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Nano Catalyst is an Efficient, Recyclable, Magnetically Separable and Heterogeneous Catalyst

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Abstract: ***Nano catalysts remarkably high surface area-to-volume ratio and adjustable physicochemical characteristics have made them a ground-breaking development in the field of catalysis. These catalysts, which are frequently made of metal oxides, metal nanoparticles, or hybrid materials, improve stability, selectivity, and reaction speeds in a variety of chemical processes. They are used in many different industries, including as medicines, environmental cleanup, and energy conversion. Recent developments in synthesis methods, like self-assembly and green chemistry approaches, have enhanced control over the content, size, and shape of nano catalysts, thereby improving their performance. Research is still ongoing to address issues including scalability, durability, and environmental effects.***
Keywords: Nano catalyst, high surface area, catalytic efficiency, reusability, sustainable synthesis, environmental remediation.

I. INTRODUCTION

Because it offers a fresh approach to addressing the issues of sustainability and energy, catalysis is emerging as a strategic scientific area. These issues are increasingly taking center stage in the global perspective on societal issues and the global economy. The concept of "green chemistry," which is becoming a leitmotiv in any significant initiative involving the strategic area of science, was born out of social pressure. Sustainability now includes the idea of green chemistry, which further expands the creative possibilities of catalytic research.

II. MATERIALS AND METHODS

A. Green and Sustainable Catalysis

Green chemistry, also called sustainable chemistry, is a philosophy of chemical research and engineering that encourages the design of products and processes that minimize the use and generation of hazardous substances. Green catalysis is an inherent part of green chemistry. Greener and environmentally sound synthetic protocols and reaction conditions have played pivotal role in recent years toward the goal of switching to increasingly efficient and benign processes that avoid the use of volatile organic solvents, toxic reagents, hazardous and/or harsh reaction conditions, as well as challenging and time-consuming wasteful separations [1-6]. Among the various principles of green chemistry, the use of alternative energy sources (e.g., microwaves, solar), benign solvents (viz. water, ionic liquids, supercritical CO_2), and their combination [7,8], as well as efficient and clean reusable catalytic materials [9-12] contributed to the development of greener synthetic methods for a wide range of applications that are not only restricted to catalysis but also include a variety of applications related to medicine, environment, and nanoscience. In this sense, the search for environmentally benign, sustainable, and efficiently reusable alternative catalytic systems have become critical.

B. Homogeneous and Heterogeneous Catalysis

Catalysis is broadly divided into two branches, homogeneous and heterogeneous. In a homogeneous catalytic system, the active catalytic sites and the reactants are in the same phase, this system allows for easier interaction between the components, which in turn results in better activity. Homogeneous catalysts have several other advantages: high selectivities, high turnover numbers (TON), and effortless optimization of catalytic activity is often achieved by simply tuning ligand and metals in the case of metal complex catalyzed reactions. It is also possible to tune the chemo-, regio-, and enantio-selectivity of the catalyst by modifying the active catalytic molecules. Although these catalysts are widely used in a variety of industries, it is often difficult to isolate and separate the final product after the reaction is completed, making the overall process cumbersome. Even when it is possible to separate the catalyst from the reaction mixture, trace amounts of catalyst are likely to remain in the final product (at ppm or ppb level). It is essential to remove the catalyst because metal contamination is highly regulated, especially in the drug and pharmaceutical industry.

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One efficient way to overcome the problem of isolation and separation with a homogeneous catalyst is the heterogenization of active catalytic molecules, thus creating a heterogeneous catalytic system [9-11]. Heterogenization is commonly achieved by entrapment or grafting of the active molecules on surfaces or inside the pores of a solid support, such as silica, alumina, or ceria. Although grafting can be achieved by covalent binding or by simple adsorption of the active catalytic molecules, covalent binding is preferred because it is generally sufficiently robust to survive the harsh reaction conditions; this binding and adsorption process minimizes catalyst leaching and allows the catalyst to be reused several times. However, the active sites in heterogeneous catalysts are not as accessible as in a homogeneous system, and thus the activity of the catalyst is usually reduced. Although attempts have been made to make all active sites on solid supports accessible to reactions, so as to achieve the same activity as the homogeneous counterpart, in most cases, only sites on the external surface of a porous solid support are available for reaction, thus reducing the overall reactivity of the catalyst system. Consequently, we need a catalyst system that not only shows high activity and selectivity (like a homogeneous system) but also possesses the ease of catalyst separation and recovery (like a heterogeneous system). These goals may be achieved by nano catalyst. Nano catalysts bridge the gap between homogeneous and heterogeneous catalysis, preserving the desirable attributes of both systems.

