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A REVIEW ARTICLE ON SYNTHESIS METHODS OF PHOTO CATALYSTS FOR WASTE WATER TREATMENT

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ABSTRACT
Water pollution has been the most challenging environmental phenomenon that poses potential risks to ecosystems and human health through contaminants of industrial, agricultural, and urban activities. Effective methods of water treatment are, therefore, crucial in alleviating their impacts and ensuring the sustainability of water resources. Among those methods, photocatalysis has been a promising approach toward the degradation of organic as well as inorganic impurities through the decomposition of harmful chemicals into nontoxic products using the power of light and photocatalysts. This paper has outlined the fundamentals, application, and developments in the field of photocatalysis; specifically pertaining to the hydrothermal method of photocatalyst synthesis. The hydrothermal method is one of the versatile and efficient methods that would give synthesis of an advanced nanostructured material with a highly crystallized structure, controlled morphology, and improved photocatalytic performance. This paper discusses photocatalysts that can possibly remove persistent pollutants in water, hydrothermally synthesized. Innovative sustainable technologies have been developed in the paper through in-depth analysis and serve to contribute to this goal of removing persistent pollutants from water.

Key words:
Photocatalysis, Nanoparticles, Hydrothermal process, X-ray diffraction.

I. Introduction
Water pollution is one of the environmental problems that threaten today's ecosystems and human health. The more people on Earth, as well as industry, grow, so do the threats to our water sources. Thus, harmful substances penetrate rivers, lakes, oceans, and underground water, and the water becomes polluted. These include factory waste, farm runoff untreated sewage, and plastic trash. The influences of water pollution run profoundly deep and are complicated. They poison not only sea life but also the health of people and the future of the planet. These toxic pollutants disrupt the equilibrium in the ecosystems. This affects the fewer types of plants and animals and damages key water resources. To combat this major issue, people have been exploring, devising, and implementing different measures to reduce and be more environmentally friendly to conserve our waters. These approaches are vital in the care of the environment besides ensuring that man and animal have a better future. The ultimate goal is restoring and maintaining the vulnerable balance of nature as it continues facing threats by the continuous process.

1.1 Causes of water pollution

1.1.1 Industrial activities

Industrial activities are the major causes of water pollution worldwide. Many industrial processes produce numerous pollutants, which generally find their way into water bodies and cause massive environmental and public health problems. As shown in figure 1.1. A few of the most important ways in which industrial activities pollute the water are discussed below:

1. Chemical Discharges
2. Wastewater Effluents
3. Oil and Petroleum Product

Figure 1.1-Industial activities

1.1.2 Agricultural practices

Agriculture practice is among the primary contributors of water pollution due to the discharge of various pollutants in water bodies within such areas. Basically, the expansion and intensification of modern agriculture have led to the contamination of rivers, lakes, and ground waters that enhance risks to aquatic ecosystems and human health as shown in figure1.2. Here are some ways through which agriculture impacts water quality:

1. Nutrient Runoff.
2. Pesticides and Herbicides.
3. Animal Manure and Waste.
4. Soil Erosion.
5. Irrigation Practices.
6. Deforestation and Wetland Destruction

Figure 1.2-Agricultural Practicies

1.1.3 Organic dyes

Organic dyes are mainly found in textiles, paper, leather, and plastics, which constitute one of the major sources of water pollution because they persist and even represent potential toxicity. These dyes can contaminate water bodies by eventually affecting aquatic life and human health when released untreated or inadequately treated as shown in figure 1.3. Some of the major ways through which organic dyes contribute to pollution:

1. Aquatic Life Toxicity.

2. Reduced Light Penetration
3. Persistence and Bioaccumulation.
4. Formation of toxic byproducts.
5. Challenges in Water Treatment.

Figure 1.3- Organic Dyes

1.2 Water treatment methods

Water treatment is critical in providing safe and clean A Primary source of pollution from agriculture is due to the emission of several types of pollutants to the surrounding water bodies. Modern agriculture has brought upon increased intensification and expansion to rivers, lakes, and groundwater with the relevant threats that affect aquatic

Some water treatment methods are shown below:

1. Ion Exchange
2. Activated Carbon Adsorption
3. Ozonation
4. Chlorination
5. Coagulation and Flocculation
6. Advanced Oxidation Processes (AOPs)
7. Photocatalyst

1.3 Photocatalyst

Photocatalysis: A New Technique in Water Purification Using Special Attention on the Products of Synthetic Dyes Used in the Textile and Cosmetic Industr y. INTRODUCTION It is a great technique that does no other thing but remove the damage and hazards that dyes cause to the environment and human health when released into water sources untreated. Photocatalysis is defined in this paper as a method, where light and photocatalysts, such as titanium dioxide, start reactions leading to the breakdown of complex dye molecules to harmless substances. Such a process is environment-friendly since it can exploit natural sunlight and has no secondary pollutants. Recent developments are enhancing the performance of photocatalysts in visible light, so that photocatalysis may emerge as a viable solution for the sustainable treatment of water and diminishing industrial pollution.

