**Application of Mesoporous Metal Oxide Nanoparticles in Wastewater Treatment**

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**Abstract:** In last few decades the material science and technology rapidly emerge as a very potential area of research due to its versatile application in various fields. In the field of material science enomorous development has been made in the fabrication of mesoporous metal oxide nanomaterials based smart and advanced device. From the study of various research groups it was found that nanodimension and mesoporosity has a great influence in the improvement of physicochemical properties of materials in comparism to their bulk counterpart. Modification of the shape and size of pores in mesoporous nanomaterials leads to a successful generation of multifunctional and desirable materials. At present both developed and developing countries suffers from the scarcity of clean water ascribed to various types water pollutions. Currently various types of mesoporous metal oxide nanoparticles exhibit efficient application in removal of the organic and inorganic pollutants from wastewater. Mesoporous metal oxides nanoparticles have great potential for treating contaminated water due to their large surface area and were established as a promising material for wastewater treatment.

**Keywords**: Material Science; Nanomaterials; Mesoporous; Metal Oxide; Wasterwater Treatment

1. **Introduction:**

**1.1 Mesoporous Materials**

 In present time the study of nanomaterials with mesoporous structure have attracted significant attention of the many materials research groups due to their efficient use in diverse area of applications. These materials are widely used in the fields of applications like as sensors, energy storage devices, bio separation, gas separation, agriculture, cosmetics, biomedicine and drug delivery, catalysts, adsorption, photocatalytic and environmental applications and many more [1-11]. These materials display outstanding physicochemical properties ascribed to their unique structural features, such as high surface area, tunable pore size, large numbers of surface defect sites and surface functionality [12-14]. In accordance with the “International Union of Pure and Applied Chemistry (IUPAC)” nomenclature the porous material containing 2 to 50 nm sized pores are described as mesoporous material [15], furthermore materials with pores diameter less than 2 nm are known as microporous and larger than 50 nm are called as macroporous materials. These mesoporous metal oxides are extensively applied in several types of environmental applications, such as wastewater treatment, photocatalytic degradation of organic pollutants, photocatalytic water splitting and removal of heavy metal and many more.

**1.2 Water Pollution and Waste Water**

Clean and fresh drinking water is necessity for life of all living organisms. Water pollution is the result of contamination of water resources by pollutants, has immensely increased as a result of rapid industrialization and the massive population explosion [26]. Water pollution is either [surface water](https://en.wikipedia.org/wiki/Surface_water) pollution or [groundwater pollution](https://en.wikipedia.org/wiki/Groundwater_pollution). Also the consumption of fresh and clean water was rapidly increased in the sector of agriculture, industry, household sectors, and other forms of consumption, which is the main reason of water pollution [27]. The wastewater is described as a municipal waste liquid product which contains contaminants or pollutants. The main categories of pollutants are organic and inorganic contaminants [28-29] such as microorganisms, toxic heavy metal ions and dyes, which have vast toxicity and hazards towards the environment. These types of contaminated water do not used for drinking purpose as the chemical, biological and physical properties of clean water are affected by these harmful contaminants [30]. Currently clean and fresh drinking water do not available to about 780 million people in worldwide [31]. Consequently wastewater treatment has becomes very important because of the hazards and toxic effects of the contaminants of wastewater towards the environment and ecosystem. Recently various research groups focus their research activities on the removal of these pollutants from the different water resources [32]. The wastewater treatment can utilize physical, chemical, and biological methods for water purification from various hazardous contaminants. Numerous strategies such as solvent extraction, evaporation, reverse osmosis chemical treatment, ion-exchange, adsorption, separation and ultrafiltration [33-36] applied to remove hazardous elements from wastewater. Among this photocatalysis and adsorption are the most interesting and efficient methods due to their unique features [37-40]. Basically adsorption is a chemical process of adhering or deposit of particles of matter from gases or liquids onto the porous interface of solids and adsorbent is a solid substance whose surface was utilized to accumulate harmful particles from a liquid or gaseous phase. In the last few decades, researchers reported the application of various materials in water treatment process such as charcoal, activated carbon, clay, silica, zeolites and sand as adsorbent. Although their applications have been limited due to many drawbacks such factors, such as low processing efficiency, low regeneration capability, high energy requirements along with less economic benefit. Currently, mesoporous metal oxide nanomaterials have been considered as promising adsorbents for purification and recycling of wastewater due to their unique characteristics such as large surface area to volume ratio, variable valences, vast number structural geometries and polycrystalline nanostructures along with large number of active sites for adsorption. Nanodimensional mesoporous metal oxide posses many excellent features like high removal capacity and heavy metals selectivity as an adsorbent. On the other hand photocatalysis is a photo-activated chemical reaction and based on nano-catalysts which happened when free radical mechanisms are started as soon as the chemical compound exposed to the photons (solar radiation) with sufficiently high energy. In wastewater treatment photocatalysis mechanism are divided into two categories: solar photocatalysis and artificial ultraviolet (UV)-light assisted photocatalytic activity. Due to their high surface area and small particle size mesoporous metal oxide nanoparticles shows excellent photocatalytic properties and considered potential candidate for nano-catalyst in polluted water purification. This chapter focused on the study of application of various mesoporous metal oxides as nano-adsorbent and nano-catalyst in wastewater treatment.