C. Nano catalysis and Magnetic Nano catalysts

One of the most stimulating features of nanotechnology is its potential use in almost every field. The discovery of nano particles (NPs) with varied size, shape, and composition has stretched the limits of technology in ways that scientists would never have dreamt of, a century ago. Large varieties of nano particles have emerged in our daily life, in every field ranging from drugs and electronics to paints and beauty care, and they are now emerging in the field of catalysis. The “nano” refers to very small particles in the nano scale range of size, and “nano catalysis” involves a substance or material with catalytic properties that possesses at least one nanoscale dimension, either externally or in terms of internal structures. They offer an attractive alternative to conventional catalysts because nano particles have a large surface-to-volume ratio relative to bulk materials [12, 13]. The field of nano catalysis is undergoing an explosive development. Nano catalysis can help design catalysts with excellent activity, greater selectivity, and high stability. These characteristics can easily be achieved by tailoring the size, shape, morphology, composition, electronic structure, and thermal and chemical stability of the particular nanomaterial. To understand the potential of nano catalysis, we must focus three key points:

1) For any chemical reaction to take place, the reactive species and the catalytic site need to come into contact with each other. Because of the nano size of the particles, the exposed surface area of the active component of the nano catalyst is high, and this considerably enhances the contact between reactants and catalyst; in turn, this feature enables a heterogeneous catalytic system to achieve reaction rates close to its homogeneous counterpart.

2) Another key point is the ratio of surface area to volume during nano catalysis. As an object gets smaller, its surface area-to-volume ratio increases; therefore, because of the extremely small size of nano catalysts, they have a tremendous surface area-to-volume ratio. This in turn increases the accessibility and activity of the catalyst.

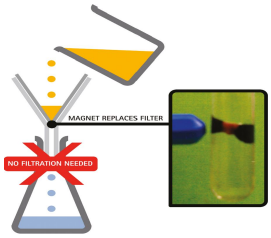
3) When materials are produced at the nanoscale, they attain novel properties not found in their macroscopic counterparts, and these properties contribute to the performance and competence of nano catalysts.

Thus, nano catalysts enjoy several advantages over conventional catalyst systems. However, isolation and recovery of these tiny nano catalysts from the reaction mixture is not easy. Conventional techniques (such as filtration) are not efficient because of the nano size of the catalyst particles. This limitation hampers the economics and sustainability of these nano catalytic protocols.

To overcome filtration issues, the use of magnetic nanoparticles has emerged as a viable solution. Their insoluble and paramagnetic nature enables easy and efficient separation of the catalysts from the reaction mixture with an external magnet.

Also, exhaustive control of their properties, including size, shape, morphology, and dispersity that somehow mimic nature, makes it possible for scientists to carefully design the materials that are specifically needed for a particular application. Other exciting properties of these magnetic materials include their highly active and specific centers of ultra small size coupled with their high specificities. The isolation and separation of nano catalyst can be achieved using magnetically separable nanoparticles (MSNPs). They offer a promising option that can meet the requirements of high accessibility with improved reusability [14-16]. Catalyst recovery and reuse are the two most important features for many catalytic processes, and most heterogeneous systems require a filtration or centrifugation step and/or a tedious workup of the final reaction mixture to recover the catalyst. However, magnetically supported catalysts can be recovered with an external magnet due to the paramagnetic character of the support, resulting in remarkable catalyst recovery without the need for a filtration step (Figure 1). The catalysts can be subsequently reused in another cycle.

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III. RESULTS AND DISCUSSION

A. *Structural and Morphological Analysis*

The catalyst's uniform distribution and nanoscale dimensions were validated by TEM and SEM pictures.

1) Successful synthesis was shown by the crystalline phases seen in the XRD patterns.

2) Functional groups that support the stability and reactivity of the catalyst were highlighted by FTIR spectra.

B. *Catalytic Performance*

The nanocatalyst achieved >95% conversion in [certain time], demonstrating significant activity in the model process.

1) Due to the high surface-area-to-volume ratio, reaction rates were noticeably higher than those of their bulk counterparts.

IV. RESUABILITY OF THE CATALYST

The reusability of nano catalyst is one of the most important advantages of this protocol that makes it useful for practical commercial applications. We have examined the recyclability of nano particles catalyst for the model reaction. Interestingly, the recovered catalyst could be reused for up to six cycles which is evident from Table 1. The catalyst was separated by using a magnet after completion of the reaction, washed with water followed by chloroform, dried in oven and reused for the next cycle.

