Marine Polysaccharide (Chitosan) and Its Derivatives as Water Purifier

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Marine Polysaccharide (Chitosan) and Its Derivatives as Water Purifier

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CONTENTS

38.1 Introduction

Water is one of the essential components of nature, frequently polluted by agricultural, industrial, and man-made activities. The exponential growth of population and industrial development has made potable water a rare commodity (Szygu et al. 2009). Chitosan, a biopolymer, is an aminopolysaccharide composed of glucosamine, 2-amino-2-deoxy-β-ᴅ-glucose. It is prepared by alkaline deacetylation of chitin, a biopolymer extracted from shell fish sources. Chitosan exhibits a variety of physicochemical and biological properties, which could be used in the fields of biotechnology, agriculture, textile, biomedical engineering, food processing, pharmaceuticals, and ophthalmology. It is a weak cationic base insoluble in water and organic solvent but soluble in aqueous acidic solution with many amine ($-NH_2$) and hydroxyl ($-OH$) groups and acts as a chelate to form complex with metal ion (Zeng et al. 2008, Bina et al. 2009, Renault et al. 2009). The nature of the pollutants present in the water and wastewater depends on the source generation that varies from place to place (Bhatnagar and Sillanpa 2009). Chitosan has been widely used for water treatment to remove the pollutants. It is a well-known biosorbent for metal cations; the reactive amino group binds with metal ion to remove the metal present in the water by ion exchange. Several methods have been used to modify the natural chitosan in order to improve the adsorption capacity (Miretzky and Cirelli 2009). Water treatment plants face many problems when removing turbidity from raw untreated water to produce drinking water. Inorganic coagulants such as aluminum sulfate (alum) and polyaluminum chloride have been widely used for the removal of raw water turbidity because it is cost-effective and easy to handle. However, the sludge obtained from those treatment leads to disposal problems and contains higher aluminum in treated water. Cationic polyelectrolytes have been used as effective coagulants or flocculants in which chitosan, a biodegradable, nontoxic, and high-molecular-weight polymer, has also been used as an eco-friendly coagulant and flocculant (Chatterjee et al. 2009).

Dye used in textile, food, plastic, and pharmaceutical industry generates the colored impurities in water. Moreover, synthetic dyes are toxic and carcinogenic and decrease the photosynthesis, which in turn disturbs the aquatic ecosystem. Chitosan-based composite biosorbent is found to remove the dyes in an effective manner (Copello et al. 2011). Fluoride is another important parameter in water for dental health; the higher concentration of fluoride causes dental and skeletal fluorosis. Removal of fluorine can be done by various methods including ion exchange, electrochemical, and coagulation, but all these processes are expensive. Chitosan prepared in several shapes, gel beads, microspheres, and nanoparticles is also used to remove the fluorine (Miretzky and Cirelli 2011). Higher concentration of nitrate present in ground and surface water leads to blue baby diseases, which can be avoided by using treated water by sorption on protonated cross-linked chitosan gel beads (Jaafari et al. 2004).

38.2 Physicochemical Characteristics of Chitosan

Chitosan is obtained by partial or total deacetylation of chitin, which in turn depends upon the isolation of chitin from raw material and experimental procedure. The degree of deacetylation makes chitosan different from chitin and their solubility in dilute acidic solution. Forty percent deacetylation makes chitosan soluble in dilute acidic solution. Even though the polymer backbone of chitosan consists of hydrophilic functional group, it is insoluble in water at near-neutral pH and most of the organic solvent. The crystalline nature of chitosan is due to the intermolecular and intramolecular hydrogen bonding between the chains and sheets, respectively. The mechanical and chemical properties of chitosan can be modified by physical or chemical process. The efficiency of the adsorbent mainly depends upon the physicochemical properties including porosity, particle size of adsorbents, and surface area. The adsorption of heavy metal ions by chitosan is due to the presence of the following properties:

- High hydrophilicity due to presence of large number of hydroxyl groups of glucose units
- Presence of a large number of functional groups including hydroxyl group, primary amino group, and acetamido group, which have high chemical reactivity
- Flexible structure of polymer chains

The chemical modification of chitosan does not change the skeleton of chitosan but shows new or improved properties (Miretzky and Cirelli 2009, 2011).