1.3.1 Principles of photocatalysis

The photocatalysis is a mechanism whereby interplay occurs between a semiconductor photocatalyst and light energy, most commonly ultraviolet or visible light. In this process, the application of the light energy on the surface of the photocatalyst creates electron-hole pairs. These further give rise to reactive species like hydroxyl radicals (OH) and superoxide radicals ($O2^{-}$), which result in several successive oxidative reactions in the degradation of organic compounds, such as synthetic dyes, into simpler, less harmful molecules.

1.3.2 Mechanism of degradation

Photocatalysis is a multi-step process, with first the adsorption of dye molecules onto the surface of a catalyst. A photoexcitation of a catalyst occurs when a catalyst is subjected to light, forming hydroxyl and superoxide radicals that go on to attack the dye molecules by oxidizing separate chromophore groups giving colour to the dye. Thus, radicals break chemical bonds in the molecules of the dyes by oxidative reactions to degrade to simpler, less hazardous substances.

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These parameters show that the degradation may depend on the efficiency of the catalyst, strength, and wavelength of incident light, the concentration of the dye used, as well as the time taken to conduct the reaction; all these factors can affect the rate at which degradation will occur and its completeness, hence affecting the efficiency of the removal of dyes from water through photocatalytic action.

Applications of Photocatalysis

1. Decolorization of Textile Industry Wastewater by Photocatalysis
2. Photocatalytic Treatment of Urban and Industrial Runoff.
3. Depletion of Persistent Organic Pollutants.
4. Photocatalytic Water Purification for Drinking.

Advancements in Photocatalysis

Researchers have continued to advance photocatalysis for the degradation of organic pollutants through many strategies, including:

1. Nanomaterials Engineering.
2. Visible Light Photocatalysis.
3. Catalyst Immobilization.

Synthesis methods of photocatalysts:

1. Hydrothermal method,
2. chemical precipitation
3. co-precipitation
4. green synthesis
5. soft chemical approach
6. sol-gel method
7. thermal decomposition

II. Literature

2.1 Microwave-Assisted

Microwave-assisted heating is a sustainable method for carbon materials. Previous studies focused on metal-containing electrocatalysts with MW heatingC-450W-140s outperformed other catalysts in H_2O_2 production. Most studies used MW heating for functionalization, not synthesis.C-450W-140s offers short preparation time and energy efficiency. Metal-free heteroatom-doped carbon catalysts were successfully synthesized. One-step MW-assisted heating approach optimized for efficiency. Significant reduction in heating time and energy consumption achieved. High surface area carbon structure formed in 140 seconds. Catalyst showed 0.73 V onset potential for oxygen reduction. Energy consumption decreased by 77-fold compared to conventional methods [1]. Zinc oxide nanoparticles exhibit antioxidant properties. They demonstrate anti-inflammatory effects in vitro. Antibacterial activity was confirmed against various pathogens. Cytotoxicity was evaluated with specific concentration ranges. Wound healing properties were observed in fibroblast migration. [2]

2.2 One-Pot Synthesis

The one-pot method involves synthesizing materials in a single reaction vessel, simplifying the process and reducing the need for multiple steps.

G Balraj noticed that ZrO_2/La_2O_3 catalyst synthesized via a simple co-precipitation method where Catalyst shows high stability and performance in reactions. Tetrahydropyrimidine derivatives yield averages 85-95% under optimal conditions. Characterization techniques include FTIR, XRD, SEM, and BET. Catalyst possesses hexagonal structure and high porosity. Reaction times are quick with simple isolation procedures. High product yield achieved within a short time span[3]. Jialin Yu discovered zeolitic material synthesis from fly ash highlights low energy consumption compared to traditional methods. A new low-energy synthesis route for zeolitic material was developed. The intermediate product showed higher Ni^{2+} adsorption than zeolite A. The synthesis process is simpler and more energy-efficient. The crystalline phase changed from mullite to amorphous and then zeolite

A. The adsorption capacity of II-4-Z reached 75.6 mg/g. Commercial zeolite A had lower adsorption capacity at 27.6 mg/g[4].