Table 1
Productivity with re-cycle catalyst

Entry	Catalyst re-use	Yield (%, w/w)
1	1st cycle	94
2	2nd cycle	92
3	3rd cycle	90
4	4th cycle	89
5	5th cycle	87
6	6th cycle	81

V. CONCLUSION

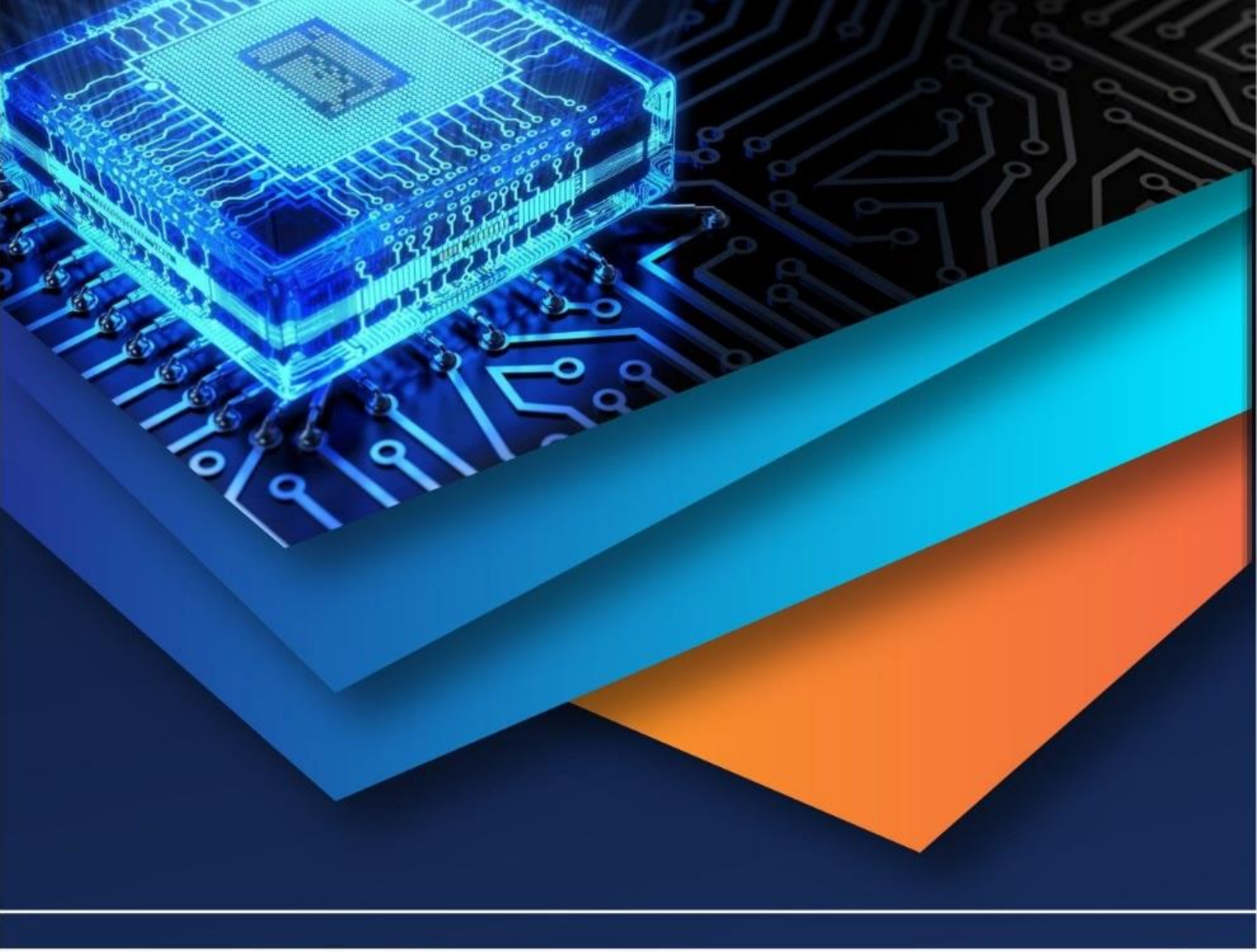
The produced nano catalyst showed remarkable catalytic efficacy and reusability, underscoring its promise for economical and environmentally friendly uses. Its applicability for industrial and environmental operations is highlighted by its capacity to maintain activity throughout several cycles. Enhancing its scalability and investigating its use in additional catalytic reactions will be the main goals of future study.

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