38.2.1 Chitosan as Natural Flocculants or Coagulant

Alum is one of the widely used coagulants in water and wastewater treatment. The sludge produced by this method is difficult to dehydrate; its efficiency depends upon the pH. The other disadvantages of using higher concentration of aluminum are the health hazards. Chitosan possesses characteristics of both coagulant and flocculant nature, i.e., high cationic charge density, long polymer chains, bridging of aggregates, and precipitation. The major advantages of using chitosan as coagulant/flocculant include its nontoxic nature biodegradability, high settling speed of flocs, and chelating behavior. The physicochemical properties to interact with various contaminants including inorganic, organic suspensions, and dissolved organic substances make it unique. The sludge produced by chitosan as coagulant is of high density and can facilitate its drying compared to sludge produced with metal salts and is degradable by microorganisms, which make them environment friendly. The organic matter released during coagulation step increases the disinfection property (Rizzo et al. 2008). The modified water-soluble chitosan has been prepared and used for coagulation and flocculation process, which shows more effectiveness than commercial one (Reyna et al. 2010). It has been used for coagulation of bentonite suspension in which maximum coagulation was achieved at 5 mg/L chitosan concentration. Coagulation of bentonite by chitosan was pH sensitive, and at acidic pH, coagulation takes place effectively (Chatterjee et al. 2009). The disadvantages are its pH-dependent and heterogeneous properties (Renault et al. 2009).

38.2.2 Separation of Water from Alcohol Mixture

Pervaporation is an attractive conventional method for the separation of water from aqueous alcohol mixture. This technique works on the selective permeation of membrane producing permeate stream enriched in the preferentially permeating species (Feng and Huang 1996). The modified chitosan membrane has also been used to separate water from alcohol mixture. Some of them are carboxymethyl chitosan, acetic acid complex chitosan, sulfonated chitosan, amidoxime chitosan, polyacronitrile chitosan, and phosphorylated chitosan membrane (Lee et al. 1997).The advantages of modified chitosan are that it is easy to separate chitosan from the azeotropic mixtures and it is less costly (Wang et al. 1996). Currently, there are several membranes to separate water, and one of them is chitosan N-methylol nylon six blend membrane for the separation of water–ethanol mixture. The permselectivity of this blend membrane was improved by acid treatment. The salting-out effect of ionized group in the chitosan matrix excludes organic solvents and decreased the permeability of ethanol while retaining the total permeability of water (Shieh and Huang 1998).

38.2.3 Recoveries of Protein from Surimi Wash Water

Protein flocculation is one of the techniques used for the removal of surimi from the wash water. Complexation of chitosan with pectin, carrageenan, or alginate yielded coagulating agent with improved protein adsorption and reduction of turbidity compared to free chitosan Chitosan–alginate complex is used to recover soluble proteins from surimi wash water at slightly acidic pH of 6. The electrostatic interaction between amino group and anionic group of chitosan was found to be the reason for this behavior (Wibowo et al. 2005). This process not only resulted in the decreased turbidity in the surimi wash water but effectively recovered the soluble protein that would otherwise be discarded in the environment as waste (Wibowo et al. 2007).

38.2.4 Removal of Dyes

Water pollution due to dyes present in the effluents of textile, leather, paper, and dye manufacturing industry is one of the major environmental concerns. The dyes used not only pollute the water but also reduce the productivity of the soil by their toxic nature. This colored dye effluents are considered to be toxic to the aquatic biota and affect the symbiotic process by disturbing the natural equilibrium through reduced photosynthetic activity. Some of the dyes also cause allergy, skin irritation, and cancer in humans. Thus the removal of dyes from water has become inevitable, and use of chitosan-based biosorbent is one of the methods of removal (Bhatnagar and Sillanpa 2009).

