



Review

Design and applications of interpenetrating polymer network hydrogels. A review



Ecaterina Stela Dragan*

"Petru Poni" Institute of Macromolecular Chemistry, Aleea Grigore Ghica Voda 41 A, 700487 Iasi, Romania

HIGHLIGHTS

- Design concepts and applications of interpenetrating polymer networks hydrogels are reviewed.
- Influence of the second network on properties of IPN hydrogels is discussed.
- Deswelling and mechanical properties of PNIPPAm are improved in IPN hydrogels.
- IPN hydrogels are recommended as efficient sorbents for heavy metal ions.
- IPN cryogels perform better than conventional hydrogels in dye removal.

ARTICLE INFO

Article history:

Received 18 November 2013

Received in revised form 16 January 2014

Accepted 20 January 2014

Available online 5 February 2014

Keywords:

Hydrogels

Interpenetrating polymer network

Dyes

Heavy metals

Sorption

ABSTRACT

Interpenetrating polymer networks (IPN) hydrogels have gained great attention in the last decades, mainly due to their biomedical applications. This review aims to give an overview of the recent design concepts of IPN hydrogels and their applications in controlled drug delivery, and separation processes. In the first part, the main strategies for the synthesis of semi-IPN and full-IPN hydrogels, their relevant properties, and biomedical applications are presented based on the nature of the networks, the main categories selected being: IPN hydrogels based on polysaccharides (chitosan, alginate, starch, and other polysaccharides), protein based IPN hydrogels, and IPN hydrogels based only on synthetic polymers. The influence of the second network on the stimuli responsiveness of the "smart" IPN hydrogels is discussed based on the most recent publications in the field. In the second part, an overview of the most specific applications of IPN hydrogels in separation processes is critically presented. Factors which control the separations of dyes and heavy metal ions by semi-IPN and full-IPN as novel sorbents are discussed based on the recently published articles and own results. A special concern is given to the macroporous IPN composite cryogels, which are very attractive materials for separation processes being endowed also with a high reusability.

© 2014 Elsevier B.V. All rights reserved.

Abbreviations: AAm, acrylamide; AAm-g-HEC, acrylamide grafted on hydroxyethylcellulose; AAPBA, 3-acrylamidophenylboronic acid; Alg, alginate; AMPS, 2-acrylamido-2-methyl-1-propansulfonic acid; BAAM, N,N'-methylenebisacrylamide; CMC, carboxymethyl cellulose; CS, chitosan; DS, diclofenac sodium; DMAEM, 2-dimethylaminoethyl methacrylate; DSC, differential scanning calorimetry; Dx, dextran; DxS, dextran sulfate; ECH, epichlorohydrin; EWC, equilibrium water content; GA, glutaraldehyde; GE, gelatine; HA, hyaluronic acid; HEMA, 2-hydroxyethyl methacrylate; IA, itaconic acid; IEP, isoelectric point; IIH, ion imprinted hydrogel; IPN, interpenetrating polymer network; LCST, lower critical solution temperature; MB, Methylene Blue; MO, methyl orange; MV, methyl violet; NaPAA, poly(sodium acrylate); NIPAAm, N-isopropylacrylamide; NVF, N-vinylformamide; PA, anionically modified potato starch; PAA, poly(acrylic acid); PAAM, poly(acrylamide); PAN, poly(acrylonitrile); PASP, poly(aspartic acid); PDADMAC, poly(diallyldimethylammonium chloride); PDMAEM, poly(N,N-dimethylaminoethyl methacrylate); PDMC, poly(methacryloyloxyethylammonium chloride); PEG, poly(ethylene glycol); PEG-DA, poly(ethylene glycol) diacrylate; PEI, poly(ethyleneimine); PFO, pseudo-first-order; PMAA, poly(methacrylic acid); PMAAm, poly(methacrylamide); PS, potato starch; PSO, pseudo-second-order; PVA, poly(vinyl alcohol); PVP, poly(vinylpyrrolidone); RB, rhodamine B; SA, sodium alginate; SEM, scanning electron microscopy; SF, silk fibroin; SPH, super-porous hydrogel; SR_{eq}, equilibrium swelling ratio; VPTT, volume phase transition temperature.

* Tel.: +40 232 217454.

E-mail address: sdragan@icmpp.ro<http://dx.doi.org/10.1016/j.cej.2014.01.065>

1385-8947/© 2014 Elsevier B.V. All rights reserved.

