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Current Advancement of Nanotechnology for Wastewater Treatments Through Zinc Oxide Nanoparticles

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Abstract **Review Article**

The dilemma of environmental pollution has become a hot issue in today's world. Globalization, industrialization, population growth, and other processes are major factors for Environmental pollution, especially water with highly toxic chemicals, heavy metals, organic contaminants, pathogenic microorganisms, and other different pollutants are major problems all over the world. Due to increased pollution of water resources, the provision of clean and safe drinking water is becoming a challenge, and that exacerbates the shortage of clean water for drinking and other domestic purposes all over the globe. Pollution levels are growing day by day, and innovative technologies are mandatory to tackle the problem. Nanotechnology offers several benefits for enhancing present environmental technologies and developing new ones that are superior to the state of the art. Nanotechnology is the intentional manufacturing or manipulation of a substance at less than 100 nm scale size, whereby this technology enables the manufacture of material-device structures with one-dimensional lengths to realize singular material-device phenomena at those lengths, since a higher reactivity ratio would mean a high volume that increases the activity. Zinc oxide nanoparticles have attracted much interest in recent years because of their diversified technological applications in photonic crystals with tunable band gaps through photocatalysis and many other special features that have the capabilities to remove diversified organic pollutants, heavy metals, and pathogenic microorganisms the way for wastewater treatments, detection of contaminants, and prevention of water pollution.

Keywords: *Nanotechnology, Nanomaterials, Water pollution, Water treatments, Zinc oxide*.

1. INTRODUCTION

Nowadays, pollution is happening on an unprecedented scale all over the world. Environmental pollution is growing day by day due to the increase in population, urbanization, and industrialization, which considerably increases the discharge of waste to the environment, predominantly water, becoming a major global concern today (Zhang *et al*., 2010). We can say that we live in a world of waste because of population growth and the production of waste amounts, which makes a significant amount and increasingly degrades the environment. Every day, an enormous amount of garbage is created in both rural and urban locations, including in agricultural areas (Suad, 2015).

Water is an indispensable resource needed to secure all forms of life, food production, economic development, and quality of life in general. Their uses cannot be substituted because it is truly a unique gift to mankind from nature. Reliable and sustainable access to clean, safe, and affordable water is essential for human beings. However, we are far from meeting the demands; this problem will increase with time. Approximately one-sixth of the world's population suffers from access to clean drinking water (UNWWAP, 2015). Nowadays, overpopulation, limited water resources; pollution, and lack of water sustainability are considered the most common difficulties facing human needs. The long-term development of the global water situation is closely connected to the rise in global population and global climate change (WHO, 2014)

Extensive industrialization, as well as intensive agricultural activities, being carried out globally in both urban and rural areas, which lead to the release of an extraordinary number of contaminants into the environment, can pollute water. The industrial pollutants along with household waste, agricultural waste, and urban runoff, are contaminating rivers and making it difficult for conventional water treatment to remove all the pollutants. These pollutants can impact the quality of rivers, the lives of aquatic animals, and human health through the consumption of water (Dalzochio *et al.*, 2018). Organic matter, heavy metals, industrial effluents, sewage, and pathogenic microorganisms are just a few examples of the many concerning contaminants of water. Therefore, an urgent need is required to develop innovative technology to provide clean and affordable water to meet human needs (Das *et al.*, 2015).

Nanotechnology is an immense field, which promises great prospects and advancements in wastewater purification, guaranteeing better treatment efficiency whereby quality water supply can be provided to humans. Nanotechnology is the creation, testing, existence, and use of structures, tools, and systems through the manipulation of their dimensions at the nanoscale (Khan *et al*., 2021). Nanoparticles are atomic or molecular aggregates with dimensions from 1 and 100 nm and exhibit new size-dependent properties. It provides a high surface area for the NPs, advanced membrane technologies, and catalytic properties of some nanomaterials used in toxic metal ion removal, pathogenic microbes, and organic pollutants from wastewater (Crane *et al.*, 2012).

