Journal of Applied Science, Innovation & Technology (JASIT)

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Review Article

Biopolymer-based materials for sustainable water treatment: A Review

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ARTICLE INFOR: *Received: 13 May 2022; Revised: 08 June 2022; Accepted: 09, June 2022*
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Abstract
Biopolymers are eco-friendly, greener, biodegradable, and sustainable materials, which are obtained from living organisms and renewable resources. Natural biopolymers such as gum, alginate, starch, cellulose, and chitin/chitosan are environmental-friendly materials due to their biocompatibility, non-toxicity, simplicity of modification, and structural features. In recent years, several biopolymers have been used to make various biopolymer-based materials; the creation of biopolymer-based materials is the most effective technology. Biopolymer-based materials are novel and more efficient nanomaterials or sorbents for the removal of contaminants from water and wastewater. This review examines recent developments in the synthesis of alginate, starch, cellulose, gum, and chitin/chitosan-based materials using natural biopolymers.
Keywords: Biopolymers; adsorption; wastewater treatment; starch; gum; cellulose; alginate; chitin/chitosan

1. Introduction

Water is one of the most pressing environmental challenges; providing safe, inexpensive potable and clean water is a huge challenge across the world. Contamination of natural resources has been rapidly increasing in recent years, and it must be addressed on a priority basis if the earth and its inhabitants are to be sustained for coming generations. Freshwater resources are few, and they are rapidly declining as a result of the release of untreated or improperly treated wastewaters. Oxidation, sedimentation, ultra-filtration, membrane separation, floatation, adsorption, ion exchange, coagulation/flocculation, reverse osmosis, advanced oxidation process, and electro-precipitation techniques have traditionally been used in wastewater treatment. Traditional purification and wastewater treatment procedures are incapable of achieving the level of purification required to meet reliable and cost-effective discharge criteria (Yorgic et al., 2015; Nasrollahzadeh et al., 2018).

The creation of green and more environmental-friendly treatment technologies must be seen as a critical component for enterprises dealing with chemically loaded, hazardous, and toxic wastewaters (Sajadi et al., 2016). Multipurpose nanomaterials that facilitate particle storage and pollutant removal/separation can be usefully exploited by utilizing nanostructures with distinctive qualities such as huge surface area, considerable chemical reactivity, lower power consumption, and cost-effectiveness (Nasrollahzadeh et al., 2021).

Heavy metals, pesticides, and dyes pollute water and wastewater globally; dye effluents, in particular, are recognized as the greatest category of industrial colorants and a serious hazard to aquatic habitats, flora/fauna, and humans (Khan et al., 2016; Sajjadi et al., 2020). Dyestuffs are non-degradable, hazardous, chemically and biologically stable, and water-soluble organic pollutants that cause a wide range of human disorders, including nervous system damage, renal failure, liver disease, skin irritation, and more (Dai et al., 2009; Mazaheri et al., 2017; Nasrollahzadeh et al., 2020). The coloration of textiles, plastics, paper, paints, inks, display systems, dye sensitive solar cells, light-emitting diodes, laser welding processes, energy transfer cascades, as well as cosmetic and/or culinary dyes, which are mostly generated from azo dyes, are the main sources of dye contamination (Singh & Arora, 2011; Sannino et al., 2013). Dye effluents of textiles are typically a blend of various colors in varying quantities, due to the production schedule, and the degree of dye-fixing on cloth (Yaseen & Scholz, 2018). As a result, removing admixed colors from wastewaters is critical. For industries that produce toxic and dangerous chemical-laden wastewater, the production of novel sustainable, and eco-friendly treatment technologies should be recognized as a crucial factor.

