Smart Polymer and Their Application

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ABSTRACT

Biological organisms react to environmental stimuli and adjust to changing situations. For the past two decades, polymer researchers have been attempting to emulate this behavior by developing so-called smart polymers. Polymers that exhibit reversible large, physical or chemical modifications in relation to tiny exterior variations in environmental variables, including heat, pH, sunlight, magnetic or electrical field, ionic variables, biomolecules, and so on, are classified as this.Smart polymers have emerged as a crucial category of polymers, with their applications expanding rapidly. The topic has grown rapidly during the last two to three centuries. Smart polymers have been employed in biotechnology, medicine, and engineering. They are also known as stimuli-responsive soluble-insoluble polymers or environmentally sensitive polymers. Smart polymers offer extremely potential biomedical applications as medicinal substance delivery methods, tissue engineering scaffolds, cell culture scaffolds, bioseparation tools, sensors, or actuator structures. The current research aims to reviewsmart polymers, as well as their most innovative and significant uses as biomaterials in tissue engineering and drug delivery. Due of their significant prospective in the biomedical area, dual-stimuli-responsive substances will also be demonstrated.Despite the fact that there have been a lot of studies published in this field recently, the current review focuses on the advancements of smart polymers in the past decade with particular industrial fields.

Keywords: Smart polymer, biomedical applications, environmental stimuli, medicinal substance delivery methods

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المستخلص

تتفاعل الكائنات البيولوجية مع المحفزات البيئية وتتكيف مع المواقف المتغيرة. على مدى العقدين الماضيين ، كان باحثو البوليمرات يحاولون محاكاة هذا السلوك من خلال تطوير ما يسمى بالبوليمرات الذكية. يتم تصنيف البوليمرات التي تظهر تعديلات كبيرة أو فيزيائية أو كيميائية قابلة للانعكاس فيما يتعلق بالتغيرات الخارجية الدقيقة في المتغيرات البيئية ، بما في ذلك الحرارة ودرجة الحموضة وضوء الشمس والمجال المغناطيسي أو الكهربائي والمتغيرات الأيونية والجزيئات الحيوية وما إلى ذلك ، على هذا النحو. ظهرت البوليمرات الذكية كفئة أساسية من البوليمرات ، مع التوسع السريع في تطبيقاتها. نما الموضوع بسرعة خلال القرنين أو الثلاثة قرون الماضية. تم استخدام البوليمرات الذكية في التكنولوجيا الحيوية والطب والهندسة. تُعرف أيضًا باسم البوليمرات القابلة للذوبان وغير القابلة للذوبان المستجيبة للمنبهات أو البوليمرات الحساسة بيئيًا. توفر البوليمرات الذكية تطبيقات طبية حيوية محتملة للغاية مثل طرق توصيل المواد الطبية ، أو سقالات هندسة الأنسجة ، أو سقالات زراعة الخلايا ، أو أدوات الفصل الحيوي ، أو أجهزة الاستشعار ، أو هياكل المشغل. يهدف البحث الحالي إلى مراجعة البوليمرات الذكية ، بالإضافة إلى استخداماتها الأكثر ابتكارًا وأهمية كمواد حيوية في هندسة الأنسجة وتوصيل الأدوية. نظرًا لما لها من إمكانات كبيرة في مجال الطب الحيوي ، سيتم أيضًا عرض المواد المستجيبة للمحفزات المزدوجة. على الرغم من وجود الكثير من الدراسات المنشورة في هذا المجال مؤخرًا ، إلا أن المراجعة الحالية تركز على تطورات البوليمرات الذكية في العقد الماضي في مجالات صناعية معينة.