**2. Application of mesoporous metal oxides in wastewater treatment:**

 **2.1 Copper oxide nanoparticles:** Copper is the oldest metal used in humans’ civilization for the sanitization as copper has many positive characteristics like abundant in nature, good corrosion resistance antimicrobial activity [41]. Copper (II) oxide is a monoclinically structured nontoxic p-type semiconductor material with a band gap of 1.2 eV [42]. It shows many unique chemical and physical properties like high electrochemical capabilities which utilized in photocatalysis, removal of toxic pollutants and antimicrobial applications. Several synthesis methods have been used to prepare mesoporous CuO nanostructures like sol–gel, chemical precipitation route, thermal decomposition, solvothermal, hydrothermal, microwave-assisted etc. Mesoporous CuO was obtained via simple sol-gel method in ethanol-water mixed solvent by M. I. said and coworkers [43]. They used Copper (II)acetate monohydrate, Sodium hydroxide and ethyl alcohol as precursors. The photocatalytic study showed the prepared materials exhibit higher efficiency for the degradation of Congo red (dye) and exhibits complete dye removal after 35 min. Also the water/ethanol ratio has a potential impact in the tuning photocatalytic properties of the prepared CuO nanoparticles which helps in wastewater treatment. N. Jing and group reported the preparation of mesoporous CuO with novel architecture via a conventional hydrothermal method followed by a facile heat treatment [44]. They used hydratedCu(NO3)2 salt and CO(NH2)2 as starting materials. Prepared mesoporous CuO exhibits a excellent photocatalytic activity and high durability under visible light for methyl orange (dye) in acidic environment. The adsorption/desorption of the dye on the CuO surface occurred due to the action of H+ ions and H2O2 using a state-changing mechanism and the reaction rate of degradation of the contaminants was increased upto 3.5 times only by controlling the methyl orange ratio. In another work hollow mesoporous CuO microspheres were prepared via a rapid one-pot hydrothermal process by S. Ghosh et al. [45]. Copper acetate, urea and water are utilized as starting materials. The hollow CuO microspheres were formed by the self assembly of 5–20 nm sized particles with a stone-wall-like structure. The hollow CuO microspheres exhibit high efficiency as recyclable catalyst in the decomposition of H2O2 during water rectification process. One of the potential applications of CuO during water purification is bacterial disinfectants. Gustavo Faúndez et al. [46] observed the activity of copper oxide against suspension Campylobacter jejuni and Salmonella enteric at various temperature conditions. These result confirmed that the copper and copper oxide surface has excellent antibacterial activity at these temperatures.

