Future Trends of Nano-Catalysis: A Review

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Abstract

In chemistry, catalysis by metal and metal oxide nano-sized structures, like clusters and nanoparticles, is a unified field. With regard to extended systems, it is possible to modify the catalytically active regions both quantitatively (surface-to-volume ratio) and qualitatively (facet types and surface atom coordination) by forming metals into the nano materials. Because of their distinct size and physicochemical characteristics, nanoparticles are becoming more and more important in the detection and removal of both persistent and new environmental contaminants. The great adsorptivity, magnetic properties, and catalytic activity of nanoparticles make it simple to remove and degrade pollutants.

This review paper focuses on the future trends of nanocatalysis and utilizes the potential of nanoparticle-based approaches in real life, however, practical obstacles must be addressed, as the results compiled in this chapter were mostly gained at the laboratory scale. Potential secondary contamination must also be considered and avoided, and best practices in industries for manufacturing different products that depend on catalysis.

Keywords

Nanocatalysis, Metal Nanoparticles, Metal Oxide Nanoparticles, Photocatalysis, Environmental Remediation.

Introduction

The Swedish chemist Berzelius first used the term "catalysis" in 1835. However, Ostwald provided the first definition of catalysis in 1894.[1] Processes are accelerated by catalysts by lowering the activation potential.[2]. Researchers and businesses are interested in the dynamic fields of nanochemistry and nanocatalysis, which combine chemistry and nanotechnology. Both homogeneous and heterogeneous systems have been used to study nanocatalysts [3].

Catalytic methods that use nanomaterials as catalysts or catalyst supports, usually particles having at least one dimension in the 1–100 nanometer range are referred to as nanocatalysis. These nanoscale materials are very effective and adjustable for catalysis because of their distinctive qualities, which include large surface area, quantum size effects, and adjustable surface reactivity.

Features of Nanocatalysis

The large surface area volume proportion: More active sites are exposed per unit mass of catalyst, leading to increased catalytic efficiency. Process catalytic effectiveness varies as a result of different metal and metal oxide nanoparticle sizes and shapes.[4]

Quantum Effects: Electromagnetic characteristics that differ from those of bulk materials affect catalytic action at small scales. The significance of properly taking the impact of quantum sizes into consideration when calculating the spectrum difference of catalytic materials at small scales[5].

Shape and Size Tunability: A range of shapes and sizes, such as cubes, spheres, and rods, can influence selection and behavior. Nanomaterials that selectively reveal the reactive aspects by controlling their size[6].

Support Effects: Nanoparticles can be supported on carbon, silica, or alumina to increase stability and prevent agglomeration.[7].

Types of Nanocatalysis

Metal nanoparticles: These include PtNPs, PdNPs, and AuNps, which are utilized in oxidation, and hydrogenation processes.

Metal Oxide Nanoparticles: Examples of metal oxide nanoparticles employed in photocatalysis and redox processes are TiO_2 and CeO_2.

Core–Shell Nanostructures: The durability and selection of core-shell nanostructures are achieved by coating a core of one material with a shell of another.

Catalysts with a single atom (SAC): Single-atom catalysts (SACs) are individual metal atoms dispersed across a support to optimize atom efficiency.

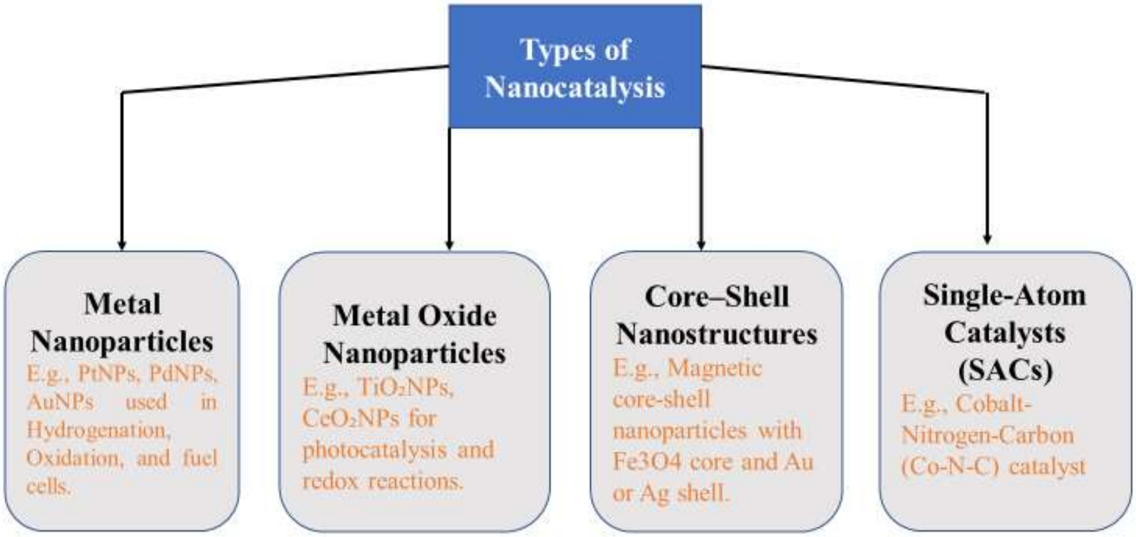

Figure 1: Types of Nanocatalysis [Ref 8-11].