Biopolymer-based materials, in general, demonstrated high coagulation/flocculation, Adsorption, and reduction/degradation efficiency for both organic (e.g., dyes and pesticides) and inorganic (heavy metals) contaminants (Kanmani et al., 2017; Sajjadi et al., 2019; Kothaplamoottil Sivan et al., 2019). Among these treatment methods, adsorption is considered the most reliable technique for the removal of contaminants from wastewater. The use of biopolymer-based materials is not bounded to heavy metals and dye removal and also includes a variety of other harmful pollutants such as hydrocarbons, nitrates, pesticides, fluorides, pharmaceuticals, radioactive ions, and phosphates (Nasrollahzadeh et al., 2021).

Biopolymers are the type of polymers that are made up of repeating unit of monomers, which is environmental-friendly and sustainable that is organically created by living organisms. Regarding this, starch, cellulose, chitosan/chitin, alginate, guar gum, pectin, and xantham gum are an example of environment-friendly and sustainable biopolymers (Ahmad et al., 2015; Sharma et al., 2016; Nasrollahzaheh et al., 2019). Among these biopolymers, cellulose is the most common biopolymer on the earth, and the second most common biopolymer, chitosan has been chosen for a variety of environmental products (Ahmad et al., 2015; Olivera et al., 2016). This study summarises current progress in the removal and remediation of contaminants and aqueous pollutants using biopolymer-based materials such as chitin/chitosan, starch, cellulose, alginate, gum, and pectin materials.

2. Biopolymer-based materials for water treatment

Biopolymer-based materials have recently been studied as innovative materials for water treatment with outstanding catalytic capability. This section summarises the various applications of biopolymer-based materials in water treatment.

2.1. Cellulose-based materials for water treatment

Cellulose-based materials have been reported in a variety of fields, including cosmetics, biomedicine, pharmaceutics, and medicine along with membranes, nanocomposites, boundary coatings, and also supercapacitors, and electronics. Because of their distinct and peculiar qualities, cellulose nanocrystals and nanofibrils have lately been explored as nanosorbents. The efficiency and efficacy of cellulose-based materials in removing various contaminants were emphasized, but their environmental consequences, as well as their biodegradability and non-toxicity characteristics, still have to be evaluated. The environmental benefits of cellulose-based materials over activated charcoal-carbon-produced materials, and also their life cycle, manufacturing costs, and availability must also be explored (Mohammed et al., 2018). Cellulose micro and nano-fibers based materials used for water treatment, derived from cellulose materials (polypyrrole, poly(acrylonitrile), poly (vinyl alcohol), poly (ether sulfone), poly (vinylidene fluoride), poly (ethylene oxide), poly (3-hydroxybutyrate), and cellulose triacetate in the fields of distillation have been presented and validated (Carpenter et al., 2015).

To avoid potential toxicological problems associated with nanotechnologies, nanostructured materials depending on the building blocks have also been suggested for environmental clean-up in the form of micro-dimensional nano-porous systems. Thermal cross-linking of branched polyethylenimine (bPEI), (2,2,6,6-Tetramethylpiperidin-1-yl) oxyl (TEMPO)-oxidized cellulose nanofibers (TOCNF), and citric acid (CA) tends to result through micro-and nano-porous hydrogel systems to sorbent effectiveness against various dyes such as Cibacron Brilliant Yellow, Orange II Sodium Salt, Naphthol Blue Black and Brilliant Blue R (Riva et al., 2020). The sorption of cyclohexane and dimethylformamide (DMF) in nanocellulose hydrogels treated with graphene oxide (Wang et al., 2014).

By utilizing HCl/citric acid to hydrolyze the microcrystalline cellulose used for MB adsorption, approximately complete UV destruction of methyl blue was detected after 4 hours, and at a faster pace than other types of Cellulose nanocomposites (CNCs) made with acids such as formic acid and sulfuric acid. The modification of carboxylated CNCs, where more carboxyl groups might efficiently bind with dyes, is credited with this outcome (Yu et al., 2016). Another study (Chen and Huang, 2015) described the manufacturing of a new insight amino cobalt phthalocyanine (CoPc) onto BC nanofibers nanomaterial through partial immobilization and decoration of CoPc@BC; the resulting nanomaterials could successfully destroy Rhodamine B (RhB) dye in contaminated water by the use of H_2O_2 within 3 h.