**2.2: Zinc oxide nanoparticles:** ZnO is considered as a highly efficient photocatalyst in wastewater treatment ascribed to its excellent photocatalytic activity and high chemical stability. ZnO is a wide bandgap (3.37 eV) semiconducting material and also possesses high exciton binding energy (60 meV) at room temperature. Porous ZnO nanomaterials with various morphology such as nanosheets, nanowires, nanobelts, nanorods, and complex structures were developed by several research groups. Mesoporous ZnO is potential candidate for photocatalytic activity due to high electrochemical stability, nontoxicity, super oxidative capability as well as they provides large surface area to volume ratio. Also ZnO are cheap and abundance in nature. Preparation of mesoporous zinc oxide nanoparticles within a silica matrix was reported by W. M. Saod and groups [47]. The nanocomposite system shows excellent efficiency in removal of pollutant Pb, Cd and Cr from solution at pH 6 and above within less time. The photocatalytic activity of ZnO in different proportion in polluted water has been observed by M. A. Gondal et al. [48]. Using Zn(NO3)2 and (NH4)2CO3 as precursors ZnO nanoparticle of 20–40 nm sized prepared. to An increase in the constant decay of bacteria has been reported with increased photocatalytic efficiency ascribed to effect of the reduced particle size and the effect of quantum containment activating ZnO to grnarate reactive oxygen species.

**2.3 Titanium oxide nanoparticles:** At present times, the most extensively studied metal oxides in the field of water rectification is titanium oxide (TiO2) nanoparticles. Titanium oxide is a very efficient photocatalyst due its unique features such as photostability, affordable price and high biological and chemical stability [49]. TiO2 is semiconducting material with the large bandgap energy (3.2eV) and ultraviolet (UV) excitation. Several works has been reported where titanium oxide is also used in disinfection, removal of pigment, dye and in the decomposition of complex organic compounds into simple less toxic material [50-51]

**2.4 Iron oxide nanoparticles:** At present times iron oxide nanoparticles have been extensively used in various fields due to its low cost and availability. Currently mesoporous iron-based nanomaterials have exhibits excellent adsorption capacity for removal of heavy metals, dyes and organic compounds from contaminated water. In iron oxide magnetism is a unique physical characteristics which extensively helps in water rectification by controlling the physical properties of pollutants in the water. As a result the combination of adsorption procedure along with magnetic separation makes iron oxide nanomaterials an outstanding nanosorbent in the field of wastewater treatment. Nowadays many research groups have concentrated on developing water treatment technology using magnetic nanomaterials specially iron oxide [52-55].

**3. Summary**

At present material science and nanotechnology leads to huge development in fabrication of smart and advanced devices using of multifunction materials. Currently nanoparticles drawn great attention by the researches for their interesting physical and chemical characteristics compared to their bulk counterpart. Furthermore mesoporous nanomaterials have outstanding applications as they provides of large surface area to volume ratio and tunable porous structure. Nowadays the requirement of the management of water pollution is rapidly increased. Metal oxides with mesoporous structure is becomes very efficient for adsorbent material for wastewater treatment. This kind of material can remove more toxic molecules from polluted water by trapped more pollutant particle onto their porous surface area. Several research groups are focused their work in fabrication of more smart and useful material for the development of more advanced techniques. They used different types of synthesis methods to prepare more efficient nanoadsorbent material. Mesoporous ZnO, TiO2, CuO, Fe2O3, Ag2O, MgO, MnO2, SnO2 are example of some promising adsorbent materials. They show excellent efficiency as a chemical adsorbent in accordance to their high surface area and presence of more active sites for adsorption in their interface. From the study of literature it can be conclude that in near future by controlling the mesoporous structure and electronic structure more efficient and advanced metal oxide based devices for purification and recycle of wastewater will developed.

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