2.3 Solid state Reaction Method

The solid-state reaction method is a technique used to synthesize materials, particularly ceramics and inorganic compounds, by combining solid reactants at high temperatures. This method relies on the chemical reactions that occur when solid powders of different components are mixed and heated together, often in a furnace. It is commonly used to prepare complex materials such as oxides, ceramics, superconductors, and semiconductors. Mohd Mubashshir Hasan Farooqi noticed ZnS nanoparticles exhibit a zinc blende structure and spherical nanoparticles are formed, as shown by SEM. Blue-shifting in absorption edge compared to bulk ZnS. Particle size increases with higher synthesis temperatures. Photocurrent varies linearly across all synthesized samples. Negative photoconductivity observed in lower temperature samples [5]. Zhong Chen noticed that the nanoparticles exhibit strong blue emission, 9 times higher than undoped in O2-doped ZnS nanoparticles synthesized via low temperature solid state method. And the average crystallite diameter ranges from 8.35 to 13.50 nm. Optimal O2 doping condition found at Zn/O ratio of 10:5.3. No impurity phases observed in XRD patterns.Lattice constant calculated between 5.4136 Å and 5.1362 Å. Crystallinity decreases with lower ZnO ratio in source materials. [6]. Rajulal Sahu stated Renewable energy sources require effective energy storage devices. Supercapacitors are prominent due to high power density and reversibility where there are limited reports exist on solid-state supercapacitors using SnO2 composites. SnO2 electrode achieved 46.4 F g-1 at 5 mV s-1. Cyclic stability of 117.30 over 10,000 cycles was observed. Solid-state supercapacitor delivered 13.04 F g-1 at 5 mV s-1. Specific energy density of 2.2 Wh kg-1 was recorded. Power density reached 416.3 W kg-1. Device powered 21 red LEDs and a small DC fan[7].

2.4 Chemical Precipitation Method

The chemical precipitation method is a widely used technique in chemistry and materials science to synthesize solid materials from a solution by inducing a chemical reaction that leads to the formation of an insoluble product (precipitate). The method involves mixing two or more soluble reactants in a solution, which leads to the formation of a solid phase that separates out from the liquid phase. The precipitate is then collected, often by filtration, washed, and dried for further use or processing. M. Ummay Sumaya briefly noticed ZnO nanoparticles synthesized using chemical precipitation method and stated that the Optimal conditions: 15 ml MEA, isopropanol, 120 min, 60°C. Crystallite size of ZnO nanoparticles: 50-60 nm. Higher transmittance and band gap energy of 3.3 eV. [MEA concentration affects hydrodynamic size of ZnO nanoparticles. Isopropanol yields better crystallinity than deionized water. Particle size varies from 100 nm to 10,000 nm. Heating improves crystallization and reduces particle size. SEM shows spherical shape after annealing at 120°C. EDX confirms complete formation of ZnO nanoparticles [8]. Abdelmajid Lassoued synthesized iron oxide (a-Fe 2O 3) nanoparticles and found that Hematite nanoparticles synthesized via chemical precipitation method. Particle sizes ranged from 21 to 82 nm. Increased precursor concentration led to larger particle sizes. XRD confirmed rhombohedral structure of a-Fe2O3. FT-IR confirmed phase purity of synthesized nanoparticles. Optical gap of samples approximately 2.1 eV. It explores the impact of precursor concentration on properties. Various characterization techniques were employed for evaluation. XRD confirmed a rhombohedral structure with space group R-3c. TEM and SEM showed uniform spherical morphology [9]. R. Subramanian discovered Piperine affects size, shape, and morphology of HAp nanoparticles. FTIR spectra confirm functional group transformations in HAp. TEM images show agglomeration of HAp nanoparticles with piperine. XRD patterns indicate increased crystallite size with piperine concentration. HAp synthesized with piperine exhibits rod-like particles without agglomeration. Green synthesis methods utilize plant extracts for hydroxyapatite production. Piperine's role in nanoparticle synthesis is underexplored [10]. Monalisha Goswami worked on synthesizes ZnO-NPs using a chemical precipitation method. Structural and optical properties depend on annealing temperature. Crystallite sizes increase with higher annealing temperatures. Annealing temperature affects structural and optical properties of ZnO-NPs. Crystallite sizes increase with higher annealing temperatures. Reduction in FWHM indicates improved crystallinity of ZnO samples. SEM shows nearly spherical particles with increased size upon annealing. FTIR confirms Zn-O stretching vibration in the samples. UV-Vis spectra show red shift and decreased band gap energy. PL intensity of UV emission increases with higher annealing temperatures [11].