ZnO NPs have attracted much interest in recent years from other nanomaterials because of their diversified technological applications. For photocatalytic removal of organic pollutants, ZnO is a superior alternative to other NPs due to the comparable band gap, i.e., 3.37 eV (Liu *et al*., 2017). It has a higher quantum yield for peroxide production, larger photocatalytic efficiencies and the ability to oxidize and reduce to remove heavy metals and release peroxide radicals which destroy microorganisms' detection of different pollutants and prevent water pollution (Dhiman *et al*., 2012). The goal of this review is to provide a general overview of the recent advances in the development of nanotechnology for wastewater treatment through functional zinc oxide nanoparticles.

2. CURRENT PROGRESS OF WASTEWATER TREATMENT THROUGH ZINC OXIDE NANOPARTICLES

Water is the most essential compound on the Earth for human activities. Providing clean water is the prime requirement of human beings for their better health. Water pollution is increasing worldwide due to the rapid growth of industry, increased human population, and domestic and agricultural activities. It brings about life-threatening diseases (Pragnesh *et al*., 2010). Pollutants from residential, commercial, and industrial areas and agricultural practices are the major water contamination causes, which results in organic, heavy metals, pathogenic, and non-pathogenic microorganisms as contaminants, which convert fresh water to wastewater (Sushma and Richa, 2015).

Wastewater treatment is an important process to treat polluted water into fresh or safe water that is usable for living life purposes. Available water treatment technologies have reached their limits regarding the demands of both humans and the environment; in this respect, nanotechnology is suitable for the detection and removal of various kinds of pollutants. ZnO NPs can remediate and purify, detect, sense, and prevent water pollution (Kumar *et al.*, 2014). Treatment of drinking water is currently being carried out through physical and chemical techniques like chlorination, ozonation, UV treatment, etc. Each of the conventional water disinfection processes has limitations, generating concerns about their mass-scale application (Baruah and Dutta, 2009). Existing wastewater treatment technologies demand a high capital investment of operation and maintenance costs, and large areas. Cost-effective treatment of pollutants requires the transformation of hazardous substances into benign forms and the subsequent development of effective risk management strategies for the harmful effects of pollutants that are highly toxic, persistent, and difficult to treat (Baruah *et al*., 2012). The application of ZnO NPs has been gaining increasing interest in the area of wastewater treatment options that might include the removal of the finest contaminants from water (< 300 nm) and "smart materials" or "reactive surface coatings" with engineered specificity to certain pollutants that destroy, transform, or immobilize and detoxify toxic compounds (Eloisa *et al*., 2019).

2.1. Photocatalysis of zinc oxide to remove organic pollutants from wastewater

A photocatalyst comes from the word photo, which means light, and catalyst, which refers to a substrate that accelerates chemical reactions by absorbing photons, or light (Mahesan *et al*., 2019). It is an advanced oxidation process were semiconductors, upon absorption of photons, act as catalysts producing highly reactive radicals. These are mainly hydroxyl radicals, which can oxidize and decompose organic compounds and be employed in wastewater treatments (Gehrke *et al.*, 2015). Intensive research over the past decade for its implementation in the purification of drinking water can be found, and the efficiency of photocatalysis in the detoxification of a wide range of industrial and agricultural effluents of separate pollutants was documented (Oller *et al*., 2011). However, it has different side effects, and nowadays NPs of ZnO can solve these problems. These NPs have the advantages of being readily available, inexpensive, and low in toxicity, and they offer a high surface-to-volume ratio, allowing higher adsorption of the target molecules. Photocatalysis, using NPs of ZnO, can be an attractive way of water purification as it is capable of removing chemical as well as biological contaminants used for water treatment (Baruah *et al*., 2012). ZnO NPs are activated by light and thus frequently studied for their ability to remove organic contaminants from various media. Pollutants are destroyed by photocatalysis of ZnO; use in aqueous solutions is primarily made easier by many hydroxylation processes started by hydroxyl radicals (•OH).

