

SYNTHESIS OF METAL-OXIDE NANOPARTICLES AND ITS APPLICATIONS IN VARIOUS FIELDS

Abstract

Metal oxides are the versatile material and it is one of the cheapest resources from the earth crust. It is effective towards many applications (i.e) catalysis, energy storage etc., Remarkable applications of metal oxides like TiO_2 are highly active towards photochemical activities especially with dye degradation of polluted water resources. Moreover Transition metal oxides owing to develop monolayer over surface of the materials which induces the activity of the material. Similarly metal oxides are also observed as the good inhibitor for the corrosion process. It has been extensively studied with variety of metals and materials. In this current chapter, the various metal oxides have been discussed for the applications of inhibition process.

Keywords: Metal oxide, Corrosion Inhibition, Catalyst, Photochemical degradation.

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I. INTRODUCTION

The metal oxides are capable of existing in nano structures. This kind of a property is an asset for many growing industries. Especially metal oxide nano particles deal with the applications like environmental remediation, water treatment, medical technology and personal care products [3]. Moreover it also exhibits the unique properties like optical, electronic and magnetic. Oxides of transition metals possess the semiconducting behavior, which have the applications in catalysis, magnetic storage media, solar energy transformation and electronics. To synthesize metal oxide particles with desired characteristics various methods are available. However some of the methods are costly, hazardous. The following is a list of numerous techniques (Fig. 1) [15], frequently used to create metal oxides: Hydrothermal/Solvothermal process, Sol-gel method substance precipitation, Thermochemical degradation, the use of templates in synthesis, Spray pyrolysis, the microemulsion method, combustion synthesis, electrochemical synthesis, and green synthesis [4], Synthesis using mechanical energy Solvothermal reduction, the hydrolysis process, and the coprecipitation method, Pulsed laser etching, Solvent thermal synthesis, microwave-assisted synthesis, and ultrasonic-assisted synthesis procedures for coating and deposition (CVD, PVD), burning synthesis using supercritical fluids photochemical creation, way of reducing hydrogen, reaction in the solid state [1]. Based on the desired metal oxide nanoparticle characteristics, production scale, and particular application needs, one of these processes may be favored over the others. It's possible that there have been more advancement was observed in the area of metal oxide production. It can give us a sense of certain cutting-edge techniques that were becoming popular around this research. Due to their adaptable qualities, metal oxides are used in a variety of industries. They play crucial roles in semiconductor devices in electronics, from silicon dioxide's insulating function to zinc oxide's use in LEDs. Metal oxide compounds, such as lithium iron phosphate in secure lithium-ion batteries and cuprate superconductors for effective energy transfer, are useful for energy storage and conversion. Metal oxides play a crucial role in the catalysts that power industrial processes, such as vanadium pentoxide in the creation of sulfuric acid. They serve as the foundation for materials used in construction and insulation in glass and ceramics. Metal oxide nanoparticles' distinctive features also apply to the medical field, where they allow for tailored drug delivery and diagnostic imaging. In addition, metal oxides are crucial for devices that reduce pollution and detect gas emissions. These uses highlight the importance of metal oxides in defining contemporary technology breakthroughs and innovations. Metal oxides have recently advanced technology by finding new, creative applications. Metal oxide nanoparticles are being used in nanomedicine for better imaging methods and tailored drug administration. Because of their special physicochemical characteristics, medicinal substances can be released into the body in a regulated manner, reducing adverse effects and increasing treatment effectiveness. Furthermore, by acting as contrast agents in cutting-edge imaging techniques, these nanoparticles enable high-resolution observation of biological structures and disease indicators. Metal oxide-based photocatalysts have gained popularity in the field of environmental sustainability for their use in air and water purification [12]. Materials like titanium dioxide, in particular, have remarkable photocatalytic activity, which degrades pollutants when exposed to natural or artificial light. The improvement of global air quality and wastewater treatment could both be revolutionized by this metaloxides. These new uses highlight the metal oxides' ongoing development, demonstrating their versatility and importance in solving difficult problems across numerous fields.