Contents

1. Introduction	573
2. Design, characterization, and biomedical applications of IPN hydrogels	573
2.1. Polysaccharide based IPN hydrogels	574
2.1.2. Alginate	576
2.1.3. Starch and derivatives	577
2.1.4. Other polysaccharides	579
2.2. Protein based IPN hydrogels	580
2.3. IPN hydrogels based only on synthetic polymers	580
3. Separations mediated by IPN hydrogels	581
3.1. Characterization of sorption properties	581
3.2. Sorption of dyes	581
3.3. Sorption of heavy metal ions	582
3.3.1. IPN hydrogels based on biopolymers	583
3.3.2. IPN hydrogels based on synthetic polymers	584
3.3.3. Ion imprinted IPN hydrogels	584
3.4. Desorption and reusability	584
4. Summary of the benefits of semi-IPN compared to single-network hydrogels, and of the influence of the second network on the properties of IPN hydrogels	585
5. Conclusions and perspectives	586
Acknowledgement	586
References	586

1. Introduction

Hydrogels are three-dimensional, hydrophilic, polymeric networks capable to retain large amounts of water, or biological fluids, characterized by a soft and rubbery consistence, being thus similar with living tissues [1,2]. Hydrogels may be chemically stable or “reversible” (physical gels) stabilized by molecular entanglements, and/or secondary forces including ionic, H-bonding or hydrophobic interactions, these hydrogels being nonhomogeneous [1,2]. Examples of reversible hydrogels are “ionotropic” hydrogels formed by the interaction between a polyelectrolyte and an oppositely charged multivalent ion, and the polyelectrolyte complexes (complex coacervates) formed by the interaction between two oppositely charged polyelectrolytes. Physical gels can be disintegrated by changes in the environment conditions such as ionic strength, pH, and temperature. Physical hydrogels have numerous biomedical applications in drug delivery, wound dressing, tissue engineering and so on. Covalently cross-linked networks form permanent or chemical gels [1]. “Smart” hydrogels are able to significantly change their volume/shape in response to small alterations of certain parameters of the environment. Responsive hydrogels have numerous applications, the most of them being focused on biological and therapeutic demands [3–5], and sensing applications [6]. However, single-network hydrogels have weak mechanical properties and slow response at swelling. To enhance the mechanical strength and swelling/deswelling response, multicomponent networks as interpenetrating polymer networks (IPNs) have been designed.

IPNs are “alloys” of cross-linked polymers, at least one of them being synthesized and/or cross-linked within the immediate presence of the other, without any covalent bonds between them, which cannot be separated unless chemical bonds are broken [7–9]. The combination of the polymers must effectively produce an advanced multicomponent polymeric system, with a new profile [10]. According to the chemistry of preparation, IPN hydrogels can be classified in: (i) simultaneous IPN, when the precursors of both networks are mixed and the two networks are synthesized at the same time by independent, noninterfering routes such as chain and stepwise polymerization [7,9,11] (Fig. 1a), and (ii) sequential IPN, typically performed by swelling of a single-network hydrogel into a solution containing the mixture of monomer, initiator and activator, with or without a cross-linker (Fig. 1b). If a cross-linker

is present, fully-IPN result, while in the absence of a cross-linker, a network having linear polymers embedded within the first network is formed (semi-IPN) [7,8,12,13].

When a linear polymer, either synthetic or biopolymer, is entrapped in a matrix, forming thus a semi-IPN hydrogel, fully-IPN can be prepared after that by a selective cross-linking of the linear polymer chains [14–16] (Fig. 1c).

By their structure, IPN hydrogels can be classified in: (i) IPNs, formed by two networks ideally juxtaposed, with many entanglements and physical interactions between them; (ii) homo-IPNs, which are a special case of IPN, where the two polymers which form the independent networks have the same structure; (iii) semi- or pseudo-IPNs, in which one component has a linear instead of a network structure. Mechanically enhanced IPN hydrogels as “double networks”, promoted by Gong et al., have attracted attention by their potential for biomaterials, mainly as a replacement of natural cartilage [17–19]. The particular feature of this new type of IPN hydrogels, characterized by high resistance to wear and high fracture strength, consists of the preparation first of a densely cross-linked ionic hydrogel, the second network being a neutral loosely cross-linked network [17,18].

This review aims to give an overview on the preparation and applications of semi- and fully-IPN hydrogels based on the most recent publications in the field. In the first part, the main synthesis strategies of IPN hydrogels, their relevant properties and biomedical applications will be presented. In the second part, an overview on the most specific applications of the IPN hydrogels in separation processes will be given.

2. Design, characterization, and biomedical applications of IPN hydrogels

A wide variety of hydrophilic polymers or their precursors have been used to synthesize hydrogels, the main classes consisting of natural polymers and their derivatives (polysaccharides and proteins), and synthetic polymers containing hydrophilic functional groups such as $-\text{COOH}$, $-\text{OH}$, $-\text{CONH}_2$, SO_3H , amines and R_4N^+ , and ether [1]. By the combination of polymers coming from these two classes, IPN composite hydrogels can be prepared by the three routes presented in Fig. 1. The most often encountered combinations of polymers used to prepare IPN composite hydrogels are summarized in Fig. 2.

Download English Version:

<https://daneshyari.com/en/article/147856>

Download Persian Version:

<https://daneshyari.com/article/147856>

[Daneshyari.com](https://daneshyari.com)