2.5 Wet Chemical Approach

The wet chemical approach is a broad term used to describe a variety of synthesis methods that involve liquid-phase chemical reactions to produce solid materials or phases. It is often applied in the preparation of nanoparticles, thin films, and bulk materials, and is characterized by the use of liquid or aqueous solutions as reaction media. The term "wet" refers to the fact that the chemical reactions typically take place in a solution or suspension, often at room or elevated temperatures. Silviya N noticed Nickel oxide (NiO) is a potent catalyst and anti-ferromagnetic layer. NiO NPs are used in optical filters and gas sensors. NiO is studied for catalysts, ceramics, and electronic components. NiO has a cubic lattice structure and is a p-type semiconductor. NiO shows potential in sensor technology and lithium-ion batteries. NiO is less harmful than other nickel compounds. NiO NPs exhibit a face-centered cubic crystal structure. Average crystal size calculated as 43 nm using Scherer's equation. Lattice parameters include cell volume of 63 A^3 and atomic radius of 1.48 A. Weight loss observed during thermal analysis at higher temperatures [12]. Sandeep A. Arote described Nanotechnology manipulates materials at subatomic levels for novel products. Metal oxide nanomaterials have diverse applications in sensors and devices. Humidity sensing properties are influenced by crystallite size and morphology. ZnO and ZnO-ZrO2 nanoparticles were successfully synthesized. XRD and EDS confirmed phase purity of nanoparticles. SEM showed morphology changes with varying ZrO2 concentration. Band gap of ZnO increased with higher ZrO2 concentration. Optical absorption decreased with increased ZrO2 in ZnO. Humidity sensing properties indicated potential for sensor applications. Maximum sensitivity of 78.26 observed for sample P3. Response and recovery times were measured for sensor performance [13]. Ali Akbar Ashkarran Researched focusing on ZnS nanoparticles' optoelectronic properties. Mn-doped ZnS NPs show tunable emission across the visible spectrum. Various transition metals and rare-earth ions have been used for doping. Applications include biological sensors and optical displays. Mn-doped ZnS nanoparticles were synthesized using a wet chemical method. XRD confirmed formation of zinc blende structure with 2 nm size. TEM analysis showed uniform spherical nanoparticles around 3 nm. Maximum photoluminescence intensity was for 7.5% Mn doped ZnS. Photocatalytic activity decreased with Mn doping in ZnS nanoparticles [14].

2.6 Green Synthesis Method

Green synthesis refers to the environmentally friendly and sustainable approach to the preparation of materials, particularly nanomaterials, using natural, non-toxic, and renewable resources. This method aims to reduce or eliminate the use of harmful chemicals, solvents, and energy-intensive processes typically involved in traditional chemical synthesis methods. Green synthesis aligns with the principles of green chemistry, which emphasizes reducing environmental impact, enhancing safety, and promoting sustainability in chemical processes. Farshad Seyed Nejad studied on iron nanoparticles in colon cancer therapy. It examines pro-apoptotic BAX and anti-apoptotic Bcl2 expressions. MS-loaded FeNPs show significant cytotoxic effects on cancer cells. Radiotherapy enhances the effectiveness of the treatment agents. MS-loaded FeNPs showed significant cytotoxic effects on LS174t cells. Higher doses and longer exposure increased toxicity against cancer cells. Radiotherapy enhanced the effectiveness of treatment agents. Pro-apoptotic BAX expression increased after treatment; anti-apoptotic Bcl 2 decreased. Study suggests potential for new cancer treatment approaches [15]. Gusliani Eka Putri observed the synthesis Cerium oxide nanoparticles using Moringa oleifera extract. Average particle size of synthesized nanoparticles is 17 nm. High antimicrobial activity with inhibition zones of 15-31 mm. Antifungal properties exceed antibacterial properties in effectiveness. Higher purity and crystallinity confirmed by XRD analysis. Band gap energy found to be 18% lower than bulk size [16].