Possible modes of radicals' generation during ZnO photocatalysis: The ZnO semiconductor photocatalyst forms electron-hole pairs when exposed to UV light. Positive charges, such as holes, interacting with water molecules result in •OH and H^+ ions. Electrons in conjunction create superoxide ions with dissolved oxygen (O_2•–), which react with water molecules to produce hydroxide ions (OH-) and peroxide radicals (•OOH). Radicals from peroxide react with H^+ ions to form (•OH) and OH-, and holes oxidize OH- to •OH. As a result, all species eventually promote the production of •OH, and these radicals target the contaminants present in the aqueous solution, and the biodegradability of heavily decomposable substances can be increased in a pretreatment step (Medana *et al*., 2017). The fundamental process during photocatalysis begins with the absorption of a photon (h*v*).

$$ZnO + h\nu \longrightarrow e^- + h^+$$

Oxygen reacted with electrons and released superoxide ions (O_2•–)

$$O_2 + e^-_{(CB)} \longrightarrow O_2^-$$

The electron-hole pairs split water molecules from the ZnO suspension into •OH and H+:

$$h^+_{(VB)} + H_2O \longrightarrow HO. + H^+$$

$$.OH + .OH \longrightarrow H_2O_2$$

$$O_2^{-\cdot} + H_2O_2 \longrightarrow .OH + HO^- + O_2$$

$$O_2^{-\cdot} + H^+ \longrightarrow .OOH$$

$$.OH + \text{Organic matter} + O_2 \longrightarrow CO_2 + H_2O$$

Generally, Photocatalysts can produce hydroxyl radicals (OH•) and superoxide (•O2) which are scavenger radicals created when the photocatalyst makes contact with water. These scavenger radicals nonselectively attack organic contaminants and reduce their size to less dangerous compounds (Low *et al*., 2017).

2.2. Nanoparticles of zinc oxide for removal of heavy metals from wastewater

Having big toxicity properties, most of the heavy metals and some ions create real damage in humans and ecosystems. Due to inefficient methods of removing the heavy metals from water and nanosized ZnO, it is an important adsorbent according to Vilardi et al. (2018). Nowadays, ZnO NPs are chosen due to their low cost and good performance in photocatalytic issues of heavy metal removal.

The photocatalytic reaction of the ZnO particles can also be excited by UV and visible light in the removal of ions from heavy metals in an aqueous solution (Jinyue *et al*., 2019). In addition to its photocatalysis, ZnO consists of many functional groups that can operate as locations that are active in the adsorption and absorption of positively charged ions, including hydroxyl groups, and it possesses a variety of nanostructures such as nanowires, nanospheres, nanorods, and porous thin films, which have special features to remove heavy metals (Khezami *et al.*, 2016). When the light source is turned on for the photocatalytic reaction, these heavy metal ions are removed from the solution by depositing onto the surface of ZnO particles, resulting in the formation of metal/metal oxide-coupled ZnO hybrid particles. ZnO NPs remove heavy metals by two types of mechanisms: physical adsorption and reduction/oxidation by photogenerated electron-hole pairs. However, the removal efficiency for different heavy metals is different, regardless of the types of light sources. Further technology advancement is needed to solve these problems (Hua *et al.*, 2012).

2.2.1 Physical adsorption

ZnO NPs are negatively charged, so the negatively charged surface of ZnO particles contributed by the OH^- groups during the photocatalysis process, and these OH^- groups became the actively adsorptive sites (Thein *et al.*, 2011). On the exterior of the surface of ZnO particles, the cationic species of the heavy metal water-based solution had a propensity to react with OH- groups to produce a thin coating. However, the adsorption process is limited by the number of negative adsorptive sites on the surface of ZnO particles; the adsorption efficiency is usually poor and might reach a saturation level after some time (Wang *et al.*, 2010).