2.2. Alginate-based materials for water treatment

Alginate is a low-cost biopolymer that is made up of linear block copolymers made up of two uronic acid residues, such as α-L-guluronic acid β-D-mannuronic and, joined by β 1,4-glycosidic linkages. Alginate-based compounds have been suggested for a variety of purposes. Alginate is widely used in the treatment of wastewater through adsorption due to its benign nature, durability, water permeability, and biodegradability, according to recent research (Li et al., 2013; Ahmad et al., 2018; Xu et al., 2019). The removal of Methyl violet (MV) from aqueous solution by using calcium alginate-based hydrogel beads (Asadi et al., 2018). Adsorption efficacy of alginate coated perlite (ACP) beads used to efficiently remove methylene blue (MB), methyl violet (MV), and malachite green (MG) from aqueous solution could be optimized by adjusting pH, temperature, mixing ratio, initial dye concentration, and adsorbent dose (Parlayici, 2019).

2.3. Starch-based materials for water treatment

Starch is a biodegradable, biocompatible, renewable, and natural biopolymer found in various sections of plants, including stalks, crop seeds, and roots; the main sources of starch such as corn, rice, potatoes, maize, cassava, wheat, and many others. D-glucose units containing bio-macromolecules such as branching (1→6)-D-glucan, amylose, amylopectin, and linear (1→4)-linked D-glucan make up the 3D architecture of starch granules, which have a crystalline structure of 15–45 percent (Zobel, 1988; Visakh et al., 2012). Microcrystalline starch, hydrolyzed starch, and starch nanocrystal are all produced by hydrolysis of the crystalline component of the starch. Starch-based materials are rapidly to be used as suitable substrates for catalytic systems due to their low cost, non-toxicity, high surface area, great availability, biocompatibility, and renewability (Ghaedi et al., 2012; Ghaderi et al., 2016; Nasrollahzadeh et al., 2020;).

Cationic starch was investigated for its ability to remove golden yellow pigment from aqueous solutions (Guo et al., 2019). Starting with uncooked corn starch, 3-chloro-2-hydroxypropyl trimethylammonium chloride was used for epichlorohydrin, and cationic etherification was used as a crosslinking agent, resulting in a crosslinked cationic starch with the greatest adsorption ability of approximately 208.77 mg/g at 308.15 K. Crosslinked porous starch, in which maize starch was crosslinked with epichlorohydrin and then hydrolyzed with -amylase, resulting in the removal of MB from water using a novel biopolymer-based adsorbent (Guo et al., 2013). Magnetic nanoparticles (MNPs)/starch-g-poly (vinyl sulphate) nanomaterials produced for cationic dye removals such as MB and MG from aqueous water through adsorption using unique magnetic nanosorbents made by grafting vinyl acetate is applied on starch in the application of magnetic nanomaterials (Pourjavadi et al., 2016).

2.4. Chitosan/chitin-based materials for water treatment

Chitin and chitosan seem to be common biopolymers found in nature. Chitosan is found in crustaceous shells and insect cuticles composed of N-deacetylated. Chitosan is made up primarily of N-deacetylated chitin, which is found in insect cuticles and crustacean shells. It is a biodegradable and renewable carbohydrate that is characterized by glucosamine, a linear amino polysaccharide. Chitin deacetylase catalyses the bioconversion of chitin to chitosan through enzymatic N-deacetylation. Hydrophobic chitosan, which has a high sorption potential and is widely available for both functional and chemical changes, has been intensively researched in industrial/agricultural fields, as biocatalysts in treating wastewater, in gene or drug delivery, and also in enzyme/cell immobilization (Wang et al., 2017; Nasrollahzadeh et al., 2020). Environmentally favourable and low-cost materials have been thoroughly investigated because of renewable, innovative, and long-lasting nanocatalysts. Particularly, the removal of dye from wastewater has also been investigated through chitosan-based coagulants and flocculants (Kanmani et al., 2017).

