Biobased superabsorbent hydrogels and their potential applications

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Summary, conclusions and future scopes

Highlights

This chapter summarizes all the results of the present research work in a clear and concise manner. The results are briefly described in the form of chapters, from which concluding remarks are made. The present chapter also addresses the future scope of current research work toward the development of biobased hydrogel nanocomposites for different fields of applications.

7.1. Summary and conclusions

The works performed to accomplish the aforementioned goals are described in the thesis in the form of chapters. The thesis consists of seven chapters. The first chapter (**Chapter 1**) presents a general introduction to superabsorbent hydrogels. A brief review of the various hydrogels and their preparative methods including reinforcing agents has been included in this chapter, with particular emphasis on bioderived hydrogels as well as on the different reinforcing agents like nanomaterials (NMs) incorporated superabsorbent hydrogel (SAH) nanocomposites (SAHNCs). Based on the literature reports, general methods for the preparation of hydrogels and reinforcing agents, different instrumentation techniques used for their characterization, property evaluation and their applications in diverse fields are briefly addressed here. Further, the chapter includes scopes and objectives as well as plan to carry out the present research work.

The second chapter (**Chapter 2**) describes the synthesis, characterization and property evaluation of starch, itaconic acid (IA) and acrylic acid (AA)-based SAHs. The hydrogels were prepared through the free radical polymerization method using N,N'-methylene bisacrylamide as the cross-linker and ammonium persulfate (APS) as the initiator. To study the effect of IA to AA ratio on water absorption capacity (WAC) of prepared SAHs under different conditions (such as distilled water, under load, salt solution, etc.), different compositions of SAHs were prepared by varying the IA to AA ratio. Further, the water swelling kinetics of the SAHs were studied using different kinetic models. Moreover, prolonged urea release property and biodegradability of the prepared SAHs were confirmed via fertilizer release and soil burial test, respectively. In addition, the effect of urea-loaded SAHs on water holding capacity, soil porosity, and germination rate of okra seeds was also investigated.

The third chapter (**Chapter 3**) presents the fabrication of superabsorbent hydrogel composites (SAHCs) using the best formulation of Chapter 2 with the incorporation of wastepaper-derived cellulosic paper powder as the micro-reinforcing agent. Here, the characterization of the cellulosic paper powder as well as the obtained SAHCs was performed using different analytical techniques. Further, by varying the amounts of the micro-reinforcing agent, its effect on the WAC of the SAHCs was investigated. In addition, SAHC with a high WAC was chosen for NPK fertilizer release and okra seed germination studies. Moreover, a soil burial test indicated the biodegradable nature of the hydrogel.

The fourth chapter (**Chapter 4**) illustrates the fabrication process of modified-cellulose nanofibers (CNFs) incorporated SAHNC using the same formulation, chosen from Chapter 2, and its application as an efficient adsorbent for cationic dye removal. Initially, the work involved the preparation of CNF from wastepaper by applying different processes such as alkali, acid, bleaching and DMSO treatments. Further, the CNF was treated with sodium monochloroacetate to produce modified-CNF. The results indicated that the modification of CNF improved its interaction with the hydrogel matrix, leading to enhanced WAC as well as the dye removal capacity of SAHNC. Further, the adsorption/desorption test and selective dye removal test were performed to investigate the dye removal ability of the SAHNC.

The fifth chapter (**Chapter 5**) describes the preparation of CNF and ZnO-based nanohybrid using an eco-friendly and non-toxic approach. In this work, the same composition (as used in Chapter 2) was selected for the fabrication of SAHNC using the prepared nanohybrid as the reinforcing agent. The formation of the nanohybrid and its successful incorporation into the hydrogel matrix were confirmed by different microscopy and spectroscopic techniques. Moreover, this work involved the utilization of the nanocomposite for the removal of metal ions from aqueous media. Additionally, to observe the effect of the nanohybrid, the biodegradability of the SAHNC was compared with the bare hydrogel.

The sixth chapter (**Chapter 6**) presents the fabrication of pH-sensitive SAHNC using CNF/ZnO-based nanohybrid prepared in Chapter 5. Here, the starch/IA/AA-based nanocomposite was blended with gelatin and used to evaluate the pH-sensitive *in vitro* drug release property in different pH solutions. Moreover, pH-sensitive swelling behavior was also studied for the prepared SAHNC. Further, the antibacterial property of the drug-loaded SAHNC was investigated against the gram-positive and gram-negative bacterial strains. A hemolysis test was also performed to study the biocompatibility of the prepared nanocomposite. Thus, the results indicate that the prepared nanocomposite can be used as a potential drug delivery system.

Finally, the seventh chapter (**Chapter 7**) summarizes the concluding remarks and future scopes for the present research work.

(i) The present study confirms that biobased SAHs with significant properties such as high-water swelling, slow-release, water holding capacity, biodegradability, etc.

were prepared by using low amounts of synthetic materials compared to biobased raw materials and could be used for their potential applications.

(ii) This study also showed that enhanced properties such as water swelling, dye and metal adsorption, slow release of fertilizer, controlled drug delivery, etc. were obtained using the optimized amount of reinforcing agent without compromising the intrinsic properties of the bare hydrogel matrix.

(iii) Cellulosic micro-reinforcing agent was prepared from easily available wastepaper by applying a simple alkali treatment and was utilized to enhance different properties of the SAHC.

(iv) Highly crystalline cellulosic NMs such as CNF and modified-CNF were obtained from wastepaper by applying mild alkali, acid, and bleaching treatments; followed by the reaction with modifying agent, which were used subsequently as nanoscale building blocks to prepare SAHNCs with enhanced properties that make them suitable for removal of dyes from different aqueous media.

(v) CNF with ZnO-based nanohybrid was prepared by using plant extract via eco-friendly approaches which not only made the process easy, but also assists in the stabilization of ZnO nanoparticles. Thus, synergistically enhanced properties were achieved by the utilization of the nanohybrid.

(vi) The study showed that the incorporation of CNF/ZnO-based nanohybrid into hydrogel could enhance the removal of metal ions from aqueous media and it could influence the sustained release of encapsulated drug from the hydrogel matrix. Moreover, the presence of ZnO introduces antibacterial properties to the hydrogel matrix.

Thus, the present research work demonstrates the development of biobased superabsorbent hydrogels by the incorporation of different cellulosic reinforcing materials with improved properties compared with the bare hydrogel matrix, making them suitable for different potential applications.

7.2. Future scopes

The thesis includes research on the fabrication of biobased hydrogel biocomposites and nanocomposites for various potential applications. Moreover, these research works pave the way to explore hydrogels in various other application fields. Some of the future scopes of present work are noted underneath as follows.

(i) The prepared hydrogel matrix may be further studied in the removal of pesticides, pharmaceuticals, etc. from wastewater.

(ii) More bio-based nanomaterials like biochar, carbon dots, other cellulosic nanomaterials, etc. can be used to prepare nanocomposite hydrogels.

(iii) Hydrogel may be studied for use as a soilless medium for agricultural applications.

(iv) A completely bio-based superabsorbent hydrogel with enhanced properties can be attempted.

(v) The application of hydrogel will be explored in different biomedical applications.