

***Keywords*---**Antimicrobial Property, Zinc Based Nanoflakes, Waste Water Purification.

Introduction

Water is an essential resource for all living things. Water availability and quality are becoming increasingly difficult to maintain as a result of population growth, industrialisation, and the future consequences. Many aspects of human health are affected by poor water quality, which has wide-ranging economic and societal consequences. Water is disinfected by using typical techniques including chlorination, UV light treatment, and ozonation to eliminate microorganisms. But these methods have some limitations. When chlorine is added to water, it can produce harmful disinfection by-products (DBP) that are carcinogenic. Some extremely resistant waterborne pathogens have proven resistance to chlorination. Given that some aquatic bacteria have become resistant to current disinfectants, higher disinfectant dosages are required, resulting in higher levels of DBP [1, a

International Journal of Health Sciences ISSN 2550-6978 E-ISSN 2550-696X © 2022.
Manuscript submitted: 18 Jan 2022, Manuscript revised: 09 Feb 2022, Accepted for publication: 27 March 2022

toxin]. Ozone disinfection produces fewer by-products than chemical disinfection, but it is more expensive and can produce deadly bromate when it combines with bromide ions in water. UV therapy don't require ozone to treat water because it leaves no residue. [2] As a result, it offers limited protection against re-infection. As a result, new ways to disinfection efficacy must be investigated. Developing an antibacterial antibiotic that works against waterborne illnesses is a big job. Due to their limitations, current disinfection methods cannot treat water treated with nanotechnology. Nanomaterials have superior characteristics over bulk materials due to their increased surface area.

Antimicrobial nanoparticles such as zinc oxide have piqued scientists' interest. SPF, protective varnishes, and paint all contain zinc oxide as an ultraviolet light absorber. Use of zinc oxide to suppress germ formation is seen in textiles, surface coatings, cosmetic and cellulose fibres [3-7]. However, nanoscale ZnO applications have revealed new and enhanced usage for this material. Due to its strong activity at small quantities, it has become attractive with some other inorganic oxides, such as titanium dioxide (TiO2) and silver nanoparticles (AgNP). 7 & 8 .ZnO is a powerful antimicrobial agent that is harmless for both people and animals. ZnO, for example, has unparalleled selectivity, durability,and heat resistance [9.] The antimicrobial properties of several microorganisms will be studied. Researchers are studying zinc oxide's production and disinfectant properties for use in water treatment.

Zinc Oxide Nanoparticles

This inorganic substance is practical, strategic, and promising. It is an II-VI semiconductor because O and Zn are in groups 6 and 2 of the cyclic table. ZnO has piezoelectricity and semi-conductivity. Excitation energy (60 meV) and inherent n-type conductivity [10] differentiate it in the near-UV spectrum. Due to these qualities, ZnO is widely used [11]. The broad bandgap of ZnO affects both electrical and optical conductivity. Other metals doped ZnO has prolonged excitonic emission [12-16]. This gives the Zn–O a solid ionic connection. Unlike organic or inorganic materials, it is heat resistant and durable. Nanosized ZnO is a novel antibacterial agent. Besides being antibacterial and antifungal, they are highly catalytic and photochemically active. Zinc oxide is a UV protector [17].

Antimicrobial activity of ZnO

It is the capacity to suppress or eradicate the development of germs in a specific environment that is known as antibacterial properties. Among the metal oxides, ZnO has been found to have powerful antibacterial properties. Furthermore, ZnO is a good choice for antibacterial applications since it can withstand harsh processing conditions.[18].

Mechanisms for antimicrobial activity
Release of ROS

Antimicrobial ZnO nanoparticles release oxygen species from their surfaces, causing bacteria to perish. DNA, cell membranes, proteins can all be damaged by reactive oxygen species (ROS). [19, 20] The ZnO's surface activity causes the entire wall to break, resulting in cell disintegration as well as the discharge of cellular membrane and cell death. Padmavathy and Vijayaraghavan [19] outlined the mechanism in this way:
When exposed to ultraviolet and visible light, zinc oxide (ZnO) emits electron-hole pairs,

$$ZnO + hv \rightarrow e^- + h+$$

The electron-hole pairs in the ZnO suspension broke water molecules into radicals, which were then split again. Radical . OH and H+: $h^+ + H_2O \rightarrow$ radical .OH + H^+

O2 molecules yield superoxide anion:

$$e^- + O_2 \rightarrow \text{radical } .O_2^-$$

To produce HO_2, superoxide anion combines with H^+. radicals:

$$\text{Radical}.O2^- + H^+ \rightarrow HO_2\text{radical.}$$

HO2 is a game changer produces hydrogen peroxide anions by interfering with electrons, and these anions combine with H+ to form hydrogen peroxide particles.:

$$HO_2\text{radical.} + H^+ + e^- \rightarrow H_2O_2$$

By penetrating the bacteria's cell membrane, hydrogen peroxide kills them..

