APPLICATIONS OF NANOMATERIALS IN CHEMICAL INDUSTRY

Abstract

The conventional chemical industry has grown into a largely mature sector with a sizable amount of common goods created using tried-and-true methods. Therefore, it is more likely that specialty chemicals, novel functionalities derived from new processing techniques, and new microstructure control procedures will lead to new product and market prospects. It is well known that a material's molecular structure and microstructure play major roles in determining its properties. In order to make new discoveries, it is essential to regulate structures at the Nano- and micro-scales. The controlled manipulation of nanomaterials with at least one dimension below 100 nm is referred to as nanotechnology in this article. The production of goods and chemical compounds by the chemical industry was expensive and required more energy. For the generation of industrial energy on a big scale, these materials are inadequate. Modern chemical methods are no longer employed as a result. Nowadays, one of the greatest approaches for creating chemical compounds from nanoparticles is biological procedures employing a chemical approach. As a result of its small size, nanomaterials have several unique characteristics. Catalysts, selective adsorbents, protection, chemical sensors, water purification, drug delivery, coatings, and the production of nanofibers and other biopharmaceuticals and medical devices are the main applications in the chemical industries, and they all play significant roles in fostering the growth of the sector.

Keywords: Nanomaterials, Chemical industries, chemical approach, chemical techniques,Water treatment, Drug delivery.

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I. INTRODUCTION

Nanomaterials are minuscule substances or substances utilized at an incredibly small scale. The term "material" encompasses an extensive array of elements that, when combined, give rise to overall statistically measurable characteristics. Due to this, the behaviour of functional nanoparticles is influenced by specific contact effects. These materials also showcase properties that emerge due to their minute size and limited building blocks. Nanomaterials are substances possessing at least one dimension within the nanoscale, ranging from 1 to 100 nm. These entities are beyond the scope of human visual perception. Approaches rooted in the materials science of nanotechnology come into play when dealing with nanoparticles. [1].

"Nanotechnology" is categorized into two subgroups: the fabrication of structures within the 1 to 100 nm size range, and the exploitation of materials' properties at the nanoscale for novel applications. This particular size range is currently capturing significant attention due to the fundamentally distinct traits exhibited by materials within it compared to their larger, bulk forms [2].Usually, this range spans from 100 nm to the scale of individual atoms. The amplified importance of surface and interfacial area is the primary driver behind this transformative shift in performance. Furthermore, nanotechnology presents a modern framework in which the bottom-up methodology is the standard approach, rather than the uncommon one, in advancing fundamental concepts and grasping the principles of the physical realm. Logical reasoning is necessary for comprehending the content of this book. Nanomaterials encompass substances with particles that are less than 100 nm in at least one dimension. [3]. Nanomaterials are distinguished from bulk materials and individual atoms by different features known as a surface effect, quantum size effect, macroscopic quantum tunneling effect, etc.

II. TYPES OF NANOMATERIALS

Nanomaterials with at least one nanoscale dimension are referred to as nano-layered. Examples include thin films and surface coatings. Two-dimensional nanomaterials at the nanoscale include nanotubes and nanowires. Carbon nanotubes and carbon nanofibers are two examples of this. Nanoparticles are described as having all three dimensions at the nanoscale. The four subcategories of nanomaterials include composites, metal-basedmaterials, dendrimers, and carbon-based materials. Imaging, thermal, mechanical, medicinal, and commercial qualities make purposely created nanoparticles in these four major categories highly sought after in applications across numerous industrial sectors [4].These NMs are categorized into groups based on their size, chemical composition, shape, and place of origin. According to the many NM types that have been synthesized from various sources, they are divided into several categories. Numerous NMs have been produced in substantial amounts as a result of the demand for various industrial uses. The two main ways of producing NMs are synthetic and naturally occurring nanoparticles (NPs) [5].