Multifunctional biohybrid aerogels based on cellulose nanofiber and adorned with chitin nanocrystals are used for the treatment of wastewater. Changing the parameters, the amount of chitin nanocrystals in a freeze-drying technique and hybrid bio-aerogels were created and decorated on CNFs; they could be reused without fail five times losing efficiency or activity (Gopi et al., 2017). The removal of MB and reactive orange 16 using Chitosan/sepiolite-based materials from aqueous solutions crosslinker and addition of sepiolite epichlorohydrin (Marrakchi et al., 2016). Magnetic chitosan-based nanomaterials have also been used with cross-linking agent glutaraldehyde to remove Acid Red-2 from textile effluent (Kadam and Lee, 2015).

2.5. Gum-based materials for water treatment

Gum is an excellent example of environmentally benign, natural polysaccharides and greener biopolymers and also has been employed to make a large number of materials for a wide range of applications. Guar gum (GG) is a biopolymer, mucoadhesive, water-soluble, and biodegradable derived from the endosperm of guar beans. It is linked by D-galactopyranosyl units for making linear chains of D-mannopyranosyl. Gum arabic (GA), also known as Acacia gum, is a branching heteropolysaccharide as well as a complex secretion of *Acacia seyal* and *Acacia senegal* trees made up of D-galactopyranosyl units. It is among the oldest known gums and has a wide range of uses in the food and pharmaceutical sectors (Yadav et al., 2007). Because of their capacity to change physical properties, GG and GA have been widely employed as ion exchange resin, binder, thickening agent, and dispersion agents (Soumya et al., 2010; Iqbal & Hussain, 2013). They have also been used to effectively stabilize magnetic nanoparticles (NPs) as well as an additive, reducing agent and emulsifying, and potential stabilizer in the formulation of traditional biosorbent and nanomaterials (Devi et al., 2011; Padil et al., 2018; Sharma et al., 2018).

Self-assembly or the use of a cross-linking agent could be used to make 3D biopolymer-based materials hydrogel from natural GG. Due to its inherent excellent features, such as high active-site, biocompatibility, wide surface areas, biodegradability, and low mass transfer constraints, Guar Gum-based hydrogel nanomaterials have recently shown promise in biosorption, separation, and drug delivery (Sharma et al., 2015; Dai et al., 2017). Gum ghatti and Fe_3O_4 magnetic NPs based nanomaterials were used to remove rhodamine B; the adsorption capacity of rhodamine B was 671.14 (mg/g) (Mittal and Mishra, 2014).

3. Conclusion

Biopolymer-based materials are used for the resource management and remediation of the environment. Greener procedures may minimize the cost of production of biopolymer-based material. The biopolymer-based materials are environmental-friendly, low-cost as well as more efficient for the treatment of industrial wastewater. Biopolymer-based materials including starch, cellulose, alginate, and chitin/chitosan have biodegradability, non-toxicity, and renewability, and are easy to modify and could bring revolution in wastewater treatment technology.

Author contributions

Devesh Vishwakarma: conceptualization, collection of literature, data analysis and interpretation, drafting of manuscripts, editing and finalization. **Shikha:** reviewing, editing, finalization, supervision.

Acknowledgement

One of us (Devesh Vishwakarma) thankful to university grant commission (UGC), New Delhi, Government of India for providing UGC Non-NET fellowship.

Conflicts of Interest

The authors report no conflicts of interest

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Cite this article:
Vishwakarma, D., Shikha, 2022. Biopolymer-based materials for sustainable water treatment: A Review. J. Appl. Sci. Innov. Technol. 1 (1), 10-14.