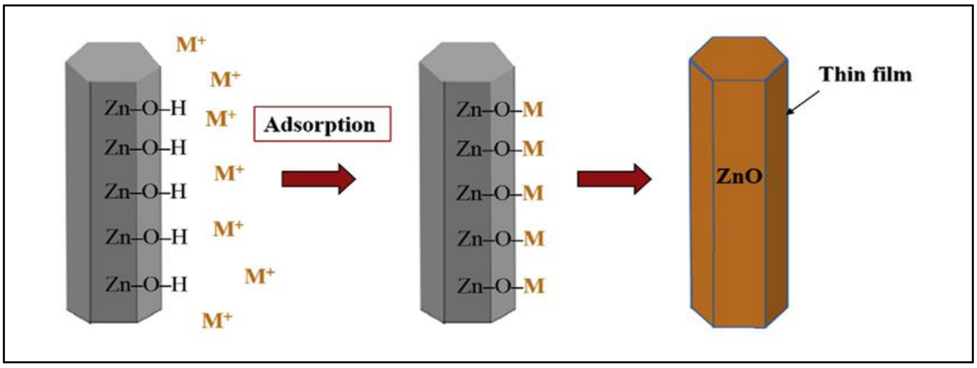

Figure 1: Mechanisms for removing heavy metal ions with ZnO particles via adsorption (Matsuda and Litter, 2015)

2.2.2. Reduction/oxidation by photogenerated electron-hole pairs

Semiconductors can absorb light with energy higher than certain energy thresholds that are determined by the band gaps of semiconductors. Once photons are absorbed, photoelectrons and photoholes are formed. The photogenerated electrons and holes quickly relax to the bottom of the conduction band and the top of the valence band, respectively, by dissipating their kinetic energy. These electrons and holes can drive a redox reaction (Tang *et al*., 2008). Thermodynamically, the energy level border of the conduction band is a measure of the reduction strength of electrons in the semiconductor, whereas that of the valence band edge is a measure of the oxidation power of holes in the semiconductor (Smith *et al.*, 2015). The reduction happened when the redox potential of the metal was positive in comparison to the $e\text{-}_{CB}$ level of ZnO particles. The oxidation of metal ions selectively occurs when the oxidation potential is less positive than the h_{VB}^{+} level (Anh *et al*., 2019). When a suitable optical excitation source is used, a large number of electrons and holes can be constantly produced to reduce or oxidize metal ions. Thus, the metal/metal oxides could be present on the surface of ZnO particles as a thin layer or as particles that either deposited onto the surface of ZnO particles or in the solution. In brief, the ions of heavy metals removed by ZnO particles, either by one of the above-mentioned mechanisms or combined mechanisms, depend on the types of metal ions and types of light sources (Matsuda and Litter, 2015).

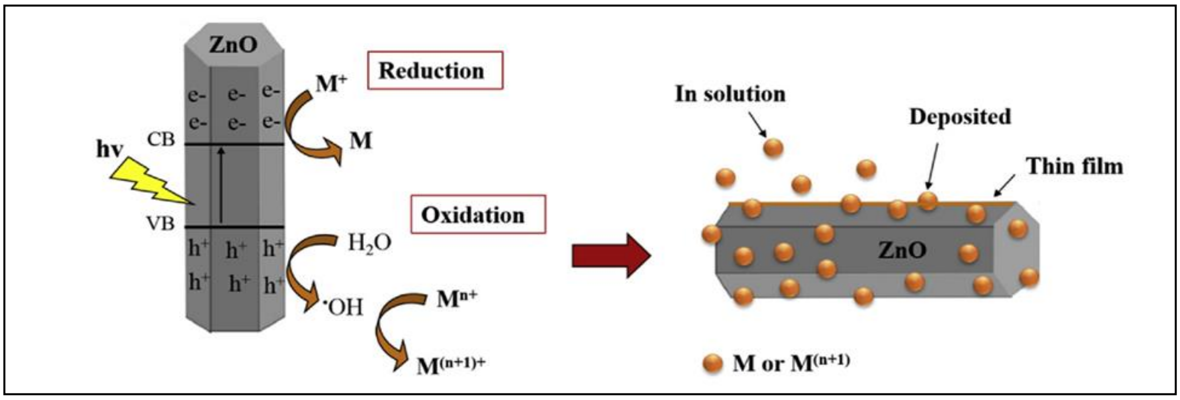

Figure 2: Mechanisms for removing heavy metal ions with ZnO particles via a reduction/oxidation process (Matsuda and Litter, 2015)

2.3. Water Disinfection with Antimicrobial Zinc Oxide Nanoparticles

Research conducted during the recent decades to treat wastewater, however, discloses a dilemma between effective disinfection and the formation of harmful DBPs. The commonly used chemical and physical disinfectants in the water industry are chlorine, chloramines, and ozone. They can react with other constituents in the water and generate harmful DBPs; most are carcinogenic. A UV disinfection process has come out as an alternative to oxidative disinfection since it generates fewer DBPs (Baruah *et al*., 2009). All these limitations urge the development of alternative methods that can enhance the robustness of disinfection while avoiding DBP formation.