III. PROPERTIES OF NANOMATERIALS

Properties of materials at the nanoscale undergo significant transformations during decomposition. Quantum size effects lead to modifications in the electrical properties of materials across various scales, spanning from individual molecules to the nanoscale. Additionally, attributes such as thermal, mechanical, and catalytic behaviors of materials can

undergo alterations due to the heightened surface area to volume ratio that emerges in the nanoscale domain [6]. When reduced to nanoscale dimensions, many insulating materials start exhibiting conductive behavior. Similarly, a multitude of captivating quantum and surface phenomena come into play at these minute levels. Nanomaterials possess an array of physical and chemical attributes, including size, shape, chemical composition, crystal structure, stability, surface area, and surface energy. As the surface-to-volume ratio increases, nanomaterial surfaces become highly interactive with each other and other systems. The size of nanomaterials significantly influences their pharmacological impacts. Upon interaction with water or other dispersing fluids, the crystal structure of nanomaterials can undergo changes. The surface charge, composition, and size of nanomaterials all contribute to their aggregation tendencies [7]. These material’s surface coatings have an impact on their magnetic, physicochemical, and psychokinetic characteristics. Van der Waals forces, strong polar or covalent bonds, or other factors are what cause particle interaction at the nanoscale. Nanomaterials' surface properties and interactions with other materials can be changed using polyelectrolytes [8].
The important physical and chemical properties of nanomaterials are as shown below.

1. Dimensions, form, surface area, and aspect ratio.
2. Agglomeration is the state of aggregation.
3. Size distribution
4. Surface topography and morphology.
5. Structure, which includes crystallinity and structural defects.
6. Solvability.

Mechanical, thermal, electrical, melting, magnetic, catalytic, diffusive, and optical characteristics are only a few of the attributes of nanomaterials. Comparing them to their bulk equivalent, nanomaterials have certain special characteristics.The size of nanomaterials is what causes them to have their particular features [9].

IV. GENERAL APPLICATIONS OF NANOMATERIALS

Due to their magnetic, electrical, optical, and chemical capabilities, nanomaterials are virtually always utilized in every discipline. Their uses span current industry and the medical field. They are used in a variety of fields including space research, environmental science, automotive technology, textiles and fabrics, electronics, the food industry, medicine, tissue engineering, solar panels, lithium-ion batteries, lightweightarmor thin films, and high-efficiency sensors [10]. Here is a quick rundown of a few recent uses for nanomaterials.

1. **Food Industry:** To improve the quality of food packaging materials and lengthen their shelf lives, polymers and nanoparticles like silver are combined. Making it more flavourful and lasting. "Smart packaging," which enables the detection of biological changes taking place in food, is one of the significant applications of nanotechnology [11]. With the aim of maintaining the safety of food, nanotechnology is employed in agriculture and agribusiness in a variety of ways. When evaluating the significance of nanotechnology in food processing, one should take into account how it has improved food items in terms of their texture, appearance, flavour, nutritional value, and shelf life.

2. **Space Science:** Space science and research is another area where nanotechnology uses are evident. Research is being done on ways to deploy spacecraft with less fuel, in

addition to employing materials like CNT to make the exterior construction of satellites strong and light [12].

3. **Automobiles:** In the last ten years, there has been a paradigm shift in the vehicle business. New two- and four-wheeler versions with cutting-edge technologies are occasionally introduced. Another area of the economy where nanotechnology is used is the medical field. Several polymer nanocomposites, including Natural Rubber-Organoclay, have been used to increase the abrasion resistance of tires [13]. Furthermore, the mechanical characteristics of automotive fluids have been improved by introducing nanoparticles like tungsten Nanospheres.

4. **Electronics and Devices:** We have switched from clunky television sets and cell phones to elegant TV sets and smartphones as a result of technological improvement. Additionally, thanks to the development of nanomaterials like graphene, thinner, lighter, higher-quality, and power-efficient TV displays have been created [14].

5. **Textiles and Fabrics:** Specialized textiles containing Nano-sized Titanium and Silver particles are being utilized to create clothing that is wrinkle-free, odor-free, and wearable throughout the seasons. As a result, lightweight, breathable fabrics have been developed [15]. This industry also makes use of nanotechnology to make fabrics more durable and stain-resistant.

6. **Sporting Equipment and Goods:** Different co-curricular activities, including athletics, have become common choices for advancing one's profession in today's culture. And as a result, numerous ground-breaking changesparticularly in tennis and golfare being made [16]. Using nanomaterials like Silica nanoparticles, Nano clay fullerenes, etc., high-end racquets, new tennis balls with air releasing gradually, lightweight hockey sticks, and club shaft material with higher durability have all been made.

