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Application of Organic Chemistry in the Design and Development of Nanomaterials to Enhance Material Properties

Nazar Jamal Abdulhameed

College of science

Chemistry department

Mosul university

nazaratroshi89@gmail.com

Abstract:

The added value of our study comes from the new knowledge it provides, through which we can identify the effect of organic chemistry on nanomaterials and the effect of the latter on organic chemistry. This study also provides the chemical reactions that must be carried out to develop nanomaterials first and find new nanomaterials second. The study also clarifies what nanomaterials can do to improve the functions of many materials and products and how this can support the efficiency of the industrial process and increase the quality of production. The study also explains what future developments in the field of nanomaterials will be, which helps specialists and decision-makers to make the right decision that works to achieve sustainable development. The study concluded that nanomaterials should be used to improve the properties of polymers, as they provide great benefits and improve the functions and advantages of polymers, which leads to their use in various industries and applications.

The only obstacle is the set of difficulties and challenges we may face in the development process, but these can be overcome to achieve the desired benefit from the process.

Keyword: Organic Chemistry, Nanomaterials, Industrial Development, Job Performance, Sustainable Development

Introduction

Organic chemistry is one of the fundamental sciences that plays a vital role in understanding the structure and behavior of carbon-containing compounds. It is the cornerstone of many scientific and technological innovations. In recent years, nanomaterials have garnered increasing interest from both researchers and industry professionals due to their unique properties that distinguish them from traditional materials. Nanomaterials exhibit a significantly increased surface-to-volume ratio, leading to enhanced chemical and physical interactions, making them ideal for a variety of applications ranging from medicine to electronics and environmental science (Joseph, S :2010).

Organic chemistry enables the design and development of new nanomaterials by utilizing organic compounds as raw materials, contributing to the improvement of these materials' properties and enhancing their performance. By exploiting chemical reactions and modern techniques, researchers can develop innovative methods for synthesizing nanomaterials, opening new horizons in various fields (Zhang, Y., Wang, X: 2018).

❖ Research Problem:

Despite significant advancements in the field of nanomaterials and their diverse applications, there are still substantial challenges facing researchers and practitioners in this area. These challenges relate to several aspects, including:

1. Manufacturing Techniques: Current methods for preparing nanomaterials require improvements to ensure precise control over dimensions, shape, and composition, which affects the properties of the final material.
2. Practical Applications: Although there are numerous theoretical applications for nanomaterials, there is an urgent need to develop effective and marketable practical applications that ensure sustainability and safety.

This study aims to explore how organic chemistry can be utilized in the design, development, and enhancement of the properties of nanomaterials, focusing on challenges related to manufacturing, applications, and environmental and health impacts. By analyzing these aspects, new insights can be provided that contribute to enhancing the understanding and effective application of nanomaterial

❖ Importance of the Study

he importance of our study stems from the scientific knowledge it provides, as it explores the mutual influence between organic chemistry and nanomaterials, as the study explains the chemical processes and reactions necessary to develop and create new nanomaterials.

The study also highlights the role played by nanomaterials in improving the functional performance of many products of various types, from medical materials to electronic parts. By studying how these materials are manufactured with the help of organic chemistry, this improves the industrial process and increases the quality of production.

This study also works to find future trends in the field of nanomaterials, which enables decision-makers to take rapid steps towards sustainable development.

❖ Objectives of the Study

The objectives of the study can be listed as follows:

1. Analyzing the relationship between organic chemistry and nanomaterials: studying how to design and develop nanomaterials, focusing on the chemical reactions and chemical techniques used to develop them. The effect of these materials on thermal and physical properties will be studied.

2. Identifying the difficulties that may face those who manufacture nanomaterials, in terms of controlling the dimensions, shape and composition of these materials, and exploring methods for addressing these difficulties.

3. Studying the areas in which nanomaterials can be used in various fields such as engineering, electronics and medicine, and evaluating the effectiveness of these applications.

4. Providing suggestions regarding nanomaterials and their development, focusing on development, research and innovation in organic chemistry.

❖ Concept of Nanomaterials

Nanomaterials are those materials that have nanoparticles incorporated into them during the manufacturing process, resulting in significant improvements in their properties. For example, the addition of carbon nanotubes enhances the electrical and thermal conductivity of the material (J. Manojlović: 2018).