Shashanka Rajendrachari Studied the plant-mediated synthesis of nanomaterials. ZnO nanoparticles are bioactive materials for various applications. Alchemilla vulgaris is used for synthesizing ZnO nanoparticles. Cauliflower-shaped ZnO exhibits good photocatalytic activity. The bandgap energy of ZnO nanoparticles is 3.43 eV. ZnO nanoparticles were synthesized using Alchemilla vulgaris leaves. Average size of ZnO nanoparticles was 120 nm. Cumulative median particle size of ZnO nanoparticles was 550 nm. Activation energy calculated as 4.98 kJ/moles using Kissinger method. ZnO nanoparticles exhibited enzyme inhibition against BChE, AChE, and a-Gly. Photocatalytic activity demonstrated in degrading Rhodamine B dye [17]. M.E. Vázquez studied on antimicrobial efficacy of nanoparticles. It discusses the synthesis methods for silver and copper oxide nanoparticles. Previous research highlights the impact of pH on nanoparticle properties. The biocidal effects of copper oxide nanoparticles are emphasized. Comparisons are made between silver and copper oxide nanoparticles' effectiveness. Silver nanoparticles range from 19-50 nm in size. Copper oxide nanoparticles range from 5-30 nm in size. Both nanoparticles exhibit high crystallinity. Silver nanoparticles have a face-centered cubic structure. Copper oxide nanoparticles have a monoclinic structure. Copper oxide nanoparticles show high antibacterial activity. Antimicrobial activity varies with pH levels. CuONP solution at pH 3 shows significant growth inhibition. CuONPs exhibit biocidal power similar to conventional drugs [18].

2.7 Chemical Synthesis Method

Chemical synthesis refers to the process of creating compounds or materials through chemical reactions, typically involving the combination of two or more reactants to form a product. This method is used to produce a wide range of substances, including small organic molecules, polymers, inorganic compounds, and advanced materials such as nanomaterials. Chemical synthesis methods can vary greatly depending on the materials being synthesized, the desired properties, and the scale of production. E. Mazarío studied on Ferrite nanoparticles materials and applications include magnetic hyperthermia and drug delivery. Ferrites are used as MRI contrast agents. Their properties depend on size and magnetic characteristics. Ferrites have a spinel structure with specific cation arrangements. Manganese ferrite nanoparticles synthesized via a combined electrochemical method. Average particle size was approximately 23 nm. X-ray diffraction confirmed a spinel structure without impurities. Fe and Mn ratio suggested $Mn_{0.5}Fe_{2.5}O_4$ formation. High crystallographic order observed in Mn cations. Similar structural and magnetic characteristics to electrochemically obtained nanoparticles [19]. Sandeep A. Arote discovered Nanotechnology manipulates materials at subatomic levels for novel products. Metal oxide nanomaterials have diverse applications in sensors and catalysts. Zinc oxide (ZnO) exhibits unique optical and electrical properties. ZnO-ZrO_2 composites enhance sensing and optoelectronic properties. Wet chemical method is popular for large-scale synthesis. Ultrasonic assisted methods improve nanomaterial properties during synthesis. ZnO and ZnO-ZrO_2 nanoparticles were successfully synthesized. XRD and EDS confirmed phase purity of nanoparticles. SEM showed morphology changes with ZrO_2 concentration. Band gap of ZnO increased with ZrO_2 concentration. Optical absorption decreased with increased ZrO_2 in ZnO. Humidity sensing properties indicate potential for sensor applications. Maximum sensitivity of 78.26 observed for sample P3. Response and recovery times were measured for sensor performance [20]. Yang Wang worked on synthesis of SnAgCu nanoparticles via chemical reduction method. Lowest melting onset temperature is 199.1 °C. Melting point is 18 °C lower than commercial alloys. Tensile strength of synthesized nanoparticles is 34.3 MPa. Particle size influenced by reaction temperature and surfactant concentration. Good solderability properties observed in synthesized nanoparticles. Synthesis parameters optimized for low melting point [21].