7. **Improving Air Quality:** Nanomaterials are widely employed to address the global problem of deteriorating air quality. On the one hand, air pollution is being removed using membranes coated with nanomaterials like graphene oxide. The effectiveness of catalysts, which may assist to reduce the impact of air pollution from industrial plants, vehicles, air conditioners, etc., is being researched, on the other hand, in an effort to increase their efficiency [17]. These nanoparticle-based catalysts offer a lot of surface area for chemical reactions.

8. **Energy Applications:** The ability of nanotechnology has substantially improved alternative energy methods to satisfy the rising global need for energy. Scientists are researching ways to use less energy and lessen the environmental toll that hazardous waste has on the ecosystem. Through enhanced catalysis, nanotechnology has increased the effectiveness of producing gasoline from unprocessed petroleum sources. Researchers are looking at carbon nanotube scrubbers to remove carbon dioxide from power plant exhaust. New battery kinds are being developed using nanotechnology, which are more efficient and have better charging capabilities [18]. The blades of windmills are made of epoxy that contains carbon nanotubes to increase the amount of electricity they can generate.

9. **Environmental Remediation:** Nanotechnology is being utilized to identify toxins and assist with environmental clean-up. Water pollutants are being identified and treated using nanotechnology. Engineers have created a thin film membrane with Nanopores for desalination that uses little energy [19]. Additionally, industrial water contaminants that collect in groundwater are cleaned with nanoparticles. Researchers have created a Nano cloth towel that can absorb 20 times its weight in oil and be used for clean-up.

10. **Nano Fertilizers:** Despite plants' poor nutrient absorption efficiency and large losses, mineral fertilizers are essential for food production. However, agricultural output may be increased and nutrient losses can be decreased by using nanotechnology. This has increased interest in bulk fertilizers that are nanotechnology-enabled, thus the term "Nano fertilizers." However, it has not yet been possible to produce Nano fertilizers on a big scale industrially [20]. Here, we highlight the scientific data and unresolved issues that are driving the fertilizer industry to produce Nano fertilizers, such as the idea that nanoscale materials are toxic, the lack of research on Nano fertilizers with important crop nutrients, the inadequateness of soil or field-based studies on Nano fertilizers, the type of nanomaterials to be produced as fertilizers, how to effectively and efficiently apply Nano fertilizers at the field scale, and the economics [21].

11. **Agriculture Field:** Contemporary studies have directed their attention towards examining how nanoparticles impact the germination and growth of plants, driven by the goal of optimizing their utilization in agricultural contexts. In the year 2005, Zheng et al. conducted a comprehensive exploration into the consequences of applying both nano and non-nano TiO2 to naturally-aged spinach seeds. The findings of the investigation unveiled noteworthy results: plants arising from seeds treated with nano-TiO2 showcased impressive enhancements. These enhancements encompassed a threefold amplification in the photosynthetic rate, a notable 45% elevation in chlorophyll-a production, and a substantial 73% increase in dry weight compared to control plants[22].

    Nano pesticides "involve either very small particles of the pesticide active ingredients or other small engineered structures with useful pesticide properties". Nano pesticides can improve agricultural formulations' dispersion and wettability (i.e., reduce organic solvent runoff) as well as unintended pesticide movement.Stiffness, permeability, crystallinity, thermal stability, and solubility are characteristics of nanomaterials and bio composites that are advantageous [23].

V. HOW AND WHY CHEMICAL INDUSTRY CAN EFFECTIVELY USE NANOMATERIALS?

The chemical industry can benefit from nanoparticles since they operate as their own reactors. Nanomaterials can provide a large surface area, high reactivity, and precise control over structure and form for chemical reactions. Nanotubes, nanowires, and Nanorods can function as Nano reactors for the synthesis of nanoparticles, polymers, and organic compounds, for example. Additionally, novel pathways for reactions such as photo, electro, and biocatalysts may be made possible by nanomaterials, which may increase the yield and selectivity of desired products [24].Nanomaterials have the potential to advance the chemical industrial sector as catalysts or catalyst supports. Chemicals called catalysts speed up chemical reactions without eating any of the end result. Nanomaterials with high activity, stability, tenability, and recyclability can be used as catalysts. For instance, metal nanoparticles made of gold, platinum, and palladium may act as catalysts in a variety of reactions such as hydrogenation, oxidation, and reduction [25]. Nanomaterials can also be used as supports or carriers to improve the dispersion, accessibility, and stability of other catalysts like enzymes, metals, or zeolites.