The removal of dyes including acid yellow 73 (Iqbal et al. 2011), acid green 25 (Wong et al. 2003, Mahmoodi et al. 2011), acid orange 10 and 12 (Wong et al. 2003, Zhou et al. 2011), acid red 18, 37, and 73, (Wong et al. 2003, Kamari et al. 2009, Shen et al. 2010), acid blue 25 (Kamari et al. 2009), food dye acid blue 9, food yellow 3 (Dotto and Pinto 2011), methylene blue (Wang et al. 2010, Chatterjee et al. 2011a), and disodium 6-hydroxy-5-((2-methoxy-5-methyl-4-sulfophenyl)azo)-2-naphthalenesulfonate (Piccin et al. 2011) using chitosan as powder, flakes, beads, and hydrogels has already been reported and summarized in the Tables 38.1 and 38.2.

38.2.5 Removal of Phenol

Phenol is one of the environmental water pollutants generated mainly from industries such as paper, plastic, metals, pharmaceuticals, and resin. Because of their toxicity, it has to be removed from water in order to maintain the ecological balance. Many synthetic resin, low-cost natural adsorbents, and microbiological water treatment are used for the removal of phenol. However, the water-soluble phenol is not satisfactorily removed from water by the aforesaid methods. The chitosan-conjugated thermoresponsive polymers have also been used to remove the phenol in water. One of the examples is the polymer prepared by condensation of chitosan with poly(*N*-isopropylacrylamide-co-acrylic acid) [PNIPPAm-AA] mediated through water-soluble imide 1-ethyl-3-(3-dimethylaminopropyl) carbodimide hydrochloride. Phenol is removed from water by tyrosine-induced oxidation in which phenol is converted to catechol and subsequently oxidized to o-quinone. The o-quinone molecules react with themselves to form dark brown oligomers, which can bind with amino moiety of chitosan to form Schiff bases or Michael-type adducts and thus get separated from water on filtration (Saitoh et al. 2009, 2011).

38.2.6 Removal of Fluoride

Fluoride is an essential element in water for dental health. The concentration of fluoride in drinking water should not exceed 1.5 mg/L. There are several methods to remove excessive fluoride from drinking water. Among them, absorption using chitosan derivatives seems to be effective, economical, and environment friendly. Fluoride ion is more electronegative and small in ionic size; because of these properties, it can possess strong affinity toward transition and rare earth metals. It is also well known that N in the NH_2 group of chitosan can act as electron donor and form chelates with metal ions. The N in the NH_2 group of chitosan can act as electron donor and form chelated complexes with metal ions, and the OH^- group can complete the coordination shells of the metals. Depending upon the pH, the OH^- groups can be protonated and adsorb F^- ions through exchange mechanism (Miretzky et al. 2011).

TABLE 38.1

Removal of Dyes Using Chitosan

Adsorbent	Adsorbate	Adsorption Capacity (mg/g)	pH	Isotherm	References
Chitosan	Acid green 25	645.1	—	Langmuir	Wong et al. (2003)
Chitosan	Acid green 25	178.0	2.0	Tempkin	Mahmoodi et al. (2011)
Chitosan	Acid orange 10	922.9	—	Langmuir	Wong et al. (2003)
Chitosan	Acid orange 12	973.3	—	Langmuir	Wong et al. (2003)
Chitosan	Acid red 18	693.2	—	Langmuir	Wong et al. (2003)
Chitosan	Acid red 73	728.2	—	Langmuir	Wong et al. (2003)
Chitosan	Direct red 23	155.0	2.0	Tempkin	Mahmoodi et al. (2011)
Chitosan	Food dye acid blue 9	226.0	3.0	Elovich	Dotto and Pinto (2011)
Chitosan	Food yellow 3	352.6	3.0	Elovich	Dotto and Pinto (2011)
Chitosan	Disodium 6-hydroxy-5-((2-metho xy-5-methyl-4-sulfophenyl) azo)-2-naphthalenesulfonate	300.0	5.7	Elovich	Piccin et al. (2011)
Chitosan beads	Acid red 37	128.2	6.0	Langmuir	Kamari et al. (2009)
Chitosan beads	Acid red 37	357.1	6.0	Langmuir	Kamari et al. (2009a)
Chitosan beads	Acid blue 25	263.1	4.0	Langmuir	Kamari et al. (2009)
Chitosan beads	Acid blue 25	178.5	4.0	Langmuir	Kamari et al. (2009a)
Chitosan hydrogel beads	Methylene blue	226.2	—	Sips	Chatterjee et al. (2011)
Chitosan flakes	Acid yellow 73	—	3.0	Langmuir and Freundlich	Iqbal et al. (2011)