Application of Nanocatalysis

Applications of nanocatalysis include Heat conservation and storage[12], environmental remediation[13], chemical Industry & fine Chemicals[14], pharmaceuticals and biotechnology[15], photocatalysis and solar Fuels[16], and biomedical[17] applications. Energy transformation and storage are essential today in many ways. Nanoparticles of platinum (Pt) are used in hydrogen fuel cells as catalysts for the oxygen decrease process .[18]. The development of hydrogen and oxygen

are catalyzed by nanocatalysts based on Ni, Co, and Fe to produce hydrogen fuel[19,20]. Lithium-ion and flow batteries benefit from improved redox processes thanks to nanocatalysts[21]. In modern day, environmental remediation is quite helpful. Organic contaminants in wastewater are broken down by TiO_2 and ZnO nanocatalysts using photocatalysis when exposed to UV or visible light.[22].In industrial emissions and vehicle exhaust, MnO_2 and CuO nanoparticles promote the breakdown of CO, NOx, and VOCs[23]. Fuels are produced by hydrogenating CO_2 using nanocatalysts based on Ni, Ru, and Fe.[24].

The chemical industry also uses nanocatalysis. Alkynes, nitro compounds, and ketones are selectively hydrogenated to produce desired products by Pd or Pt nanoparticles[25, 26]. In mild conditions, gold nanoparticles (AuNPs) catalyze the oxidation of alcohol [27]. Pd nanocatalysts work well in the Suzuki, Heck, and Sonogashira coupling for the production of agrochemicals and pharmaceuticals[28]. Biosensors and targeted drug activation utilize enzyme-mimicking nanocatalysts (nanozymes)[29]; Sunlight-absorbing semiconductor nanostructures (such as CdS, g-C_3N_4, and TiO_2) are what drive photocatalytic CO_2 reduction or hydrogen evolution.[30]; and catalytic cancer therapy (chemodynamic therapy) uses Fe_3O_4 or MnO_2 nanocatalysts to transform H_2O_2 into toxic radicals in tumor microenvironments[31].

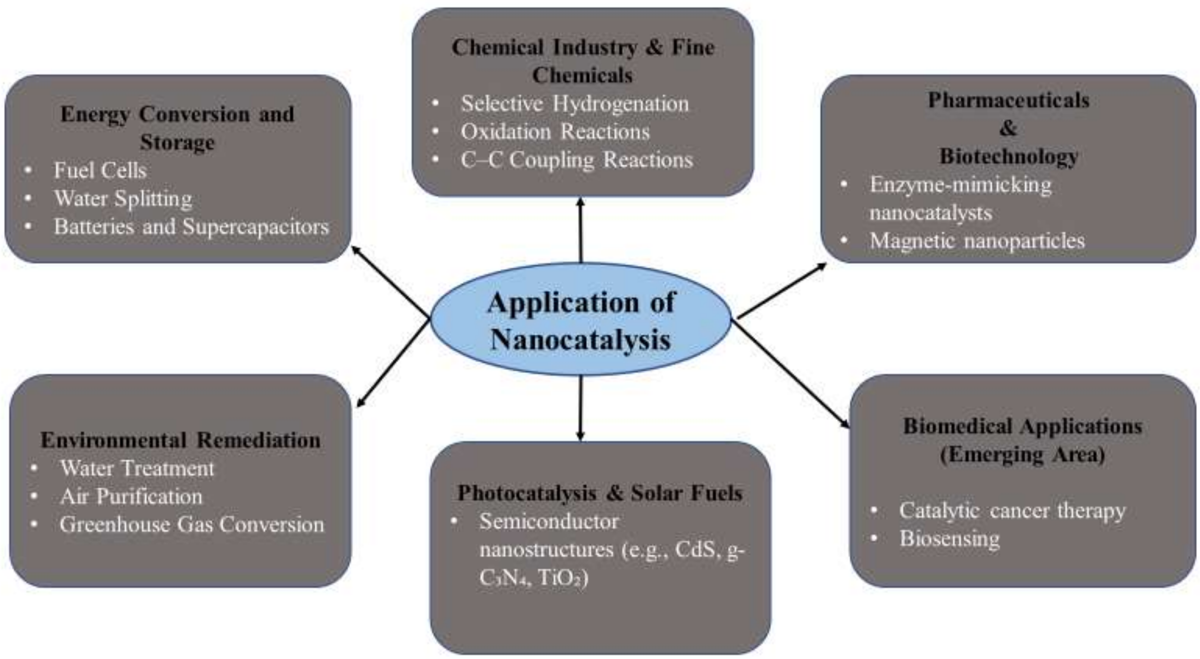

Figure 2. Application of Nanocatalysis in Different Areas. [Ref 12-31].

Conclusion

Nanocatalysis is a revolutionary approach to catalysis that provides significant improvements in accuracy, flexibility, and sustainability when compared to traditional catalytic systems.

Because nanocatalysts focus on the unique properties of nanomaterials, such as huge surface area, quantum effects, and programmable morphologies, they can achieve higher speeds of reaction and lower energy requirements. These innovations have a broad range of applications in environmental remediation, chemical synthesis, and conversion of energy. But issues like scalability, catalyst stability, and exact control over nanostructures still exist. More study is needed to fully explore the potential of nanocatalysis in commercial and green chemical applications.

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