Release of Zn^{2+}

Zn2+ ions that can permeate the cell membrane and damage the cell's internal stuff, are assumed to be responsible for ZnO's antibacterial properties. Toxic effects of nano-ZnO were caused by the bacteria's emission of Zn2+, according to Li et al. [21]. Toxic effects of ZnO nanoparticles on Saccharomyces cerevisiae may be shown to the solubility of Zn2+ ions in the microbe's environment, as per Kasemets et al. [22].

Direct contact of nanoparticles with cell membrane

As perHeinlaan et al. [23], metal oxide particles in the cell do not always cause cell damage. Moreover, the bacterial cell-particle interaction alters the environment within the organism-particle contact area, which is vital. In addition, Brayner et al. [24] found that bacteria's cell walls were damaged and disorganised when exposed to ZnO nanoparticles. In addition to improving membrane permeability, ZnO increased nanoparticle integration into cells.

Other researches on disinfection mechanism

Navale et al. [25] came to the conclusion that the antibacterial action of ZnO was mostly attributable to particulate ZnO, and that the particle sizes was a factor in this activity. According to Zhang et al [26], ZnO possesses disinfectant capabilities with an emphasis on H2O2 production. Assuming that H2O2 played a role in the disinfection process, an H2O2 quencher, catalase, was used during the testing.

Researchers discovered that hydrogen peroxide (H2O2) is not the preferred disinfectant. Speculations link ZnO's antimicrobial activity to its photocatalytic activity. By absorbing UV light, ZnO nanoparticle suspensions can form ROS like H2O2, which promotes bacterial interaction [27]. ROS like H2O2 are phototoxic to bacteria. According to a few studies, exposure to varied illumination conditions, such as natural sunshine, fluorescent lighting, or even full darkness, increases the toxicity of ZnO nanoparticles. The presence of inhibition can exist even when there is no brightness, as will be outlined in the following debates. A modest amount of ultraviolet light, as well as fluorescent illumination, was studied by Jones and colleagues [28] to determine whether ZnO could be triggered by these sources of light. As a result of the research, it was revealed that the biocidal power of ZnO nanoparticles could've been maintained for an extended period of time under ambient laboratory settings, with size of the particles probably controlling this action. The findings also suggested that ZnO could be used as an antimicrobial in visible light.

When comparing ZnO and TiO2, Adams et al. [29] discovered that illumination had no influence on the ZnO’s antibacterial activity. Bacillus subtilis growth was severely decreased by both dark and light circumstances; however, E. coli growth was only minimally affected by ZnO, actually at a low ZnO concentration of 10 parts per million (ppm). Conclusion: Because light is necessary for photocatalytic ROS generation, toxicity to creatures in the dark may be due to oxidative stress, organic radicals generated in the night, and membrane stability degradation mediated by nanomaterial interactions.

Several researchers, including Baruah et al. [30], have studied photocatalysis as a potential water disinfection method. Pollutants are oxidised into carbon dioxide and water using a metal oxide photocatalyst, lowering their toxicity. Upon being exposed to light with an energy greater than the photocatalyst's energy gap, electrons from the valence band are propelled into the conduction band, resulting in positively charged holes remaining in the valence band of the catalyst. It is possible for a hole to form in the valence band or for an electron to form in the conduction band. Microbiological pollutants can be degraded by electrons and ions created by light sources. We conducted a study to investigate the photocatalytic activity of different ZnO levels of salinity that had been infected with the pathogen.

Gondal and colleagues [31] It was discovered that ZnO may be created from Zn(NO3)2 and (NH4)2CO3 with size ranging from 20–40 nm by combining these two elements. The smaller particle size and the impact of quantum confinement, due to which the ZnOgot activated and led it to produce reactive oxygen species, were responsible for the increased photocatalytic efficacy (ROS).

Factors affecting the antimicrobial activity

Nanoparticles have a strong antimicrobial effect. No effect of ZnO metal oxide on microbial nanoparticleinternalisation. Two factors a) nanoparticle properties; b) bacterium species The microenvironment of nanoparticles can kill bacteria [32, 33].

Disinfection of water with ZnO

Disinfection by nanomaterials

The most dangerous waterborne pathogens are bacteria, viruses, and fungi. Chlorination and ozonation are encountering new problems. These resistant microorganisms produce DBP such as bromates and trihalomethanes,(Ineffective treatment) [34]. In contrast to conventional materials, in contrast to conventional materials, nanoparticles are not potent oxidants and therefore do not contribute to DBP degeneration. So much can be done to improve current therapy methods [35]. Nanotechnology can help treat water and wastewater. It's being tested as a water purification material for nanoparticles [36]. Antimicrobial nanoparticles assault bacterial cells in a variety of ways. Currently, AgNP nanoparticles outnumber TiO_2 and ZnO. Their microbial control applications include household appliances,medical gadgets, and H_2O. The silver ions Ag^+ generated by AgNP may lead to oxidative stress in bacteria that produce reactive oxygen species (ROS). When UV light hits another well-studied nanomaterial, TiO_2, it produces reactive oxygen species (ROS) [8].