Magnesia (MgO) is a well-known absorbent against fluoride. The adsorption of MgO can be improved by the preparation of composite with chitosan. The chitosan-modified MgO acts as efficient defluorinating agent when compared with MgO alone (Sundaram et al. 2009). Like chitosan-modified MgO, some of the metals bind with chitosan such as titanium–aluminum binary metal oxide supported beads of chitosan (Thakre et al. 2010), lanthanum-incorporated chitosan (Kamble et al. 2007, Thakre et al. 2010a, Jagtap et al. 2011), and neodymium-modified chitosan (Yao et al. 2009) and were used for defluoridation. From the brackish underground water, fluoride can be removed by chitosan. However, the efficiency of this support in salt water is very weak. Electrodialysis method for salt water to remove fluoride is more effective but is costly. The combination

TABLE 38.2

Removal of Dyes Using Chitosan Derivatives

Adsorbent	Adsorbate	Adsorption Capacity (mg/g)	pH	Isotherm	References
Chitosan grafted acrylamide	Remazol yellow gelb 3RS	1211.0	2.0	Langmuir–Freundlich	Kyzas and Lazaridis (2009)
Chitosan grafted acrylic acid	Basic yellow 37	595.0	10.0	Langmuir–Freundlich	Kyzas and Lazaridis (2009)
Chitosan grafted poly(methyl methacrylate)	Procion yellow MX	250.0	7.0	Langmuir and Freundlich	Singh et al. (2009)
Chitosan grafted poly(methyl methacrylate)	Remazol brilliant violet	357.0	7.0	Langmuir and Freundlich	Singh et al. (2009)
Chitosan grafted poly(methyl methacrylate)	Reactive blue H5G	178.0	7.0	Langmuir and Freundlich	Singh et al. (2009)
Chitosan hydrogel beads (by alkali) grafted polyethyleneimine	Reactive black 5	709.3	6.0	Langmuir	Chatterjee et al. (2011b)
Chitosan hydrogel beads (by sodium dodecyl sulfate) grafted polyethyleneimine	Reactive black 5	413.2	6.0	Langmuir	Chatterjee et al. (2011b)
Chitosan–glutaraldehyde beads	Acid blue 25	127.0	4.0	Langmuir	Kamari et al. (2009)
Chitosan–glutaraldehyde beads	Acid red 37	166.7	6.0	Langmuir	Kamari et al. (2009)
Chitosan–sulfuric acid beads	Acid blue 25	102.5	4.0	Langmuir	Kamari et al. (2009)
Chitosan–sulfuric acid beads	Acid red 37	139.3	6.0	Langmuir	Kamari et al. (2009)
Chitosan cross-linked with ethylenediamine	Eosin Y	294.1	5.0	Langmuir	Huang et al. (2011)
Tetraethylenepentamine-modified chitosan	Eosin Y	292.4	5.0	Langmuir	Huang et al. (2011a)
Chitosan–ethylene glycol diglycidyl ether beads	Acid red 37	59.5	6.0	Langmuir	Kamari et al. (2009)
Chitosan–ethylene glycol diglycidyl ether beads	Acid blue 25	142.8	4.0	Langmuir	Kamari et al. (2009)
Ethylenediamine-modified magnetic chitosan nanoparticles	Acid orange 7	1215.0	4.0	Langmuir	Zhou et al. (2011)
Ethylenediamine-modified magnetic chitosan nanoparticles	Acid orange 10	1017.0	3.0	Langmuir	Zhou et al. (2011)
Chitosan with 4-formyl-1,3-benzene sodium disulfonate	Basic blue 3	166.5	3.0	Langmuir	Crini et al. (2008)