2.8 Hydrothermal Process

The hydrothermal process is a widely used method for synthesizing nanoparticles and other nanomaterials by conducting chemical reactions in a high-pressure, high-temperature aqueous environment. In this process, reactions occur in a sealed vessel (called an autoclave) under conditions where water or another solvent is heated beyond its boiling point, typically between 100°C and 400°C. The term "hydrothermal" is derived from "hydro" (meaning water) and "thermal" (referring to heat), as it involves the use of water under high temperature and pressure. Nguyen Thi Mai Tho observed The rGO/$ZnBi_2O_4$ catalyst degraded over 90% of 2,4-D. Best performance observed with 2.0rGO/$ZnBi_2O_4$ at 1.0 g/L. Catalyst showed excellent stability over four cycles. Degradation efficiency increased to 94.2% with $AgNO_3$ addition. Photocatalytic efficiency reduced by only 7% after four cycles [22]. Yabin Zhang studied on Bi-based semiconductors for photocatalysis. Bi_2WO_6 is effective due to its suitable band gap and stability. High electron-hole recombination limits Bi_2WO_6 applications. Various methods enhance visible-light photocatalytic efficiency. Hydrothermal synthesis is used for $Bi_2Sn_2O_7$/Bi_2WO_6 composites. $Bi_2Sn_2O_7$/Bi_2WO_6 composites show enhanced photocatalytic activity.7% $Bi_2Sn_2O_7$/Bi_2WO_6 exhibits highest photocatalytic efficiency. Main active species are holes and hydroxyl radicals. Photocatalysts maintain activity after three cycles.Degradation efficiency of 7% composite is 97.8%. Higher $Bi_2Sn_2O_7$ content reduces photocatalytic efficiency [23]. Hua Tang studied on photocatalytic properties of TiO_2 composites. Magnetic separation enhances recycling of photocatalysts. Previous studies focused on various composite photocatalyst fabrication methods. Doped TiO_2 improves visible light absorption and photocatalytic activity. RhB degradation efficiency is low without catalysts under visible light. α-Fe_2O_3/TiO_2 composite hollow spheres were successfully synthesized.The composite shows high photocatalytic activity for RhB degradation. Calcination temperature and titanium-to-iron ratio affect photocatalytic activity. Samples can be magnetically separated and reused easily. The composite has a hollow structure with 60 nm shell thickness. Photocatalytic activity peaks at R 14 2:1.5 ratio [24]. Xuemei Liu studied ton Various methods exist for synthesizing Ga-TiO_2. Traditional methods require post heat treatment or high temperatures. Higher temperatures can lead to grain growth and agglomeration. Ga doping significantly affects TiO_2 photocatalytic performance. Nano-sized Ga-TiO_2 powders were synthesized via mild hydrothermal method. Doping concentrations ranged from 0.1 to 1.2 mol%. Best photocatalytic activity reached 82% with 0.6 mol% Ga-TiO_2. All samples exhibited well crystallized anatase TiO_2 structure. Particle sizes were approximately 10-15 nm in diameter. Specific surface areas ranged from 147 to 153 m^2/g. Ga doping improved visible light absorption significantly [25]. Yahong Xie studied on synthesis of Copper bismuth complex oxides via hydrothermal process. Samples exhibited leaf-like nanosheet morphology with uniform structure. Photocatalytic properties depend on microstructure, morphology, and lattice orientation. Enhanced visible light absorption compared to commercial TiO_2-P25. Band gaps of samples ranged from 1.30 to 1.43 eV. Degradation rate of methylene blue increased with H_2O_2 concentration. Leaf-like nanosheets showed superior photocatalytic degradation properties. Specific surface areas of samples varied significantly. $CuBi_2O_4$ shows excellent visible light absorption properties. Its photocatalytic activity is limited by high photostability. Recent studies report $CuBi_2O_4$'s catalytic ability for organic pollutant degradation [26].