II. SYNTHESIS OF METAL OXIDE NANOPARTICLES

- 1. Green Synthesis:** Metal oxide nanoparticle synthesis using natural resources like plant extracts, microbes, or other biologically produced materials is referred to as "green synthesis." This method is environmentally beneficial and sustainable. Due to its low environmental impact, affordability, and potential to create nanoparticles with special features, this approach has drawn a lot of interest. The selection of suitable bioactive agents, such as plant extracts or microorganisms, rich in chemicals capable of lowering metal ions, is the first step in the procedure. These selected agents are combined with metal salt solutions containing the desired metal ions during the reduction and nucleation process. The agents' bioactive components make it easier for metal ions to be reduced to metal nanoparticles, which start the nucleation process. The biomolecules also act as capping agents throughout the reaction, preventing the nanoparticles from clumping together and regulating their growth. The size, shape, content, and stability of the produced nanoparticles are subsequently confirmed using a variety of analytical techniques. Reduced environmental impact, cost-effectiveness, and the capacity to create nanoparticles with specific features are some benefits of this green synthesis method [2].
- 2. Conventional Synthesis:** Metal oxide nanoparticles are typically synthesized using conventional procedures that are based on established techniques that have been applied to create these nanoscale materials for decades. The sol-gel method is a commonly used technique in which metal precursors are dissolved in a solvent to create a sol, which is then followed by the controlled hydrolysis and condensation events that produce gel. Another popular method is the co-precipitation method, which involves mixing aqueous solutions of metal salts to produce metal hydroxide precipitates, which are then heated to produce metal oxides. In order to encourage the formation of crystalline metal oxide nanoparticles, the hydrothermal approach also involves the reaction of metal salts with water at high temperatures and pressures. These conventional methods provide simplicity and precise control over particle structure [5].
- 3. Conventional Synthesis versus Green Synthesis:** However, compared to conventional approaches, parameter tuning and exact control over nanoparticle features can be more challenging. Although they have been essential to technological and scientific progress, conventional methods for making metal oxide nanoparticles do have some drawbacks. The environmental impact of several of these methods is a notable disadvantage. The employment of harmful chemicals, high temperatures, and energy-intensive processes are frequently necessary with conventional methods. Pollution is caused by the generation of hazardous waste and byproducts, which also presents difficulties for waste management and disposal. Additionally, some conventional processes could result in irregular particle distributions, sizes, and shapes, which could affect the performance and reproducibility of the finished product. These techniques can also be expensive and time-consuming, particularly when large-scale production is necessary. Scalability and accessibility issues for research and applications might be caused by a reliance on expensive machinery and severe environments. These drawbacks highlight the need for more environmentally friendly methods, such as the developing field of green synthesis, which seeks to address these issues and provide a more sustainable alternative for metal oxide nanoparticle synthesis as the demand for sustainable and green technologies increases.

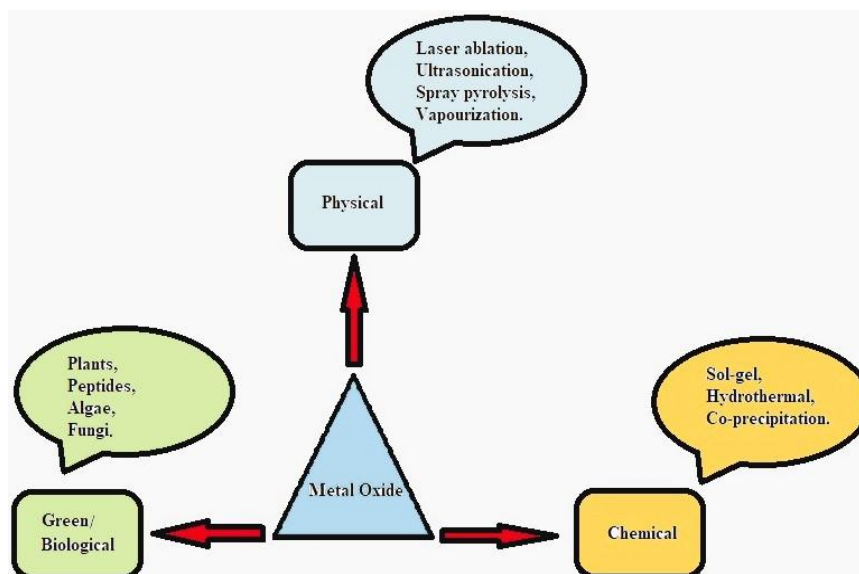


Figure 1: Methods of Metal Oxide Synthesis.

