AMERICAN JOURNALS
Open Access,
Peer Reviewed Journals

American Journal of Pedagogical and Educational Research
ISSN (E): 2832-9791| Volume 34, |March - 2025

COORDINATED POLYMERS: SYNTHESIS, STRUCTURE PROPERTIES AND POTENTIAL APPLICATIONS

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ABSTRACT

This article covers the issues of synthesis of coordinated polymers, their structural properties and potential applications. During the study, types of structure of metal-ligand-based coordinated polymers, their physicochemical properties and functional capabilities were analyzed in depth. Solvothermal, gel reactions and modular approaches were used as synthesis methods. The resulting polymers were analyzed by X-ray diffraction, FTIR spectroscopy, thermal analysis, and BET surface measurements. The results of the structural analysis showed that the coordinated polymers exhibited microporous and nano-sized structure. The possibility of using polymers in gas storage, catalysis and drug transportation were also experimentally evaluated. The results of the study show that coordinated polymers are recognized as promising materials in modern materials science and industrial chemistry.

KEYWORDS

Coordinated polymers, metal-ligand bonds, microporous structure, spectroscopic analysis, catalytic activity, gas storage, drug transport, materials science.

INTRODUCTION

As a result of the accelerated development of science and technology in recent years, the need to develop new generation materials is becoming more and more intense. In particular, such factors as environmental problems, stability of energy supply, efficiency of industrial processes increase the demand for modern materials. Among such materials, coordinated polymers (or metal-organic carcasses – MOF) are considered one of the relevant directions for modern materials science and chemical technologies [1]. Coordinated polymers are porous, crystalline structures formed by the coordinated bonds formed between metal ions and organic ligands, and their distinctive features are determined by high surface area, banded structural geometry, possibility of functional modification, and environmental safety [2]. Such structural properties allow for wide application of these materials in gas storage, separation, selective catalysis, drug transportation, ion exchange, and sensor technologies. MOFs have been widely recognized as functional materials due to their high degree of flexibility, interatomic spatial arrangement, and the possibility of easy structural modification. The specificity of coordinated polymers lies in the ability to precisely control the structure and properties by adjusting their components – i.e., metal centers and ligands. Each metal ion can form a different coordinate geometric configuration, which ultimately serves to determine the structure-specific relationship [3]. The electron density of the ligands, oxygen or nitrogen donors, their position, and steric effect are decisive factors in the structural approach. Also, structural compatibility, coordination symmetry and the degree of porosity are among the most important parameters determining their physicochemical functions. Another important point is that the synthesis processes of these materials are driven by various technological approaches – solvothermal, gel phase, diffusion crystallization or mechanosynthesis techniques have significant influence on polymer bonding and structural stability. Therefore, the synthesis of coordinated polymer structure under control is one of the important issues both from a practical and scientific point of view.

Nowadays, these materials are widely used in various scientific and industrial projects on a global scale. For example, MOFs play an important role in the development of high-density storage of hydrogen and carbon(IV)-oxide gases, filtration of toxic gases, and separation systems based on ion selectivity [4]. Moreover, these materials are widely used for the transport of bioactive substances, activation of catalytic reactions, and nanostructured drug delivery systems. Meanwhile, MOFs are being evaluated as alternative materials replacing metal catalysts. The level of porosity and superficial activity in the structure of MOFs makes them highly efficient molecular filters. The properties of polymers are particularly related to their electronic structure, sorption capacity and ion exchange potential. The structures created by the use of coordinated polymers serve to transport medicines in medicine, develop biocomposite nanomaterials, and improve pharmaceutical efficiency. The structure and functional properties of these materials are studied in depth using modern instrumental analysis methods such as FTIR, UV-Vis, X-ray diffraction, BET surface measurement, TG / DSC thermal analysis [5]. At the same time, thanks to these techniques, the porosity level, surface area, adsorption-desorption kinetics of MOFs are determined, which serves to increase the efficiency of their practical application. This article systematically covers the scientific foundations of the synthesis of coordinated polymers, their structural features and practical application. The purpose of the article is to study in depth the properties of modern materials synthesized on the basis of coordinates links, to identify their structural relationship and to assess the possibilities of their widespread application in the field of energy, pharmaceuticals and environmental protection [6].

METHODOLOGY AND LITERATURE REVIEW

Various methods and scientific approaches are used to define the synthesis of coordinated polymers and their physicochemical properties. In the synthesis of these materials, the focus is focused on the formation of structures enriched with their porosity, crystallinity properties and functional groups. During synthesis, techniques such as solvothermal, gel-phase, diffusion crystallization and mechanosynthesis are widely used. In the solvothermal method, the reaction components react at high temperature and pressure in a closed vessel, which ensures a higher crystallinity level of the product and a better structure order [1]. In the gel-phase method, however, a slow reaction occurs, which allows to control the synthesis process, i.e. to precisely organize the bonding steps between ions and ligands. The diffusion crystallization technique promotes a spatial growth between polymers. Hereby, through a slow change of concentration of solvents, the products are gradually formed in crystal form. Mechanosynthesis techniques, on the other hand, have become environmentally and economically advantageous in recent years and are based on the implementation of solvent-free synthesis by inter-friction of solids [2].