الكلمات المفتاحية: البوليمر الذكي ، التطبيقات الطبية الحيوية ، المحفزات البيئية ، طرق توصيل المواد الطبية

1. INTRODUCTION

In recent decades, there has been a significant increase in interest in intelligent and reactive products. It is widely acknowledged that the capacity of the components to establish independent features or to offer a preferred reaction to external behavior is of the utmost significance for the advancement of active equipment, sensors, and effectors that are intended for use in innovative disciplines, particularly those that are dedicated to small-scale applications **(Wei et al., 2017).**

The use of a specific configuration of multiple components inside a predetermined pattern, also known as metamaterials, in order to endow the assemblage with the appropriate mechanical performance is a tactic that is often utilized in the development of smart gadgets **(Jackson et al., 2018)**. Scientific research are being pursued in this regard because of the need to use even more compact structures and gadgets in cutting-edge technological activities.

Nevertheless, the metamaterials technique has dimensional restrictions that must be considered. In point of fact, while contemporary 3D printing techniques make it possible to manufacture objects with a microscale size, they do not expand to the nano or molecular dimensions. This limitation can be circumvented by making use of materials that are relied on adaptable molecules, specifically polymers **(Brighenti and Vernerey, 2020)**. In these components, the desired performance and configurability are accomplished by the collaborative contraction of the integrated smart particles, which allows for the circumvention of the aforementioned limitation. Nowadays, in contemporary material research, a multidisciplinary strategy including chemistry, physics, and engineering is an essential need for effectively designing the necessary elements that are suited for certain purposes **(Manrique-Juarez et al., 2016)**.

Stimulus-sensitive or "smart" polymeric materials are polymers that can withstand substantial characteristic modifications in response to minor environmental modifications. Additionally from a biological standpoint, the most essential processes are the ones that are affected by pH or temperature. The pH of the human body varies throughout the gastrointestinal system, as well as in particular tissues (including tumorous regions) and subcellular divisions **(Aguilar and San Román, 2019)**.

The physical properties of such biodegradable, robust, durable, and elastic polymers, as well as the stimulus to which they react, are used to classify them into several categories. If you were to classify them according to their physical form, you could put them into one of three categories: reversible gels that have been covalently cross-linked, free linear chain solutions, or polymer chains that have been transplanted onto surfaces.

When categorized according to the stimuli to which they react, they may be placed into one of these three groups:

- The physical aspects include things like temperature, ultrasounds, sunlight, and mechanical force.
- Biological – biomolecules and enzymes.
- The chemical aspect, including the ionic strength and pH.

Polymers that are susceptible to pH changes include acidic or basic units and either receive or release protons as a reaction to the pH shift. Thermo-responsive polymers are polymers that vary their microstructural characteristics in response to changes in temperature.

2. APPLICATIONS

pH-sensitive polymers were employed in a variety of biological purposes, the most notable of which include gene and drug delivery methods, as well as glucose sensors. In this part, we provide the most appealing instances of technologies documented in the literature during the previous several years.

2.1. Drug Administration Techniques

The pH of the gastrointestinal tract (GIT) ranges from 2 (stomach) to 10 (colon). Because of this, pH-sensitive polymers are suited for colon-specific medication delivery. The most prevalent method employs enteric polymers, which resist breakdown in acidic environments and release medication in alkaline solutions owing to salt production.

Various researchers have created polymeric derivatives (polymers with the drug covalently bonded to the macromolecular structure) that are vulnerable to pH-dependent hydrolytic cleavage and therefore appropriate for colon drug administration. This is the case with or poly(methacryloylethoxyethyl 5-aminosalycilic acid) or poly(N-methacryloylaminoethyl 5-aminosalycilamide) **(Sardo et al., 2019)** the copolymeric structure established predicated on a methacrylic derivative of Triflusal and 2-

acrylamido-2-methylpropane sulfonic acid (AMPS) (Fig. 1) **(Hardy et al., 2016)**.

2.2. Gene Transporter

Polyelectrolytes have great promise as biomaterials because they can distribute reversely polarized substances. Non-viral gene transfers are one of the most promising uses for pH-sensitive polymers. Since it is adversely charged and possesses a very big size under physiological circumstances, bare DNA is extremely problematic to absorb into cells. Liposomes and polycations are the two basic chemical (non-viral) genome engineering technologies for condensing DNA into charge balanced nanoparticles that may be transported into cellular components.