III. APPLICATIONS OF METAL OXIDE NANOPARTICLES

- 1. Nanomedicine:** In numerous fields, metal oxide nanoparticles are continuously being used in creative and novel ways. Here is a summary of some recent uses for metal oxide nanoparticles that have recently attracted attention. Due to their distinctive characteristics and functions that can be tailored for a variety of biomedical reasons, metal oxide nanoparticles have found a wide range of uses in the field of nanomedicine. Targeted delivery of drugs is one common use for metal oxide nanoparticles, where they are designed to encapsulate therapeutic chemicals and release them at particular disease areas, reducing adverse effects and maximizing treatment success. Additionally, these nanoparticles shine in diagnostic imaging, acting as contrast agents in procedures like magnetic resonance imaging (MRI) to make tissues and abnormalities more clearly visible [10]. Iron oxide nanoparticles are utilized for hyperthermia-induced cell death, and gold nanoparticles are used in photothermal treatment to selectively kill cancer cells when exposed to light. Metal oxide nanoparticles are also making progress in the field of cancer therapy. Their adaptability also extends to photodynamic treatment, in which they produce reactive oxygen species in response to light exposure to treat localized cell damage. Furthermore, metal oxide nanoparticles are essential for biosensing because they allow for the sensitive and quick detection of biomolecules for the diagnosis and monitoring of diseases. These uses highlight the potential of metal oxide nanoparticles to fundamentally alter how we identify, manage, and treat medical problems. However, in order to successfully translate them into clinical practice, thorough safety evaluations are required [6].
- 2. Environmental Remediation:** Through novel applications in remediation, metal oxide nanoparticles have emerged as promising instruments for solving environmental concerns. Iron oxide (Fe_3O_4) and titanium dioxide (TiO_2) metal oxide nanoparticles function as photocatalysts in the water purification process, which is one significant usage. These nanoparticles may utilize light energy to break down toxins and organic pollutants, improving the quality of water supplies. In addition, air filtering devices

employ metal oxide nanoparticles [11]. They can efficiently absorb and degrade dangerous gases and volatile organic compounds (VOCs) found in indoor and outdoor air settings when included into coatings and filters. The ability of metal oxide nanoparticles to reduce both water and air pollution demonstrates their adaptability in fostering healthy and sustainable ecosystems. In order to ensure their durability and any potential environmental effects during their use and disposal, however, extensive research is necessary [7].

- 3. Energy Storage and Conversion:** Metal oxide nanoparticles have become essential elements in the field of energy conversion and storage, providing revolutionary ways to tackle the world's energy concerns. These nanoparticles are used in supercapacitors and improved lithium-ion batteries for energy storage. Higher energy densities, quicker charging rates, and longer cycling stability can be achieved by enhancing the surface area and electrochemical performance of the electrode materials with metal oxide nanoparticles. Additionally, metal oxide nanoparticles are used to improve light absorption and energy conversion efficiency in energy-efficient solar panel coatings. These nanoparticles are also being investigated in new energy conversion technologies including fuel cells and thermoelectrics, which can use waste heat to generate power, and electrochemical processes, which can provide clean energy. By enabling improvements in energy storage and conversion technologies, metal oxide nanoparticles contribute to a more environmentally friendly and efficient energy environment. However, to maximize their effectiveness, scalability, and environmental impact, further research is needed [8].
- 4. Flexible Electronics:** Flexible electronics and energy conversion technologies are being improved by metal oxide nanoparticles. Numerous applications in this field have been made possible by their excellent electrical and mechanical characteristics. These nanoparticles offer high-performance functionality while maintaining mechanical flexibility in flexible electronic devices, such as flexible displays and wearable sensors. With their combination of electrical conductivity and optical transparency, metal oxide nanoparticles, in particular indium tin oxide (ITO) nanoparticles, are used as transparent conductive sheets in touchscreens and flexible displays. Additionally, these nanoparticles are essential for energy conversion, improving light absorption and allowing charge transport in flexible solar cells to increase their effectiveness. Metal oxide nanoparticles have the potential to alter the appearance and functionality of these technologies as the need for small, flexible, wearable electronic devices rises. To fully utilize their promise in flexible electronics and energy conversion applications, it is difficult to develop scalable and affordable manufacturing procedures.
- 5. Catalysis:** Metal oxide nanoparticles are used in a wide range of catalytic processes, where their unique characteristics are crucial in accelerating certain chemical reactions. These nanoparticles are used as catalysts in a variety of industries, from petrochemicals to environmental remediation, to speed up reactions, increase yields, and provide more sustainable paths. For instance, titanium dioxide (TiO_2) nanoparticles are used in photocatalysis to initiate processes and destroy contaminants by harnessing light energy. In catalytic converters, where cerium oxide (CeO_2) nanoparticles function as catalysts to minimize hazardous emissions from vehicle exhaust, metal oxide nanoparticles also perform outstandingly. Additionally, iron oxide (Fe_3O_4) nanoparticles are used in the Fischer-Tropsch synthesis to transform hydrogen and carbon monoxide into liquid hydrocarbons, which could have an impact on the production of fuel. These uses