VI. APPLICATIONS OF NANOMATERIALS IN CHEMICAL INDUSTRIES

Chemical enterprises that employ inexpensive methods for the manufacture of electricity use nanotechnology to create chemical substances. Through the use of nanotechnology, certain significant industrially manufactured nanoparticles are employed to create various components of biomedical equipment. In all of the aforementioned applications of nanotechnology in the chemical industry, it is increasingly crucial to employ the technology in many domains for present and future generations as well as other energy-generating techniques [26].

1. **Role in Water Detoxification System:** When employing an integrated approach to water filtration, nanotechnology is important. Water containing harmful metals was consumed by several enterprises and discharged into the environment. Cellular toxicity and other issues connected to water are caused by metal concentrations that are too high. The production of 1 kilogram of textile fabric in textile factories requires 200–400 liters of water, making it one of the most chemically and water-intensive businesses in the world. Nearly all of the water consumed in this sector is released as waste [27]. Additionally, up to 75% of the dye might be lost in the textile industry's effluents. The elimination of colour from wastewater was thought to be more crucial than the elimination of other organic materials.

2. **Catalysis:** The realms of catalysis and nanotechnology have intertwined, resulting in a fusion where catalysis and nanotechnology are jointly harnessed. This amalgamation stands as the prevailing industrial trajectory for accelerating reactions across diverse sectors, all the while maintaining low costs and yielding high-quality end products. Within this swiftly evolving landscape, the domain of Nanocatalysis has emerged prominently, encompassing the employment of nanoparticles as catalysts for various applications in both homogeneous and heterogeneous catalysis. Among the initial practical implementations of nanoscience, heterogeneous catalysis has prominently arisen. This facet frequently employs nanoparticles comprised of metals, semiconductors, oxides, and other materials. [28].In the industrial field, novel metal constituents are supplanting their predecessors in various components, while the application of nanotechnology processes is driving the escalation of final material and industrial component production. Despite the substantial insights gained from surface science investigations that have enriched our foundational comprehension of catalysis, a prevailing approach in the creation of commercial catalysts persists in a process colloquially referred to as "mixing, shaking, and baking," which involves combining multiple components. However, the nanoscale structures of these catalysts remain inadequately controlled, and our grasp of the relationships between synthesis, structure, and performance in this context remains limited[29].

   Due to their complex physio-chemical properties at the nanoscale, even characterizing the multiple active sites of the majority of commercial catalysts is difficult. Nanocatalysis is an industrial phenomenon that monitors the rate of reactions, the development of a particular product at different rates of reactions, and the final, controlled reactions throughout all processes that raise the Caliber of completed goods and instrument parts. In the last 10 years, the subject of Nanocatalysis, which is centered on the use of nanoparticles to catalyse processes, has seen remarkable growth in both homogeneous and heterogeneous catalysis. The fact that nanoparticles have a larger surface-to-volume ratio than bulk materials make them good candidates for use as catalysts [30]

3. **Nanotechnology in Coatings & Paint Industry:** Nano polymer coatings can reflect heat to control temperature and improve the fuel efficiency of air conditioners when put over automotive paint. Paints using ceramic nanoparticles can shield automobiles from tiny dings, while Nano polymer coatings on top of the paint can reflect heat to control temperature and improve the fuel efficiency of air conditioners [31].It has been noted recently that the development of intelligent nanoparticles for use in solid surface coating has increased. Numerous capabilities, including anticorrosive, antibacterial, and self-cleaning qualities, are offered by these nanostructures. Titanium dioxide (TiO_2) and zinc oxide (ZnO) nanoparticles were synthesized utilizing green chemistry principles. [32]. The nanoparticles underwent comprehensive characterization employing SEM, energy-dispersive X-ray analysis, high-resolution transmission electron microscopy, X-ray diffraction, ultraviolet-visible spectroscopy, the Brunauer-Emmett-Teller test, and nitrogen adsorption-desorption isotherms. Subsequently, for the modification of commercial enamel-type paint, three distinct nanoparticle concentrations (2%, 3.5%, and 5% w/v) were introduced into the paint formulation [33].