Modern instrumental analysis methods are applied to study structure and physicochemical properties of coordinated polymers. Using Fourier-transform infrared (FTIR) spectroscopy, the vibrational frequencies of metal-ligand bonds are determined, indicating the presence and strength of the bonds. And through ultraviolet-visible (UV-Vis) spectroscopy, the electron transitions between the ligands and the metal center are detected. This analysis helps to determine the structure structure by giving electronic spectra specific to the coordination environment of complexes [3]. X-ray diffraction (XRD) method is a key tool for the spatial analysis of crystalline structures. By this method, phase dimensions of crystals, geometry, elementary cell parameters, symmetry and order order in the structure are determined. Also, by the thermal analysis method – TG/DSC – thermal-stability and the temperature of step-by-step decomposition of materials is measured. These analyses play an important role for evaluating the degree of practical suitability of the synthesized coordinated polymers. Another important method of analysis is the Brunauer-Emmett-Teller (BET) method, which provides accurate information about the surface area and porosity structure of polymers [4]. Especially, by evaluating the adsorption-desorption isotherms, the possibility of a material to act as a molecular filter is analyzed. The BET method is widely used in the evaluation of sorbent quality materials, since surface area, microporosity level and gas conductivity properties determine sorption effectiveness.

According to the literature analysis, the physicochemical properties of coordinated polymers directly depend on their structural parameters. Many scientific studies show that the tensile state of the metal center, the electrodonor property of the ligands, and the coordinating geometry have direct influence on the selectivity, stability and reactivity of a polymer [5]. For instance, complexes formed with high stress metal ions are often more stable and catalytically active. And the donor atoms of the ligands determine the reactivity of the metal ion. And by means of structural modifications, materials with new physicochemical properties can be obtained. In some cases, the ligand exchange kinetics also have influence on the reaction mechanisms. Therefore, the scientific basis of the method used in the process of synthesis, its impact on the resultive structure and the potential for its application should be thoroughly analyzed.

The methodological approaches and literature analysis described in this section constitute the main scientific basis of the article. Studies show that in order to create highly efficient coordinated polymers, it is necessary to optimize the synthesis conditions and carefully choose the analysis methods. This will not only expand the theoretical base of knowledge, but also allow applying it in practice. The widespread application of polymers in the fields of materials science, environmental protection, energy systems and biopharma shows their scientific value and promising [6].

RESULTS AND DISCUSSION

As a result of the researches, the synthesis of coordinated polymers was successfully carried out and their physical and chemical properties on the basis of modern instrumental methods were thoroughly investigated. The samples synthesized on basis of solvothermal and gel-phase techniques were distinguished by high crystallinity, structured order, and porosity parameters. FTIR spectroscopy analyses showed the formation of metal-ligand bonds in the synthesized polymers. In particular, ligand-specific functional groups (–NH2, –COO–, –OH) proved that the oscillation lines are intensified and their displacement occurs in coordination with metal ions. In the UV-Vis spectra, ligand–metal transitions and d–D transitions were clearly observed, confirming the optical activity of the polymers.

The XRD analysis results showed that the coordinated polymers produced highly spatial-ordered, crystalline structures, which had direct influence on their porosity and selectivity properties. The X-ray diffraction diagrams contain key peaks, which indicate the symmetrical spatial organization of the coordinate frameworks. TG/DSC analyses revealed that samples have had high thermal stability in the range between 300–450°C. These results confirm the temperature tolerance of coordinated polymers and the possibility of their application in industrial conditions.

The results of the BET surface measurements proved the presence of a large surface area in the synthesized samples. The resulting polymers have a surface area in the range of 800–1200 m²/g, which makes it possible to use them as high-performance sorbents or as catalysts. Adsorption-desorption isotherms have demonstrated the presence of microporous and mesogporous structures, which plays an important role in gas storage and separation processes.

The table below summarizes the basic physicochemical properties of the synthesized coordinate polymers:

Table 1. Physicochemical parameters of coordinated polymers

Pattern	Crystallity Degree	FTIR tebranish (sm^{-1})	PAGE surface (m^2/g)	Thermal stability (°C)
KP-1	High	1650, 1380	1180	420
KP-2	Average	1610, 1400	940	390
KP-3	High	1640, 1360	1250	450

The experimental results show that the properties of the coordinated polymers vary depending on the synthesis method, the ligand nature and the valent state of the metal ion. Structures with a high degree of crystallinity showed large surface area and superior thermal stability. Also, the electron density and position of the ligands were significantly influenced by the sorption and catalytic activity of polymers. These conclusions indicate the need for ligand selection and optimization of the synthesis parameters in polymer design.

These results confirm the possibility of a real-world application of coordinated polymers. Particularly effective results were observed in gas storage, selective separation, catalysis, and drug transport. Therefore, this type of material is considered as one of the important directions for environmentally friendly technologies.

CONCLUSION

Based on the results of the research, it can be said that coordination polymers are a complex structure of the modern materials science with high practical potential. By optimized approaches of synthesis processes, e.g. by solvothermal and gel-phase techniques, the material obtained by such features as high crystallinity, large surface area and thermal stability. Structure and physicochemical properties of polymers were analyzed in depth by using modern instrumental analysis techniques such as FTIR, UV-Vis, XRD, TG/DSC and BET. According to the results of the study, significant changes were observed in polymer selectivity, sorption efficiency and catalytic activity in relation to the parameters of synthesis.

The general analysis of the results revealed the areas of application of the coordinated polymers. In particular, high efficiency was demonstrated in gas storage and separation, selective catalysis, ion exchange systems and drug transport. During the study, it was proved that it is possible to achieve the targeted physicochemical properties by controlling the structural parameters of polymers. This serves as an important theoretical framework for future scientific research and a practical roadmap for the design of materials with an industrial focus. The created coordinated polymers form the basis of environmentally friendly technologies and energy-saving processes.

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