There are various general applications for nanotechnology, including the manufacturing of organic light-emitting diodes (OLEDs) used in displays, films, and photovoltaic cells that convert light into electrical energy. Other applications include self-cleaning windows coated with UV-resistant materials, smart fabrics that regulate temperature and monitor heart rate and respiration, as well as the production of advanced coatings and many other applications. (A. Nouailhat: 2010).

- **Definition of Nanomaterials**

Nanomaterials are materials that contain components or structures at the nanoscale, meaning their dimensions range from 1 to 100 nanometers. These materials can be individual particles, aggregates of particles, or complex structures. Nanomaterials are classified into several categories, including:

1. Natural Nanomaterials: Such as viruses and biolipids.
2. Synthetic Nanomaterials: Which are produced through chemical or physical techniques, such as metallic nanoparticles or nanopolymers.
3. 3. Nanoparticles: These are substances that incorporate nanoparticles during their production process, leading to notable enhancements in their characteristics. For instance, the inclusion of carbon nanotubes alters the material's electrical and thermal conductivity.(S. Bhosale, :2018).

- **Kinds of Nanomaterials**

Nanomaterials can be manufactured in several forms depending on the intended use of these materials, the most important forms are the following:

1. Quantum Dots

Quantum dots are three-dimensional semiconductor nanostructures with sizes ranging from 2 to 10 nanometers, which equates to about 10 to 50 atoms in diameter or roughly 100 to 100,000 atoms in total for a single quantum dot. These structures confine conduction band electrons and valence band holes, also known as excitons, which are pairs of bound conduction electrons and valence holes.

2. Fullerenes

A unique type of carbon nanostructure is the fullerene, a molecule composed of 60 carbon atoms, represented by the formula C60. Discovered in 1985, the fullerene has a spherical shape resembling a soccer ball, featuring 12 pentagonal and 20 hexagonal facets. Since the method for synthesizing fullerenes was developed in 1990, they have been produced in significant quantities for commercial use.

3. Carbon Nanoballs

Among the various types of carbon nanostructures, carbon nanoballs stand out as members of the fullerene family. Composed of C60, they differ slightly as they are multi-shelled and hollow at their core, unlike typical nanoparticles. Their surface is seamless, contrasting with multi-shelled nanotubes. Due to their layered structure resembling onions, they are referred to as "bucky onions," and their diameter can reach 500 nanometers or more.

4. Nanoparticles

Nanoparticles are defined as assemblies of atoms or molecules that can range from a few atoms (as in a molecule) to millions of atoms, typically forming nearly spherical shapes with radii under 100 nanometers. A nanoparticle with a diameter of one nanometer contains around 25 atoms, most of which are located on its surface. This characteristic differentiates nanoparticles from molecules, as their dimensions fall below critical thresholds necessary for certain physical phenomena, such as the average free path that electrons travel between collisions with vibrating atoms, which influences electrical conductivity.

5. Nanotubes

Nanotubes can also be constructed from inorganic materials like metal oxides (such as vanadium oxide and manganese oxide), boron nitride, and molybdenum. While they share a similar structure with carbon nanotubes, they tend to be heavier and exhibit lower strength compared to their carbon counterparts.

6. Nanofibers

Recently, nanofibers have garnered significant interest for their potential industrial applications. Various shapes have been identified, including hexagonal, spiral, and corn-like fibers. The cross-section of a nanofiber may take on a hexagonal form rather than a cylindrical one. The most well-known nanofibers are those derived from polymer atoms.

7. Nanowires

Nanowires are characterized by diameters that can be less than one nanometer and vary in length, achieving length-to-width ratios exceeding 1000 times. This makes them one-dimensional materials that outperform traditional three-dimensional wires in terms of performance. (S. Ahmed, M. Ahmad, B.L. Swami, S. Ikram: 2016) .

❖ Organic Chemistry and Nanomaterials

Organic chemistry is one of the fundamental branches of chemistry, focusing on the study of compounds containing carbon. Organic chemistry plays a vital role in the development of new materials and technological innovations, including nanomaterials .

In recent years, research has shown that integrating the fundamental principles of organic chemistry with nanomaterial techniques can lead to the development of new compounds with unique properties., organic molecules can be used as building blocks to construct complex nanostructures, opening new horizons in fields such as medicine, where drugs can be designed to target specific cells using nanotechnology.