   The Nano-filled paints were subsequently administered onto diverse substrates like carbon steel sheets, wooden panels, and aluminum disks. The suitability of these Nano-filled paints for various applications was gauged through an assessment of their anti-corrosive, self-cleaning, and antibacterial properties. The outcomes of the characterization unveiled that both TiO_2 and ZnO nanoparticles exhibited physicochemical attributes akin to those generated through conventional means. In terms of anti-corrosion efficacy, the nanoparticle-infused paints acted as a protective barrier, employing minimal nanoparticle concentrations to hinder the development of excessive porosity [34]. Agglomerates on the surface are diminished, which is why. Due to a supposed mechanism of degradation that demonstrated substantial methylene blue degradation during self-cleaning, both nanoparticles were present in the paint.As businesses and structures grow, antimicrobial, antifungal, and antibacterial biocides are expected to be used increasingly often. As fungus, algae, and bacteria may all be very harmful to painted surfaces, biocides in paint prevent their growth, giving the surfaces an anti-microbial layer [35].Nanomaterials may alter the chemical makeup of any solution. They are typically only added in traces to the coating material. They might alter the coating material's structure, flow behavior, surface tension, gloss, UV and weather resistance, and a host of other properties.

4. **Drug Delivery:** In the realm of Nanomedicine, the field of drug delivery and its associated pharmaceutical advancement can be understood as the study and application of intricate systems at the nanoscale (ranging from 10 to 1000 nm). These systems comprise of a minimum of two constituents, with one being a pharmacologically active component. It is worth noting that even nanoparticle-based formulations of the drug are conceivable. This holistic assembly serves a distinct purpose in the realms of treating, preventing, or

detecting medical conditions. These features are usually referred to as agnostics or smart drugs. The following are the primary goals of research into the use of Nano-biotechnologies in the administration of medications: more precise medicine distribution and targeting [36].

Desirable results include increased safety and biocompatibility, a reduction in toxicity while maintaining therapeutic efficacy, and a speedier development of new safe drugs.The following factors are the main issues in the hunt for appropriate carriers as drug delivery systems since they are prerequisites for the development of innovative materials. They include topics such as medication integration and release, formulation shelf life and stability, biocompatibility, biodistribution and targeting, and operation [37]. Furthermore, it is critical to consider any potential detrimental effects of any residual material following medicine delivery when it is solely used as a carrier. In this context, short-lived biodegradable nanoparticles that may be used for as long as needed for therapeutic reasons are desirable.

5. **Chemical Sensors:** The presence of chemical species and nanoparticles may be detected using Nanosensors, which can be mechanical or chemical in nature. They can also be used to assess physical values like temperature. Since the small particles are nanometre-sized, Nanosensors can detect them.Nanosensors possess the remarkable capability to detect even a single molecule. These sensors consist of essential components, namely the analyte, sensor, transducer (which transforms one form of energy to another), and detector. The operational mechanism of nanosensors often involves monitoring electrical variations within the sensor materials. The analyte migrates from the solution to the sensor surface, initiating an effective and discerning reaction that induces alterations in the physicochemical attributes of the transducer surface[38].