The current disinfection methods for the treatment of drinking water can effectively control microbial pathogens. The ideal disinfectant is ZnO NPs because it has the following properties: very broad, instantaneous antibacterial activity at ambient temperature; cannot produce any negative byproducts both during and after use; does not affect human health; is inexpensive; is easy to apply for the intended use; is easy to store; is highly soluble in water; is not corrosive for any equipment or surface; and is amenable to safe disposal (Husain *et al*., 2014).

2.3.1 Antimicrobial Action of zinc oxide particles at the nanoscale

Zinc is a vital nutrient that plays a significant role in the growth, development, and well-being of mammals (Osredkar and Sustar, 2011). On the nanoscale, ZnO has antimicrobial effects and is frequently for food preservation, manufacturing stability, and increasing the duration of products. The mechanism of antimicrobial action is attributed to be from electrostatic interaction with the membrane, reactive oxygen species, and/or release of ions (Rahman *et al.*, 2017).

The attachment of the NPs to the membrane of the bacteria is a vital first step for ZnO antibacterial mechanisms. Once the ZnO NPs attach to the membrane of the bacteria, “pitting” occurs in the membrane due to ROS formation, which fatally damages the cell (Franklin *et al.*, 2007).

ZnO has optical characteristics which is a semiconductor with a wide band gap (3.37 eV), causing sensitivity to short wavelengths. Upon light exposure, electron-hole pairs are created on the surface of ZnO. These holes split water molecules and cause ROS formation, specifically OH^-, H_2O_2, and O_2^{2-}. Once formed, hydrogen peroxide can enter the cell and destroy various organelles. In addition, lipid peroxidation can occur on the bacterial membrane, weakening membrane integrity and promoting cell lysis (Xia *et al.*, 2008).

2.3.2 Release of reactive oxygen species

An alternative mechanism by which NPs kill bacteria is through the production of ROS or oxygen-free radicals like hydrogen peroxide or superoxide anions. The generation of ROS is induced by the NPs themselves (Tay *et al.*, 2014). The antimicrobial activity NPs of the ZnO NPs involves the release of oxygen species from the ZnO surface, which causes fatal damage to microorganisms. ROS are known to cause oxidative stress by damaging DNA, cell membranes, and cellular proteins. The rupture of the cell wall results from the surface activity of ZnO, which causes the decomposition cellular wall and subsequently the cell membrane, the leakage of cell contents, and eventually cell death (Vijayaraghavan, 2012).

ROS leads to severe oxidative stress and damage to the cell's macromolecules which overall cause lipid peroxidation, alteration of proteins, inhibition of enzymes, and RNA/DNA damage. This severe oxidative stress can also form holes or pits within the bacterial membrane, causing cell lysis (Nathan and Cunningham-Bussel, 2013)

Mechanisms are presented as follows:

ZnO is activated by UV and visible light to form electron-hole pairs:

$$ZnO + h\nu \longrightarrow e^- + h^+$$

The electron-hole pairs split water molecules from ZnO suspension into •OH and H+:

$$h^+ + H_2O \longrightarrow {}^{\cdot}OH + H^+$$

O_2 molecules yield superoxide anion:

$$e^- + O_2 \longrightarrow {}^{\cdot}O_2^-$$

Superoxide anion reacts with H^+ to generate HO_2 • radicals.

$${}^{\cdot}O_2^- + H^+ \longrightarrow HO_2^{\cdot}$$

HO_2• interferes with electrons, generating hydrogen peroxide anions which react with H+ to

Produce hydrogen peroxide molecules: (Padmavathy and Vijayaraghavan, 2008).

$$HO_2^{\cdot} + H^+ + e^- \longrightarrow H_2O_2$$

The hydrogen peroxide can enter cellular membranes and kill the bacteria.