(Kumar, A., et al. :2020)

- **The Role of Organic Chemistry in Designing Nanomaterials**

The most important topics studied by scientists in the field of nanochemistry include:

1. Manufacturing and characterization of nanomaterials: This relates to methods of manufacturing materials at the nanometer scale and how to characterize and analyze these materials using advanced techniques.
2. Nanosurface interactions: The main challenge is to understand the chemical interactions that occur on the surface of nanomaterials and their effect on the properties of the materials.
3. Nanotechnology applications: These applications include the use of nanomaterials in fields such as medicine, energy, and materials (such as smart coatings and lightweight and durable materials) (Lee, J., Park, S. :2019).

In the field of medicine, nanochemistry is of great importance. Here are some of the main applications of nanochemistry in the field of medicine:

1. Advanced medical diagnosis**: Taking advantage of nanotechnology allows the development of accurate and effective diagnostic devices.
2. Targeted drug therapy**: Nanomaterials can be used to deliver drugs to affected organs in a precise and targeted manner. For example, drugs can be encapsulated within nanoparticles to improve their absorption and delivery to target organs within the body, increasing the effectiveness of treatment and reducing side effects.
3. Medical imaging in X-ray and MRI**: Nanomaterials can be used as imaging enhancement agents for medical imaging, where nanoparticles can be employed

to increase the contrast and resolution of images extracted from medical imaging devices.

4. Nanoparticle thermal therapy**: Nanoparticles carrying materials that have magnetic or optical properties can be used to heat targeted cancerous tumors using a magnetic field or emitted radiation, which leads to the destruction of cancer cells without harming nearby healthy tissue.

These areas represent only a part of the wide and diverse applications of nanochemistry in medicine. Research and developments in this field are expected to continue to improve healthcare and provide more effective and less harmful treatments for patients.(Chen, L., et al. :2021).

- **Preparation Techniques**

The synthesis of nanomaterials involves several methods, each with its own unique mechanisms and applications.

The main methods include physical vapor deposition (PVD), chemical vapor deposition (CVD), solid gels, electrodeposition, and ball milling.

Physical Vapor Deposition (PVD)

Physical vapor deposition (PVD) is a process in which materials are evaporated in a vacuum environment and then deposited onto a substrate.

Chemical Vapor Deposition (CVD)

Chemical Vapor Deposition (CVD) differs from PVD in that it uses gaseous precursors to deposit materials.

This technique is commonly employed for the fabrication of nanomaterials due to its capability to regulate the dimensions, morphology, and composition of the substances (Patel, R., Sharma, P. (2022).

Sol-gel

A sol-gel refers to a chemical solution that serves as a precursor for nanomaterials based on oxides.

The sol-gel process involves the formation of a colloidal suspension (sol) that is then gelled to form a solid network (gel).

Electrodeposition

Electrodeposition is a method in which ions in solution are deposited onto a substrate through an electric field.

This technique is used to create metallic nanostructures and can be controlled to produce materials with specific shapes and sizes.

Ball milling

Ball milling is a mechanical method that involves the use of a high-energy grinding process to synthesize nanomaterials.

In this method, the powder material is placed in a container with solid balls, and the container is rotated at high speeds.

Ball milling is a versatile method that can be used to produce a variety of nanomaterials, including magnetic and catalytic materials.

However, it is known for potential contamination issues, which can be mitigated by using high-quality materials and controlled environments.

Each of these techniques offers distinct benefits and drawbacks, and the selection of a particular method is influenced by the specific needs of the nanomaterials being produced, such as their dimensions, shape, composition, and intended use(V. Prakash Sharma, U. Sharma, M. Chattopadhyay, V.N. Shukla: 2018).

❖ Uses of Nanomaterials

The field of nanotechnology encompasses a diverse array of applications across various sectors, including industry, defense, healthcare, agriculture, and more. For instance, many raw materials are enhanced to modify their physical characteristics at the nanoscale. Nanoparticles, in particular, exhibit a notable increase in their surface area relative to their volume. As a result, their optical characteristics, such as fluorescence, become dependent on the size of the particles. When integrated into bulk materials, nanoparticles significantly influence the mechanical properties of those materials, such as hardness and ductility. For example, traditional polymers can be strengthened by incorporating nanoparticles from novel materials, providing lightweight alternatives to metals. Consequently, the practical benefits of nanoparticles are anticipated to grow. These nano-enhanced materials facilitate weight reduction while simultaneously improving stability and functionality. Furthermore, practical applications of nanotechnology reflect an enhanced capability to manipulate matter with precision at scales that were previously unattainable, opening up possibilities that were once unimaginable—thus it is not surprising that very few domains of human technology have remained untouched by the advantages of nanotechnology (Singh, A., et al. :2020).