2.9 Solvo Thermal

The solvothermal method is a synthesis technique similar to the hydrothermal method, but instead of using water as the solvent, it uses organic solvents or other non-aqueous solvents. The term "solvothermal" comes from "solvent" and "thermal," indicating that the process involves high-temperature reactions in a solvent under pressure. T.A. Lastovina discussed about magnetic iron oxide nanoparticles doped with samarium. Solvothermal polyol method is used for nanoparticle synthesis. Differences in properties with and without capping agent are outlined. The product is suitable for biomedical applications, like MRI contrast agents. Previous methods lacked control over particle size distribution. Rare earth ions improve magnetic and optical properties of materials. Sm^{3+}-doped Fe_3O_4 nanoparticles were synthesized. Average particle size reduced to 9 nm with 2,2'-bipyridine. XRD patterns showed no other crystalline phases. Average crystallite size was 7-9 nm for Sm:MNPs-Bpy. TEM images indicated agglomerated particles with roundlike shapes. TGA analysis revealed weight loss due to desorption of EG. Magnetic properties demonstrated significant coercivity differences between samples [27]. Mohammad Golrokh Siahroud discovered Co_3O_4-nanographitic flakes synthesized via solvothermal process. Stirring during synthesis leads to agglomeration of nanoparticles. Non-stirred electrocatalyst shows better OER performance. NGr-Co_3O_4 exhibits excellent onset potential of 1.53 V. Current density of 125 mA/cm² at 1.65 V achieved. Higher electrochemical active surface area enhances OER activity. NGr-Co3O4 shows lower charge transfer resistance than stirred counterpart [28]. Prakash Iruthayanathan discussed about PVP's role in nanoparticle synthesis. PVP stabilizes nanoparticles and prevents agglomeration. Previous studies explored PVP's effects on CuSbS2 nanoparticles. PVP enhances optical properties of metal chalcogenide nanoparticles. Polymer blends are promising for solar cells and sensors. Famatinite nanoparticles synthesized using various PVP ratios. XRD confirmed tetragonal crystal structure of nanoparticles. PVP reduced crystallite sizes and mitigated agglomeration. Raman spectroscopy validated pure famatinite phase presence. SEM showed uniform spherical morphology in all samples. UV spectroscopy revealed direct bandgaps of 0.88 - 0.97 eV. PVP significantly influenced structural, morphological, and optical properties. Optimal bandgap value for photovoltaic application was 0.88 eV [29]. Aref Mamakhel observed that Continuous flow reactors enable precise control in nanoparticle synthesis. Amphoteric oxides are sensitive to pH during synthesis. Previous studies focused on pH and temperature effects in SnO2 synthesis. Solvothermal chemistry allows for versatile nanoparticle preparation. Alcohols decompose to aldehydes, aiding nanoparticle synthesis. SnO2 has applications in gas sensing and catalysis. Amphoteric SnO2 nanoparticles were synthesized via continuous flow solvothermal synthesis. Particle sizes ranged from 3 nm to 7 nm. Phase purity confirmed by powder X-ray diffraction data. Nanosized SnO2 particles produced with narrow resonance in NMR spectra. Synthesis temperature affects crystallite size and particle morphology. SnO2 synthesized at 250°C showed better electrochemical performance. Initial discharge capacity was 1675 mAhg for SnO2 at 250°C. Capacity retention improved with lower synthesis temperature [30]. A. Dandre discussed various synthetic methods for SrTiO3. Supercritical synthesis is highlighted as a relevant technology. Previous studies on BaTiO3 synthesis are referenced. The impact of precursor types on synthesis is analysed. The significance of physicochemical properties in materials is emphasized. Strontium titanate nanoparticles were successfully synthesized. Crystallized phase confirmed via PXRD pattern analysis. Lattice parameter measured at 3.911 Å. Crystallite size calculated as 20 nm. Surface groups identified using Fourier Transform Infrared spectroscopy. Raman spectra indicated presence of defects and polar instability. Strontium and titanium molar contents confirmed via EDS [31]. Diego A. Acevedo-Guzm ́an discusses solvothermal synthesis of lanthanide-functionalized graphene oxide. Previous methods required long reaction times and specific media. Existing studies focused on limited lanthanides and environmental impact. The study aims to explore broader lanthanide applications. Detailed composition and structure of nanohybrid materials were analysed. Raman spectra showed characteristic D and G bands in samples. FTIR analysis indicated changes in oxygen-containing functional groups. XRD patterns confirmed exfoliation of graphene oxide sheets. TGA-DTA showed decreased thermal stability in GO-Ln composites. Homogeneous distribution of nanoparticles was observed in La composites. Solvothermal method proved efficient for synthesizing GO-Ln nanocomposites [32].

