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Polymer Hydrogels and Their Applications

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Abstract
Hydrogels are the three dimensional network of hydrophilic co-polymers or homopolymers. These gels are also named as Hydrophilic gels, in which the dispersion medium is a biological fluid or water. The softness, elasticity, swelling, absorbent nature, flexibility and the capacity to store water are some of the important properties of hydrogels. These polymers may be obtained from natural sources or they can be produced synthetically. The synthetic hydrogel have replaced natural hydrogel due to better absorption capacity of water, stability, and hydrophobic/hydrophillic nature. Hydrogels can be prepared by adding cross linked polymers to water or biological fluids, and allowing the mixture to swell. They can be prepared from polymers containing hydrophilic group such as hydroxyl, carboxylic acid, imide, sulphonic acid, and amide either embedded in or grafted to their polymeric back-bones. These gels are useful in daily life and their major applications are in food, agriculture, industry, cosmetics, medicine and medical treatments etc. Today, hydrogels find wide range of applications because of their lower cost, non- toxic, and environment-friendly nature. The aim of this paper is to give an overview of the hydrogels, their classification, properties and several important applications.

Keywords: Hydrophilic gels, Hydrogels, Gelators, Gelling agents, Polymer gels, Biomaterials.

Introduction

Hydrogels are also referred as hydrophilic gels that are three-dimensional cross-linked networks of polymer chains. These are developed as colloidal gels, which contain water as dispersion medium [1]. These gels are intelligently responding to the variations of environmental catalyst such as ionic strength, pH, electric field, temperature, enzyme etc. Hydrogels resembles with the living tissue (in swollen state) due to their soft, flexible and biocompatible nature [2]. Hence, these are used as biomaterials that find application in several fields of biomedical or pharmaceutical industry [3]. The important properties of hydrogels are softness, elasticity, swelling, absorbent nature, flexibility and the capacity to store water etc. Hydrogels can be prepared by adding cross linked polymers to water or biological fluids, and allowing the mixture to swell. They can be prepared from polymers containing hydrophilic group such as hydroxyl, carboxylic acid, imide, sulphonic acid, and amide either embedded in or grafted to their polymeric back-bones [4]. Due to their exceptional performance in various fields of applications, they have received considerable attention [5, 6, 7]. In 1980, Ferry *et al* defined gels as a substantially dilute cross-linked system and the gels are mainly classified as weak or strong depending on their flow behavior in steady-state [8]. For food materials and biomaterials, gels and the hydrogels terms are used mutually. Rosiak *et al* define hydrogel as the three-dimensional network structures obtained from synthetic or natural polymers that absorb and retain large amount of water [9]. Hydrogels have various types of physical forms *viz.* solid molded (used in soft contact lenses), coatings (used as implants or catheters, pills or capsules or coatings on the inside capillary wall in capillary electrophoresis), pressed power matrices (used in pills or capsules for oral ingestion), membranes or sheets (used as reservoir in a transdermal drug delivery patch or for two dimensional electrophoresis gels), microparticles (used as bioadhesive carriers or wound treatments), encapsulated solids (used in osmotic pumps), liquids (forms gels on heating or cooling)[18]. For chemical or physical hydrogels, different types of macromolecular structures are possible which includes linear copolymers, entangled or cross-linked networks of linear polymers and copolymers; polyion-polyion, polyion-multivalent ion or hydrogen bonded complexes; hydrophobic domains stabilized hydrophilic networks; and IPNs or physical blends. Hydrogels may be obtained from natural sources or they can be prepared synthetically. Alginate, Xanthan, Dextran, Pullulan, Hyaluronic acid, Guar gum, Okra gum, and Locust gum, Gellan, Xyloglucan, Pectin and Scleroglucan are some of the examples of natural polymers capable of forming hydrogels. Some of the examples of synthetic polymeric gelators are Poly (vinylalcohol),Polymethacrylic acid (PMAA), Polyacrylic Acid (PAA) Poly N-vinylpyrrolidone) PVP), polyethyleneglycol diacryl ate/dimethacrylate PEGDA/PEGDMA), Polyethyleneglycol acrylate/methacrylate (PEGA/PEGMA), and Poly (styrene) (PS) [17]. The synthetic hydrogel have replaced natural hydrogel for most of the applications due to larger absorption capacity of water, stability and hydrophobic nature Hydrogels are useful in daily life and their major applications are in food, agriculture, industry, cosmetics, medicine and medical treatments etc.

Features

An ideal hydrogel material has following features [10]

- Very high absorption capacity in saline
- Very high absorbency under load
- Very low soluble content and residual monomer
- Low cost
- Very high durability and stability during storage and in the swelling environment
- Colorless, odorless, and non-toxic
- Very high biodegradability
- Desired rate of absorption
- Photo stability
- Re-wetting capacity
- pH-neutrality after swelling in water

Classification

The hydrogel products can be classified as:

Based on source [11]

- Natural hydrogels
- Synthetic hydrogels
- Semi-synthetic hydrogels

According to polymeric composition

- Homopolymeric hydrogels: These are the networks of polymer derived from a species of monomer, which is basic in nature [12]. They have cross linked structure.
- Copolymeric hydrogels: Contain several different type monomers which comprise minimum one hydrophilic component that have block, random or alternate type structure [13].
- Multipolymer interpenetrating polymeric hydrogel: It is the important class of hydrogels, which is made of two independent cross-linked synthetic or natural polymer components [14, 15].