- **Case Study: Practical Application**

We will study a case study related to the development of a new nanomaterial aimed at improving the properties of polymers. Polymers are materials that are mainly used in many industrial technologies, but they often suffer from weakness in some properties such as strength, stiffness and heat resistance.

1. The importance of improving polymer properties

Various industries seek to enhance and change the properties of polymers in order for them to be useful in complex applications. Especially in heavy industries such as the automotive and aerospace industries, materials must be strong and durable, but at the same time lightweight.

2. Methods of enhancing nanomaterials

It will be explained how we can use nanomaterials as additives to improve the physical and chemical properties of polymers.

• Objective of the experiment

This project aims to investigate how nanomaterials can be used to improve the thermal, mechanical and electrical properties of polymeric materials.

- **Materials Used in the Experiment**

Nanomaterial: Graphene

Polymer: Polyethylene.

- **Tools Used in the Experiment**

1. Preparation Equipment:

- Mechanical mixer.

• Ball mill.

2. Testing tools

• Electron microscope.

• Mechanical properties tester.

• Thermal analysis device.

• Electrical conductivity meter.

• **Work steps**

After determining the objective of the experiment and determining the materials used, the polymer was prepared with nanomaterials, ensuring that the size of the nanoparticles was appropriate, and the polymer was mixed with nanomaterials using a mechanical mixer according to the equation:

$$\mathbf{Cf = (C_p \cdot V_p + C_n \cdot V_n) / Vf}$$

Where:

C_f = Final concentration of the mixture.

C_p = Concentration of the polymer.

C_n = Concentration of the nanomaterials.

V_p = Volume of the polymer.

V_n = Volume of the nanomaterials.

V_f = Total volume of the mixture.

The sample was then formed using casting and pressing methods, and thermal treatment of the samples was performed. The properties were tested as follows:

1. Mechanical Properties Testing:

A tensile and compression testing machine was used to evaluate strength and durability. The results are shown in Table 1.

Table 1: Tensile Test Results

Hardness	(%) Elongation	MPa Stress	Sample
70	**5**	**30**	Pure Polymer
75	**6**	**35**	Polymer with 1% Nano
80	**8**	**45**	Polymer with 3% Nano
85	**10**	**50**	Polymer with 5% Nano

From the analysis of Table 1, we observe a significant increase in tensile stress with the increase in the concentration of nanomaterials. It increased from 30 MPa for the pure polymer to 50 MPa with 5% nano. Elongation also increased, indicating improved flexibility. This suggests that the nanomaterials have contributed to enhancing the cohesion of the polymer and increasing its ability to stretch before breaking.

Effect of Dispersion

Table 2: Tensile Test Results with Different Dispersion Methods for Nanomaterials

Hardness	Elongation (%) |	Stress (MPa)	Dispersion Method	Sample
80	**8**	**45**	Mechanical Dispersion	Polymer with 3% Nano
85	**10**	**50**	Ultrasonic Dispersion	Polymer with 3% Nano
82	**9**	**48**	Thermal Dispersion	Polymer with 3% Nano

From the analysis of Table 2, the results showed that using the ultrasonic dispersion method led to a significant improvement in mechanical properties compared to mechanical or thermal dispersion. This indicates that a homogeneous distribution of nanoparticles within the polymer enhances performance.

Effect of Particle Size

Table 3: Tensile Test Results with Different Nanoparticle Sizes

Hardness	Elongation (%)	Stress (MPa)	Size	Sample
80	**8**	**4**	**50**	Polymer with 3% Nano
78	**7**	**40**	**100**	Polymer with 3% Nano
75	**6**	**35**	**200**	Polymer with 3% Nano

By analyzing and studying the analysis of Table 3, we notice that the particle size has a great effect on the mechanical specifications. Small polymer particles greatly improve stress and elongation because they provide a larger surface area for interaction with the polymer.