Godbey and Mikos examined a number of the recent achievements in non-viral genome engineering studies, citing poly(ethylenimine) (PEI) and poly(L-lysine) (PLL) as two of the most promising possibilities for this purpose. PEI is an extremely polycationic synthetic polymer that condenses DNA in solution, creating combinations that several cell types may easily endocytoze. Chitosan, a cationic aminopolysaccharide that is biodegradable and degradable, is also widely employed as a DNA transporter **(Sun et al., 2019; Trivedi and Kumar, 2022)**.

2.3. Glucose Sensors

Among the most common and widespread uses of pH-sensitive polymers is in the production of insulin drug carriers, which are used in the medical treatment of diabetic patients. The administration of insulin is performed in a manner that is distinct from the administration of other pharmaceuticals due to the fact that insulin must be administered in an exact quantity at an exact moment when it is required. This objective has inspired the creation of a great number of different devices, each of which incorporates a glucose sensor into its operational architecture. The oxidation of glucose to gluconic acid, which is catalyzed by glucose oxidase (GluOx), may bring the pH down to roughly 5.8 in an environment that is rich in glucose, including the bloodstream after a meal. This enzyme is perhaps the most extensively used one for glucose sensing, and it enables the application of several kinds of pH-sensitive hydrogels for regulated insulin administration **(Wang et al., 2019)**.

2.4. The Purification of Proteins

Protein purification is one potential use for smart polymers, which are distinguished by the fact that they are capable of undergoing fast and reversible transformations in response to changes in the characteristics of the medium. These kinds of intelligent polymers may be discovered in conjugated systems, which are put to use in physical separation, chemical detachment, and immunoassays. Precipitation development is an indication of microstructural changes that have occurred in the polymer structure. They are successful because the protein that is to be separated creates a bioconjugate, which is a permanent covalent connection between the biomolecule and a further molecule, with a polymer **(Ofridam et al., 2021)**.

3. CONCLUSIONS

This review covers the key properties and models of the most common smart polymers. Today's smart gadgets, sensors, and actuators employ responsive materials and active structural systems to react to external stimuli. The triggering stimuli might be physical (temperature, light, electric or magnetic field, mechanical stress), chemical (pH, ligands), or biological (enzymes, etc.) depending on the sensitive material under investigation. Metamaterials may achieve such responsiveness by appropriately planning the meso- or macroscopic arrangement of constitutive components, or by employing sensitive substances whose sensitivity derives from their chemistry. When molecular sensitivity is structured, the nanoscale response may be collectively recognized at the macroscale, creating a responsive material. We evaluated the vast universe of responsive polymers by describing their major features, properties, and responsive processes and provided a mechanical modeling viewpoint.

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Figures

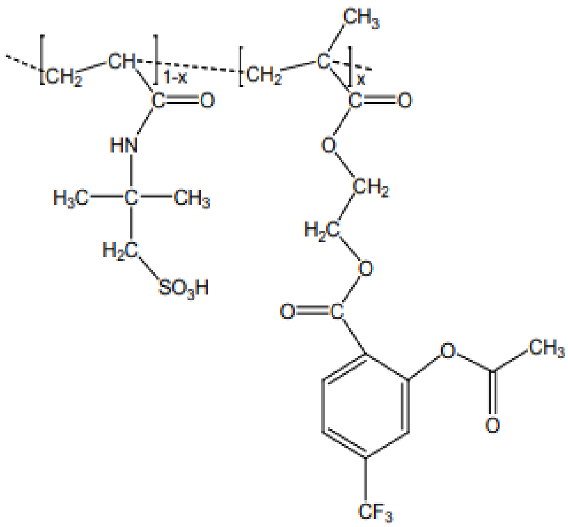

Figure 1. A layout of the copolymeric system.