highlight the revolutionary effects of metal oxide nanoparticles in increasing catalysis, boosting effectiveness, and promoting more environmentally friendly industrial processes [9].

- 6. Agriculture:** The use of metal oxide nanoparticles in agriculture is growing due to their novel approaches to improving agricultural sustainability and productivity. One use is in the creation of nanopesticides, where metal oxide nanoparticles are added to formulations to boost the effectiveness of managing pests and diseases. These nanoparticles have less of an adverse effect on the environment and can target pests more precisely. Zinc oxide (ZnO), a metal oxide nanoparticle, can also be added to fertilizers to help plants better absorb nutrients. They minimize waste and nutrient runoff with their controlled release systems, which guarantee adequate nutrient delivery. Metal oxide nanoparticles are also used in soil remediation to help remove pollutants and heavy metals from the soil. Their ion-exchange and adsorption capabilities help to promote soil health. These nanoparticles are also being studied as a seed treatment to increase plant growth and germination rates. Although the prospective uses for metal oxide nanoparticles in agriculture are exciting, careful study of the long-term consequences on plants, soil, and the environment is necessary to assure sustainable and ethical application.
- 7. Textiles:** By endowing fabrics with improved qualities and functions, metal oxide nanoparticles are having a fundamentally transformational effect on the textile industry. These nanoparticles are incorporated into fabrics to produce surfaces that clean themselves and repel dirt and stains. When exposed to light, materials like titanium dioxide (TiO₂) nanoparticles activate photocatalytic activities, breaking down organic materials and contaminants on the surface of the fabric [13]. Metal oxide nanoparticles can also give textiles antibacterial qualities that prevent the growth of bacteria and fungi. This helps to increase hygiene and odor control in everyday apparel, sporting, and medical fabrics. Additionally, these nanoparticles help fabrics provide UV protection, protecting wearers from damaging ultraviolet light. Zinc oxide (ZnO), a metal oxide nanoparticle, is effective at blocking UV radiation without impairing the appearance of the fabric. In addition, metal oxide nanoparticle-infused smart textiles are being developed, with features including color-changing capabilities dependent on stimuli or the environment. Metal oxide nanoparticles are at the vanguard of the textile industry's embrace of innovation, pushing the evolution of functional and high-performance fabrics that meet a variety of customer needs. However, during the integration and lifetime of these nanoparticle-treated textiles, thorough assessment of potential health and environmental repercussions is required.
- 8. Antimicrobial Applications:** Metal oxide nanoparticles are known to be successful tools for tackling antibacterial challenges across a number of applications. These nanoparticles, like silver nanoparticles, have special qualities that make them effective at preventing the development of bacteria, viruses, and fungi. They are incorporated into implantable devices, surgical tools, and wound dressings in medical settings to stop infections. These nanoparticles damage microbial cell membranes, obstruct cellular processes, and prevent cell division. They end up in fabrics, coatings, and packaging materials used in consumer items, improving sanitation and security. Face masks, hospital linens, and athletic apparel all have antimicrobial textiles that assist lower microbial contamination. Additionally, metal oxide nanoparticles are used in water treatment systems to get rid of harmful bacteria in drinking water. They aid in food packing by inhibiting microbial development

and deterioration, hence extending shelf life. These applications show considerable promise for improving public health, infection prevention, and product preservation through the use of metal oxide nanoparticles. To address potential issues with nanoparticle release and environmental repercussions, it is essential to ensure responsible and sustainable use [14].