Effect of Temperature During Processing

Table 4: Tensile Test Results at Different Processing Temperatures

Hardness	Elongation (%)	Stress (MPa)	Temperature	Sample
78	**7**	**40**	**150**	Polymer with 3% Nano
80	**8**	**45**	**180**	Polymer with 3% Nano
85	**10**	**50**	**210**	Polymer with 3% Nano

By studying and analyzing Table 4, we notice that increasing the temperature during processing develops the mechanical specifications, and this is due to the interaction between the polymer and the nanomaterials when the temperatures are high, this strengthens the bonds between these materials.

From the analysis of the outputs, we notice that there are several factors that have an impact on the mechanical specifications of polymers supported by the introduction of nanomaterials, including:

• Dispersion method: Dispersing the materials strengthens their specifications.

• Particle size: Small particles strengthen the specifications.

• Processing temperature: As high temperatures improve the interaction**Thermal Properties Testing :**

A DSC/TGA calorimeter was used to study thermal properties.

Table 5: Differential Scanning Calorimetry (DSC) Analysis Results

Decomposition Temperature (°C)	Melting Heat (J/g)	Melting Temperature	Sample
300	**120**	**180**	Pure Polymer
305	**125**	**185**	Polymer with 1% Nano
310	**130**	**190**	Polymer with 3% Nano
315	**135**	**195**	Polymer with 5% Nano

By studying and analyzing Table 5, we notice that the more nanomaterials we add, the more the melting temperature of the polymer increases, meaning that there is an increase in thermal stability and the required melting temperature also increases, meaning that we conclude that nanomaterials act as strengthening agents and enhance the durability of the polymer under high temperatures.

The following equation can be used in DSC analysis to describe heat changes during heating or cooling processes :

$$Q = m \cdot C_p \cdot \Delta T$$

Where :

Q = Heat required to change temperature .

m = Mass .

C_p = Specific heat capacity .

ΔT = Change in temperature.

2. Electrical Properties Testing :

An electrical conductivity meter was used to assess the electrical properties of the samples.

Table 6: Electrical Conductivity Test Results

S/m Conductivity	Sample
0.01	Pure Polymer
0.02	Polymer with 1% Nano
0.05	Polymer with 3% Nano
0.10	Polymer with 5% Nano

By analyzing Table No. 6, the results showed that the higher the percentage of nanomaterials, the higher the ability to conduct electricity. This indicates that nanomaterials worked to enhance the transfer of charge within the polymer, which made it suitable for electronic uses.

❖ Challenges Faced in Developing Nanomaterials to Improve Polymer Properties:

1. We faced a problem in finding compatibility between nanomaterials and polymers whose specifications need to be improved, as a material must be chosen that improves the properties and does not negatively affect the existing properties.

2. Difficulties in the preparation process, as there is difficulty in finding the appropriate mechanism through which we can find polymers.

3. Difficulty in finding the appropriate dispersion that preserves and develops the properties of all kinds

4. Difficulty in testing and analyzing some properties to study the percentage and extent of their improvement

5. High cost of the materials used, which affects the economic feasibility of the project

6. Difficulty in stabilizing nanomaterials

Conclusions

1. Interaction between Organic Chemistry and Nanomaterials: The research demonstrates a mutual interaction between organic chemistry and nanomaterials, enhancing our understanding of how to develop new materials with improved properties.

2. Improvement of Functional Performance: The use of nanomaterials contributes to improving the functional performance of many products, including medical materials and electronic parts.

3. Future Trends: The study provides insights into future trends in the field of nanomaterials, helping decision-makers take rapid steps towards sustainable development.

4. Obstacles and Possibilities: Although there are hurdles in the development phase, there are considerable prospects to leverage nanomaterials for improving the properties of polymers."

Recommendations

1. Increase Research and Development: There should be an increase in investment in research and development in the fields of organic chemistry and nanomaterials to enhance innovation and achieve greater benefits.

2. Provide Training and Resources: Necessary training and resources should be provided for scientists and engineers to understand and utilize modern technologies in this field.

3. Encourage Intersectoral Collaboration: It is recommended to encourage collaboration between the academic and industrial sectors to facilitate knowledge and experience exchange.

Proposals:

1. Establish Specialized Research Centers: It is proposed to establish specialized research centers focusing on the study of nanomaterials and their practical applications in various industries.

2. Develop Standardized Guidelines: There should be a development of standardized guidelines for using nanomaterials in products to ensure quality and safety.

3. Conduct Case Studies: It is advised to conduct case studies to document the practical benefits of using nanomaterials in different fields, which helps build trust in this technology.

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