6. **Nanofiltration:** Since their initial discovery in the late 1980s, nanofiltration membranes have undergone significant advancements. These membranes typically feature nanopores measuring around 1 nm in size, corresponding to a molecular weight cut-off (MWCO) of 300–500 Da. Positioned between reverse osmosis (RO) and ultrafiltration (UF), nanofiltration membranes exhibit properties that bridge these two methods. When in contact with an aqueous solution, nanofiltration membranes develop a slight electrical charge due to the dissociation of surface functional groups or the adsorption of charged solutes. This phenomenon is evident in polymeric nanofiltration membranes containing ionizable groups like carboxylic and sulfonic acid groups, which lead to charged surfaces when a feed solution is present. Just as with RO membranes, nanofiltration membranes excel in separating inorganic ions from small organic molecules. Notably, the distinctive feature that sets nanofiltration apart is its capacity for efficient separation despite lower rejection rates [39]. Two membrane liquid separation techniques, reverse osmosis (RO) and nanofiltration (NF), have several things in common. In contrast to RO, which has a high rejection of practically all dissolved solutes, NF offers a significant rejection of multivalent ions like calcium and a modest rejection of monovalent ions like chloride.Ca^{2+}, Mg^{2+}, Al^{3+}, CO_3^{2}, and SO_4^{2} are just a few examples of the bi- or trivalent ions that Nanofiltration (NF) effectively eliminates, while Na+, K+, and Cl are removed with an efficiency of up to 40% [40].

7. **Adsorption:** Dendrimer-like molecules with several branches, known as polymeric nano adsorbents, are efficient in removing both organic and heavy metal pollutants. They

consist of specially crafted outside branches that can adsorb heavy metals and inside hydrophobic shells that can absorb organic compounds.The new remediation strategy for removing NOM from water uses Nano adsorbents. The effect of coagulation on the adsorption capacity of carbon black has been researched. When NOM-enriched water was treated to modest dosages of alum coagulation before adsorption, the rate of carbon black adsorption effectiveness improved (by 90%), according to Wang et al. (2010), who observed that employing carbon black at pH 3-5 removed >60% of NOM. Utilizing multiple-walled Nano carbon tubes to remove [41].

8. **Oil and Gas:** The potential of nanotechnologies to induce transformative shifts in the materials employed within the oil and gas domains is substantial. The integration of nanomaterials, such as solid composites and functional nanoparticle fluids, has facilitated noteworthy technological strides across the oil and gas industry. These advancements span key areas including drilling, oil well cementing, hydraulic fracturing, heavy oil extraction, flow assurance, and drilling processes, where nanomaterials find essential applications. The realm of nanotechnology research holds considerable potential for ushering in a revolutionary era within the petroleum sector[42]. The expansion of innovative technology in hydrocarbon recovery procedures has been considerably aided by the rise in global energy consumption and the rising need for fossil fuels as the primary energy source. Numerous studies have been conducted on new classes of materials, such as nanoparticles, in an effort to provide easier and more cost-effective oil exploration and production procedures, particularly in difficult and hostile reservoir conditions. Nanomaterials are used in nearly every oil and gas-related operation, including exploration, reservoir characterization, drilling, cementing, production and stimulation, enhanced oil recovery (EOR), refining, and processing, due to their special physical and chemical characteristics [43]. The most recent advancements in nanomaterials and their roles in novel or improved applications in the oil and gas sector are thoroughly discussed in this review article.

VII. FUTURE APPLICATIONS AND RESEARCH ON NANOMATERIALS

In upcoming times, the field of nanotechnology holds the promise of empowering objects to harness energy from their surroundings. By harnessing novel nanomaterials and innovative concepts, there is a potential for achieving impressive conversion efficiencies in generating energy from various sources like motion, light, temperature fluctuations, glucose, and more. Additionally, nanotechnology supports advancements in areas like precise biology, quantum computing, and additive manufacturing. The top nanotechnology trends are Nanoencapsulation and improved carbon and composite-based nanomaterials [44].

The topmost future trends in nanotechnology include Nanocarbon materials, nanoscale semiconductor devices Sustainable NanotechnologyNanocomposites, Nanosensors, Nanofilms, Nanoencapsulation, Energy NanomaterialsNanotechnology Computational [45-48].

VIII. CONCLUSION

The idea behind nanotechnology is that atoms will form the foundation of future technologies. It has an influence on every field of science and technology and offers enabling technology that is applicable to industry and will lead to huge new product and market possibilities. The chemical industry currently experiences the effects of nanotechnology in numerous domains, and this influence will continue to rise exponentially in our daily lives. Research on nanomaterials is currently being conducted by industry leaders. If new nanomaterials are created, the chemical sector can gain greatly from nanotechnology in the future. The possibilities of nanotechnology are endless.

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