Based on configuration this classification based on their chemical composition and physical structure [16]

- Amorphous
- Crystalline
- Semicrystalline

Based on network electrical charge Based on the presence or absence of electrical charge located on the cross linked chains [16], they may be classified as

- Non ionic (neutral)
- Ionic (cationic or anionic)
- Amphoteric (acidic and basic group both) or Ampholytic
- Zwitterionic (cationic or anionic group both) or polybetaines

Based on physical appearance Based on the technique of polymerization [14], polymers may classified as

- Film or microsphere
- Matrix

Based on type of cross linking [16]

- Chemically cross linked networks have permanent junction
- Physically cross linked networks have transient junction

Based on respond to stimuli [17]

- Smart
- Conventional

Based on durability [17]

- Durable
- Degradable

Properties

The characteristic properties of hydrogels i.e., swelling properties, mechanical and toxicity studies etc are used successfully in the different fields.

Swelling Properties

Generally, in hydrogel polymer have chains which are cross linked to each other either chemically and physically and thus assumed as a molecule anyway of its size. There is no concept of molecular weight of hydrogels and therefore, they are named as super macromolecules. The slight changes in environmental factor may response rapidly to the reversible changes in hydrogel. Different types of environmental factors are temperature, pH, electric signal, and enzyme or ionic species, which lead to different physical texture of the gel [19]. Experimentally, the percentage swelling can be determined by weight difference method and is represented by the following equation [20]

$$\text{Percentage Swelling} = [(Ws-Wd)/Wd] \times 100$$

Where, Ws is the weight of swollen gel and
Wd is the weight of dry gel

Mechanical Strength

This is the important property of hydrogels that are mostly used in biomedical and pharmaceutical field as wound dressing substance, tendon repair, in drug delivery, in tissue engineering and as cartilage replacement substance. It can maintain the physical texture of the hydrogels in drug delivery. By increasing the density of crosslinking, the mechanical strength may be increased that resulting stronger hydrogels and the elongation percentage of gel decreased, hence the gel turns into brittle structure [19].

Biocompatibility

It is desirable for the hydrogels to be nontoxic and biocompatible which make them suitable especially in biomedical applications. The concept followed by mostly polymers in these properties is *in-vivo* toxicity tests and cytotoxicity tests. Biocompatibility is the capacity of the polymers that do not produce toxic and immunological response when exposed to biological environment (tissue). It consist bio-safety and bio-functionality, which is the basic element. The bio-safety is the appropriate host response to systemic and local (the surrounding tissue), the lack of mutagenesis, cytotoxicity and carcinogenesis. The bio-functionality is the capacity of polymer to carry out, for the particular task to which it is proposed. The definition of bio-safety and bio-functionality is relevant in tissue engineering [17]. The organic solvents, initiators, emulsifiers, stabilizers, unreacted different monomers and various crosslinkers which is used in hydrogel synthesis and polymerization may be toxic to different host cells, if they scaped out to different tissues or cells. The purification processes such as dialysis or solvent washing is used to remove toxic chemicals from gels.

Applications

Hydrogels are widely used in various areas of tissue engineering, proteomic, bioseparations, electrophoresis and chromatography (as separation materials), foods, medicines, in diapers (as absorbents), in water purification (as filters), in controlled drug release [21]. Some of the applications of hydrogels are explained below:

Domestic applications

It consist diapers [22, 23, 24, 25, 26], cosmetics [27, 28], perfume delivery [29, 30, 31, 32], water beeds for plants …etc. Water adsorption nature of hydrogels is used in diaper that they hold water, also used in creams and perfume.

Environmental applications

Different types of hydrogels are used for waste water treatment that can hold a lot of microorganism in their matrix. Currently, the biggest environmental problem is the loss of oil in seas or in other water sources. Many researchers and authors attempted to develop different types of hydrogels to retain water with oil-pollutant molecules [33]

Bacteria culture

Bacteria can be cultured inside the matrix of hydrogels. Agar is main substrate for bacterial culture in biotechnological applications [34, 35].

Biosensor

Biosensors can be prepared by hydrogels, act as supports for immobilization of enzymes. The hydrogel Polycarbamoylsulphonate is used for immobilization of the D-fructose dehydrogenase enzyme [36].

Sealant and adhesive

Hydrogels can adhere to various materials as plastics due to hydrophobic interactions and it can be used as sealant for vessels containing corrosive acids.

Contact lenses

It is the most widely used application of this polymer. For soft contact lenses, poly(2-hydroxyethyl methacrylate)-based hydrogels are used due to their extensive property [37].

Electronics

In electronics, hydrogels are used as matrixes which consider maximum tunability and precision of capacitors with hydrogel dielectrics for example, potassium poly(acrylate), poly(vinyl alcohol), poly(ethylene oxide), and gelatin etc [38] .

Biomedical application

Hydrogels are widely used in biomedical applications such as, in Immunotherapy, Vaccine, Plastic surgery, Wound healing, Electrophoresis, Proteomic, Tissue engineering (Bone regeneration, Cardiac, Dental), Drug delivery, Wound dressing and so on.

Conclusions

Hydrogels have many desirable properties i.e. swelling, mechanical strength and biocompatible nature which makes them suitable in various fields. Some of the most important applications of hydrogels are in food, agriculture, industry, cosmetics, medicine and medical treatments etc.

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