- 9. Automotive Applications:** Automotive applications are being transformed by metal oxide nanoparticles, which are enhancing performance, efficiency, and sustainability. The use of metal oxide nanoparticles, such as cerium oxide (CeO_2), as catalysts to enable the conversion of dangerous exhaust gases into less toxic molecules, enabling cleaner air quality and lower emissions, is one such use. Additionally, metal oxide nanoparticles are useful as fuel additives that reduce engine knocking and improve combustion efficiency in internal combustion engines. These nanoparticles are used in automotive coatings to offer corrosion resistance and UV protection, increasing the lifespan of vehicles and preserving their aesthetic appeal. In addition, metal oxide nanoparticles are being investigated for cutting-edge sensor technologies that allow for real-time monitoring of emissions, tire pressure, and driver assistance systems. Metal oxide nanoparticles provide a broad range of solutions that contribute to develop safer, cleaner, and more effective automobiles as the automotive industry embraces innovation and sustainability. To ensure their successful integration and beneficial influence on automotive applications, however, it is crucial to carefully analyze the dispersion, stability, and long-term effects of nanoparticles.
- 10. Cosmetics and Sunscreens:** The development of sunscreens and cosmetic products, in particular, has benefited significantly from the utilization of metal oxide nanoparticles in the cosmetic and skincare field. Metal oxide nanoparticles, such as zinc oxide (ZnO) and titanium dioxide (TiO_2), are widely used in sunscreens as active components because they effectively block UV rays. These nanoparticles function as physical blockers, deflecting and scattering UV rays away from the skin to provide both UVA and UVB radiation protection. They can be made into transparent, light-weight sunscreens that are less prone to create a white cast on the skin because of their nanoscale size. Metal oxide nanoparticles are also used to improve the texture, look, and coverage of cosmetic products like foundations and creams. These nanoparticles help make applications go more smoothly with enhanced product performance. The usage of metal oxide nanoparticles in various applications emphasizes their function in enhancing skin health and general wellbeing as consumer awareness of the value of sun protection and safe cosmetic components rises. To address issues regarding nanoparticle penetration and potential consequences on skin health, however, ongoing research is necessary.
- 11. Gas Sensors:** The detection and monitoring of various gases and volatile organic compounds (VOCs) have been transformed by the use of metal oxide nanoparticles, which have found considerable uses in the field of gas sensing. To take advantage of their distinctive electrical and chemical capabilities, these nanoparticles are incorporated into gas sensors. Tin oxide (SnO_2) and zinc oxide (ZnO) are two examples of metal oxide nanoparticles that vary their electrical conductivity when exposed to certain gases. This phenomenon serves as the foundation for resistive gas sensors, which convert the fluctuations in conductivity of the nanoparticles into quantifiable signals. With the ability to detect gases including carbon monoxide, nitrogen dioxide, and methane, these sensors are used in environmental monitoring, industrial safety, and healthcare. Additionally, by

functionalizing the surfaces of metal oxide nanoparticles with particular substances, the selectivity of these particles can be improved, enabling the targeted detection of particular gases. Metal oxide nanoparticles continue to fuel progress in this crucial field as the demand for dependable and sensitive gas sensors has increased with the growth of urbanization and industrialisation. To ensure precise and reliable gas detection, however, thorough calibration, optimization, and understanding of the sensor's performance are essential.

IV. CONCLUSION

In conclusion, the creation of metal oxide nanoparticles is evidence of the extraordinary advancements made in the field of nanotechnology. Researchers have harnessed the special physicochemical features of these nanoparticles by precise control of the synthesis settings, leading to a wide range of game-changing applications. Metal oxide nanoparticles have demonstrated their ability to transform industries and enhance human wellbeing, from improving the effectiveness of renewable energy sources to revolutionizing medical diagnostics and therapies. However, it is essential to approach this emerging topic with an equal perspective as we look closer into the global field of metal oxide nanoparticle manufacturing and applications. While the possibilities are undoubtedly exciting, it's important to also consider any potential environmental and health effects linked to the creation. In order to ensure that the advantages these materials offer are sustained without experiencing adverse effects, thorough research into the safe handling, disposal, and long-term implications of these materials is essential. We can realize the full potential of metal oxide nanoparticles while preserving our planet and its inhabitants for future generations by encouraging responsible innovation and diverse collaboration.

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