2.3.3 Release of zinc ions

Another possible mechanism for the ZnO antibacterial activity is the release of Zn^{2+} ions, which can damage the membrane of the cell penetrate the intracellular contents, and bind to cytosolic proteins, such as enzymes and DNA (Dimapilis *et al.*, 2017). This interaction leads to decreased function, inhibiting respiratory and metabolic pathways and ATP production. These ions bind to enzymes within the respiratory chain, as well as DNA, inhibiting replication and division. In addition to that, others interact with DNA by up-regulating genes within the cell. This results in decreased membrane integrity and a buildup of ROS within the cytosol of the cell (Cai *et al.*, 2019).

2.3.4 Direct interaction between nanoparticles and cell membrane

The beginning of the metal oxide particles into the cell does not always lead to cell damage. More important is the contact between each bacterial cell particle, which causes changes in the microenvironment within the contact area of the organism and particle. Contact with ZnO NPs damaged and disorganized bacterial cell walls damaged and disorganized. The abrasive ZnO caused increased membrane permeability leading to subsequent cellular internalization of the NPs (Heinlaan *et al.*, 2008). Due to the breaking of the cell barrier, an abundant amount of water from the cytosol is released. Cells try to compensate for this loss through the bacteria's proton efflux pumps and electron transport. However, the high demand for these ions causes severe damage to these Trans membrane systems. Overall, this imbalance of ions and membrane stability results in impaired respiration, interruption of energy transduction, and eventually cell death (Pelgrift and Friedman, 2013).

2.4. Nanoparticle zinc oxide for sensors and detectors of Water Pollution

Nanosensors are any biological or chemical sensors used to convey information to the macroscopic world. Nanoparticles, the development of sensitive and targeted pollutant detectors has utilized sensors with optical characteristics. Single cells or even atoms are detectable by Nanosensors, making them far more sensitive than with larger components. Nanosensors for the detection of contaminants and pathogens can improve health, maintain a safe food and water supply, and allow for the use of otherwise unusable water sources. Such sensors prove valuable for water quality monitoring (Mohan *et al.*, 2015).

NPs sensor development has received a lot of research attention in recent years, since they combine the general merits of electronic sensors, like speed, size, and system integration, with the semiconductors, such as low-cost production, facile integration with flexible substrates, and biocompatibility (Lin and Yan, 2012). Therefore, an authentic means for the effective recognition of harmful chemicals by using chemical and biological sensors is in urgent need of present. ZnO-based sensors have gained extensive attention around the world. The presence of a good response rate towards chemical toxins with outstanding selectivity and sensitivity makes it one of the most significant materials for preparing low-cost sensors (Raza and Ahmad, 2018).

The presence of high surface area, ZnO NPs contender for creating practical biological and chemical sensors for a variety of moieties due to their biocompatibility, thermal stability, broadband gap, and better reactivity concerning the photoelectric reaction (Guo *et al*., 2014). They are particularly adsorption effective for hazardous analytes on the external aspect of particles because of their small size range and wide fluctuations in the ratio of surface to volume. ZnO's larger surface area has also given the analytes more surface-active sites to bind (Zhang *et al*., 2013). ZnO is biocompatible, and it is a (bio) chemical sensor, which is a tool that transforms the chemical information related to the composition and/or concentration of a specific analyte into an analytically valuable signal. The chemical information here might come from the chemical reaction of the analyte or a physical process occurring in the investigated system. Generally, (bio) chemical sensors contain two functional units: a receptor and a transducer. The receptor unit is responsible for a chemical information transformation to a certain form of energy, which can then be recognized by a transducer. The transducer is a device capable of transforming electrical energy into measurable analytical signals (Long *et al.*, 2013).