Difficulties in applying zinc oxide for water purification on a broad scale

It is necessary to consider treated wastewater on a large scale. This is true regardless of whether ZnO disinfection is the key piece or whether other techniques are employed.

Stability of ZnO in water

Due to the possibility of removing nanoparticles from water treatment plants in the future, their water stability is crucial. If commercial nanoparticles can be removed by water treatment, Fe_2O_3, ZnO nanoparticles were examined by Zhang et al. Ultrasound or chemical dispersants are unable to break up water nanoparticles in their natural state. Aspiration eliminates less than 80% of the material. This research investigates the physical features and interconnections of metal oxide nanoparticles in H_2O. According to one group of experts, metal oxide nanoparticles aggregated and settled in purified H_2O.Aquatic nanoparticle ultrasonic dispersion Water temperature affects nanoparticle stability, researchers discovered. In lake and wastewater samples, humic acids and surfactants hampered aggregate formation. According to Li et al [39] Water chemistry affects ZnO nanoparticle toxicity.

ZnO nanoparticles and their use in wastewater treatment are discussed in detail

S. No	Year	Characteristics	References
1.	2010	Antimicrobial Activity: *Escherichia coli:30 nm particle size 30 min and 2h EC50, mg compound l-1 bZnO toxicity for E. coli AB1157, E. coli JI130, E. coli JI131, E. coli AS393, E. coli JI132 = 43 6.9, E. coli AS391 = 16 6.1*	40
2.	2011	Antimicrobial Activity: *Pseudomonas aeruginosa, Staphylococcus aureus* and *Escherichia coli:*Particle size: 25 nm. Gram-positive Staphylococcus aureus was more affected than Gram-negative Pseudomonas aeruginosa and Escherichia coli.	41
3.	2013	Antimicrobial activity: pH 5.7 to 8.7 had no effect. Bacterial mortality dropped from 90%–20% at pH 8.7.	42
4.	2015	Antimicrobial Activity: 86 nm average particle The optimum removal rate was 78%.	43
5.	2015	Antimicrobial Activity: At 2.0 wt% loading, ZnO nanoparticles inhibited the development of Bacillus subtilis and Escherichia coli.	44
6.	2017	Adsorption: Pb(II): Pseudo-second-order model with endothermic absorption was seen at pH 5 at removal rate of 95%	45
7.	2018	Adsorption: As(III): Adsorption was pseudo-second-order. Maximum clearance 52.63 mg/g at pH 7. Endothermic adsorption Best suited isothermal Langmuir model.	46
8.	2018	Adsorption: RB19 and AB210 dyes: 12 nm average. Adsorption equilibrium takes 15 minutes. It worked well at pH 3. Both stains were P2nd. It best matched the experimental results. Adsorption capabilities of 38.02 mg/g RB19 and 34.13 mg/g AB210.	47
9.	2019	Adsorption: Cr(VI): Particle size: 31 nm. In this more absorption was seen as it started to fll based on pH.Adsorption capacity max 139.47 mg/g monolayer at 50°	48
10.	2019	Adsorption: Azo dyes: ZnO-NPs at pH 6 eliminated each colour (40 ppm). It best matched the experimental results. Pseudo-second order adsorption	49
11.	2019	Adsorption: Arsenic (As(V)): At neutral pH, particles are 7 nm broad and 80 nm long (7).Best suited isothermal Langmuir model.	50

Retention and reuse

Antimicrobial nanomaterial dispersion and retention issues. This is necessary if nanomaterials escape the water system and end up in the water supply. On hazard, though, is They aggregate in water. The upstream separation phase is usually membrane filtration or flocculation. Immobilising nanomaterials in resins and membranes can improve retention. Including reactor and filter membranes. Lessening therapeutic efficacy of current immobilisation procedures necess Nanoparticles can be used to safeguard the environment [51, 52].

Conclusion

Decades of research show that ZnO is a potent antibacterial agent that can kill a wide range of bacteria. Aquatic disinfection with Zinc Oxide (ZnO) is promising Conventional water treatment procedures have drawbacks, chief among which is the creation of DBP. ZnO as an antibacterial agent still needs to be improved in many ways. Future growth will face technical, economic, and societal challenges. Converting ZnO to a cost-effective water treatment method is a difficulty. Its promise as an industrial water disinfectant is evident despite the numerous unexplored areas.

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