2.10 Sol-Gel Method

The sol-gel method is a widely used chemical process for synthesizing nanomaterials, particularly metal oxides and ceramic materials. The term "sol-gel" refers to the transition of a sol (a colloidal suspension of particles in a liquid) to a gel (a solid network structure). This method involves the conversion of molecular precursors into a solid nanostructured material through a series of chemical reactions, including hydrolysis and condensation, followed by drying and heat treatment. The sol-gel method is often employed to produce thin films, coatings, nanoparticles, and bulk materials with high purity, uniformity, and control over composition and structure. Nurul Nadia Mohd Zorkipli studied about NiO nanoparticles were synthesized using the sol-gel method. The average diameter of NiO nanoparticles is approximately 32.9 nm. A cubic structure of NiO was confirmed without impurities. Elemental analysis showed a Ni to O ratio of 1:1. The optimum calcination temperature was determined to be 450 °C. Thermal analysis indicated weight loss patterns during temperature changes. XRD confirmed the crystalline phase of synthesized NiO nanoparticles [33]. Pavithra C studied on synthesis of NiTiO3 nanoparticles were successfully via sol-gel method. X-ray diffraction confirmed rhombohedral phase and dense NiTiO3 formation. Thermal analysis indicated crystallization starting point at 600°C.FTIR confirmed Ni-O, Ti-O, and Ni-O-Ti bond formations. HRSEM analysis showed uniform grain growth with particle size 56-71 nm. EDX spectrum confirmed the purity of synthesized NiTiO3.Conductivity studies indicated semiconducting nature with 0.04 eV activation energy. Magnetometry revealed superparamagnetic behavior at room temperature. NiTiO3 exhibits semiconductor behavior and superparamagnetic properties. Various synthesis methods include sol-gel, hydrothermal, and electrospinning. Sol-gel method is easy and controlled for NiTiO3 synthesis. NiTiO3 is used in photocatalysis and gas sensitivity applications. It shows antiferromagnetism and high Curie transition temperature. Metal oxide nanoparticles are crucial for catalysts and sensors [34]. Bibi Ayesha observed that ZTO nanoparticles synthesized via sol-gel method at room temperature. Photocatalytic degradation of methyl orange and methylene blue tested. Methyl orange degraded by 73% under UV light. Methylene blue degraded by 62% under UV light. ZTO nanoparticles showed good photocatalytic activity. Average particle size estimated at 13.5 nm. Thin films fabricated using drop cost method. High crystallinity confirmed by pXRD analysis. Cube-like morphology observed in SEM images.Zn2SnO4 synthesized via various methods, including sol-gel. Few reports on sol-gel synthesis of Zn2SnO4 exist. Previous studies used different precursors and calcination temperatures. Morphology and crystallinity of Zn2SnO4 were characterized by SEM and pXRD. Photocatalytic activity assessed using methyl orange and methylene blue dyes [35]. A. Dinesh noticed Cerium substitution affects morphological and magnetic characteristics of nanoparticles. Samples exhibit ferromagnetic behaviour at room temperature. Coercivity increases with higher Ce content in ferrites. Photocatalytic degradation efficiency for dyes was demonstrated. XRD analysis confirms single phase crystalline structure development. Crystalline size varies due to ionic radius differences. The paper discusses cerium substitution in ferrite nanoparticles. It examines morphological, magnetic, and structural characteristics. Techniques used include X-ray diffraction and magnetic measurements. Samples exhibit ferromagnetic behaviour at room temperature. The study focuses on photocatalytic dye degradation mechanisms [36]. Zakia H observed that Ni-doped ZnO nanoparticles exhibit wurtzite structure. NiO phase forms on ZnO nanoparticle surfaces. Average crystallite size remains around 40 nm. Room temperature ferromagnetic behaviour observed in all samples. Energy band gap averages 3.164 eV across samples. Increased Ni content raises Urbach energy values. Non-monotonic variations in magnetic properties with Ni concentration. Reflectance values decrease with higher Ni doping. The paper discusses Ni-doped ZnO nanoparticles' properties. It highlights structural, optical, and magnetic characteristics. RTFM behaviour is observed in Ni-doped samples. Oxygen vacancies contribute to ferromagnetic ordering. Non-monotonic variations in magnetic properties with Ni concentration are noted [37]. Lotfi Ben Tahar NiZn studied on ferrite nanoparticles effectively remove methylene blue dye. Optimal calcination temperature for removal efficiency is 500 °C. Removal efficiency increases with pH, peaking at pH 11.2.Fast adsorption occurs within the first 30 seconds. Nanoparticles maintain removal efficiency over five reuse cycles. The paper focuses on NiZn ferrite nanoparticles for dye removal. Methylene blue (MB) is a cationic organic dye. pH affects adsorption efficiency of MB on nanoparticles. Higher pH increases negative charge on nanoparticles, enhancing adsorption. Fast adsorption occurs within the first 30 seconds. Nanoparticles maintain efficiency over multiple reuse cycles [38].

III. Conclusion

Hydrothermal synthesis as a method stands superior over other methods for producing photocatalysts due to its cost-effectiveness and the simplicity of controlling particle size, morphology, and the crystallinity required for advanced photactivity. Unlike most other complex synthesis techniques, the hydrothermal method works under relatively moderate conditions and therefore requires less energy. This immediately helps in cutting down the cost of operations. The process has an ability to accommodate a wide range of precursor materials besides being scalable for production of advanced nano-structured photocatalysts with uniform quality. The reduced requirement for post-treatment combined with the straightforward process offers it an appeal and a very practical application as a sustainable choice for the solution to address water pollution. Because it is an efficient pathway to develop effective photocatalysts, the hydrothermal method significantly contributes to the advancement of photocatalytic water treatment technologies concerning the removal of persistent pollutants and thus ensures water sustainability.

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