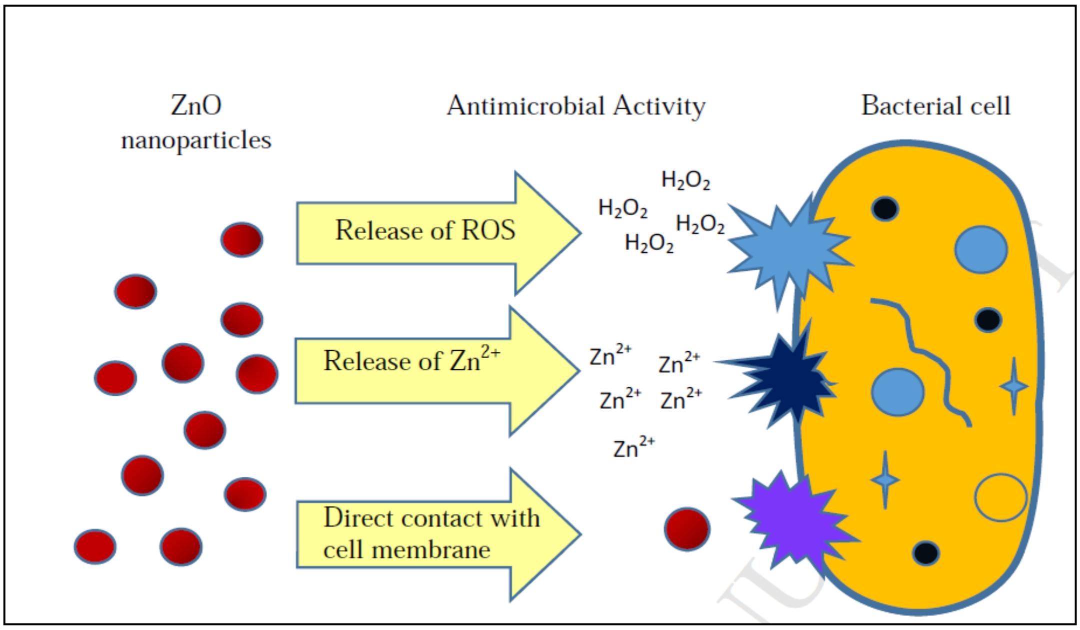

Figure 3: ZnO disinfection mechanisms (Dimapilis *et al.*, 2017)

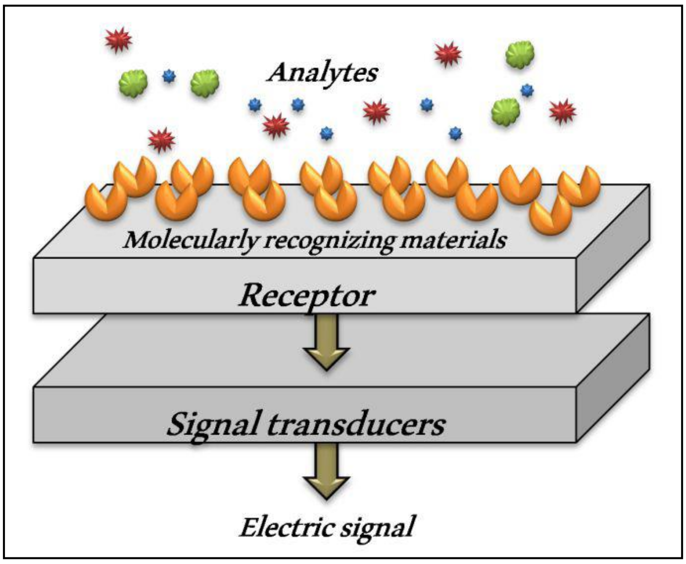

Figure 4: Diagrammatic representation of the components of chemical (bio) sensors (Long et al., 2013).

Biosensors are measurement devices combined with the bio-recognition element of ZnO ensuring high affinity and specificity to the targeted molecule. The most popular biomolecules used for biosensor design are antibodies, oligonucleotides, enzymes, and cells, which are compatible with NPs ZnO. As opposed to that, Chemical sensors of ZnO material interact with different contaminants via its adsorption or absorption and many other processes. These sensors exploit the electromagnetic waves to gain important information concerning the molecular structure and thus their identification (Eltzov *et al.*, 2013).

2.5. Nanoparticles of zinc oxide for water pollution prevention

Prevention of pollution refers to a reduction in pollution sources and other practices that utilize raw materials, energy, utilities, and other resources effectively to reduce or eliminate waste generation. ZnO NPs provide a variety of creative methods to decrease waste output in many operations, including streamlining manufacturing procedures and minimizing dangerous chemicals, implementing conservation techniques, and reusing materials rather than dumping them into the trash (Mohamed, 2017). Different materials are applied in the manufacturing industry and have different negative effects on our ecosystems. ZnO has interesting features to substitute these hazardous materials, and ZnO prevents water pollution by optimizing the different stages of the process. Products that are less toxic, less polluting, and wear-resistant; Processes that are more efficient and waste-reducing; Energy and Resource Efficiency–processes or products that use less energy and fewer raw materials because of greater efficiency (Pandey and Fulekar, 2012).

3. REGENERATION OF NANOPARTICLES OF ZINC OXIDE AFTER THE TREATMENT OF WASTEWATER

Regeneration of NPs in water purification is among the crucial aspects since it controls the economy of water treatment technology. NPs of ZnO photocatalysis efficiently degrade both chemical and biological contaminants. However, it should remove these NPs after the treatment. ZnO nano adsorbents can be regenerated by changing the solution pH. The zeroth point of charge for ZnO NPs is pH 9.3, where aggregation is at a maximum. Above pH 9.3, ZnO NPs partially aggregate with a net negative charge, and below pH 9.3, they partially aggregate with a net positive charge (Omar *et al.*, 2014). In addition to this, ZnO NPs have magnetic properties and can be regenerated and separated easily from the aqueous solution after treatment by adding a magnetic field. They could also immobilize nanoparticles in the context of treatment or using a separation device. However, in some cases, the adsorbing capacity is reduced after regeneration because of the emergence of aggregates by van der Waals and other forces, and in the coming years, other technological advancements should be conducted to alleviate these limitations (Qu *et al.*, 2013).

4. CHALLENGE AND FUTURE PROSPECTS OF NANOPARTICLES OF ZINC OXIDE IN THE WAY OF WASTEWATER TREATMENT

There is a significant need for novel advanced wastewater treatment technologies, in particular, to ensure high-quality drinking water, eliminate micropollutants, and intensify industrial production processes via means of flexible and adjustable water treatment systems. Wastewater-treatment processes by nanotechnology show great promise, and Nano-engineered ZnO materials offer the potential for novel wastewater treatment technologies that can be easily adapted to customer-specific applications. However, there are still several drawbacks that have to be negotiated. Materials functionalized with NPs incorporated or deposited on their surface have risk potential since NPs might be released and emitted to the environment, where they can accumulate for long periods. Therefore, significant research is necessary before scalable it. Their commercialization is challenging; we need to overcome many technical hurdles and make them cost-effective and safe. Research is needed before the full-scale operation of ZnO for treating natural and wastewater. Studies should be conducted under realistic conditions to assess the efficiency of available nanotechnology to validate ZnO NPs for remediating mixed pollutants and use them for decentralized treatment systems.

5. CONCLUSION

In an ever-increasing field of development, environmental pollution, mainly water becoming a serious issue. Today, we need water purification technologies that provide clean and safe water by removing pollutants and intensifying the different processes. There are immense demands for new technologies that can advance the cleanliness and consistency of water, whether for human consumption or agricultural and industrial applications. To combat such pollution, nanotechnology has emerged as a powerful tool to make the environment clean. Nanotechnology provides unique properties of NPs that are ideal candidates for developing rapid water-treatment technology. NPs of ZnO eliminate metal ions, organic pollutants, and pathogenic microorganisms. In addition to these, it can detect, sense, and prevent water pollution. For this accomplishment, ZnO NPs will have the ability to remediate mixed pollutants and their performance should be evaluated.

LIST OF ABBREVIATIONS

CB: Conduction band
DBPs: Disinfection By-products
eV: Electron volt
NPs: Nanoparticles
ROS: Reactive oxygen species
UV: Ultraviolet
VB: Valence band
ZnO: zinc oxide

DECLARATION

We declare that the manuscript entitled: Current Advancement of Nanotechnology for Wastewater Treatments through Zinc Oxide Nanoparticles is our original work at the University of Gondar, Institute of Biotechnology, under the guidance of the corresponding Author, Mr. Mulu Muche.

This manuscript contains no material that has been submitted previously, in whole or in part, which signifies the manuscript is our work only. All sources of material used for the manuscript have been duly acknowledged.

DATA AVAILABILITY

The materials and information used to write this review article are accessible from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this document.

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