TABLE 38.2 (continued)

Removal of Dyes Using Chitosan Derivatives

Adsorbent	Adsorbate	Adsorption Capacity (mg/g)	pH	Isotherm	References
N-benzyl disulfonate derivatives of chitosan	Basic blue 9	121.9	3.0	—	Crini et al. (2008a)
N,O-carboxymethyl-chitosan	Methylene blue	349.0	8.0	Langmuir	Wang et al. (2010)
γ-Fe_2O_3-SiO_2-chitosan composite	Methyl orange	34.3	2.9	Freundlich	Zhu et al. (2011)
β-cyclodextrin–chitosan modified Fe_3O_4 nanoparticles	Methyl blue	2780.0	5.0	Langmuir	Fan et al. (2012)
Chitosan coated on magnetite (Fe_3O_4)	Alizarin red	40.12	3.0	Langmuir	Fan et al. (2012a)

of both these methods removes fluoride from brackish groundwater effectively and economically (Sahlia et al. 2007). Chemically modified and protonated chitosan beads for the removal of fluoride from water are reviewed and given in Table 38.3 (Viswanathan et al. 2009).

38.2.7 Removal of Metal Ions

Activated carbon has been used as a sorbent to remove the metal ions from water. However, the use of activated carbon is expensive, so there is an increasing interest to prepare other adsorbent material with low cost. Chitosan is an excellent biosorbent to remove metal cation from water at neutral pH. Several methods are used to modify the natural biopolymer chitosan either by physical or chemical methods to improve the adsorption capacity of chitosan (Miretzky and Cirelli 2009). Some of the metal ions removed by chitosan and chitosan derivates are shown in Tables 38.4 through 38.10.

38.2.8 Removal of Nitrate

Groundwater or surface water resource all over the globe is heavily contaminated by nitrate ion. The high concentration of nitrate in drinking water is undesirable and causes blue baby syndrome due to the conversions of hemoglobin in to methemoglobin, inhibiting the oxygen transport. The conventional methods used for denitrification are biological denitrification and ion exchange process. In biological denitrification process, the use of carbonaceous substrate makes it cumbersome and expensive. Moreover, it is effective only at low temperature, i.e., below 7°C. In ion exchange resin process, the chloride ion concentration in water is increased. Electrodialysis or reverse osmosis to remove the nitrate is not a usual method because of the cost involved. Protonated gel beads of chitosan effectively remove the nitrate from groundwater and are cheaper. The sorption capacity of the chitosan beads depend upon the pH, and in the pH range of 3–5, it is more efficient, whereas the efficiency is reduced as the pH is 2 or less. This may be due to the breakage of chitosan beads (Jaafari et al. 2004).

TABLE 38.3

Removal of Fluoride Using Chitosan and Its Derivatives

Adsorbent	Adsorption Capacity (mg/g)	pH	Isotherm	References
Chitosan-based mesoporous Ti–Al binary metal oxide beads	2.22	3.0–9.0	Langmuir	Thakre et al. (2010)
Neodymium-modified chitosan	22.38	7.0	Langmuir	Yao et al. (2009)
Lanthanum-incorporated chitosan beads	4.70	5.0	Langmuir	Bansiwal et al. (2009)
Lanthanum-impregnated chitosan beads	1.27	6.7	Freundlich	Jagtap et al. (2011)
La(III)-incorporated carboxylated chitosan beads	11.95	7.0	Langmuir, Freundlich	Viswanathan and Meenakshi (2008a)
Magnetic chitosan	22.49	7.0	Langmuir and Bradley's	Ma et al. (2007)
Fe(III)-loaded carboxylated chitosan beads	15.38	7.0	Langmuir, Freundlich	Viswanathan and Meenakshi (2008b)
Glutaraldehyde-cross-linked protonated chitosan beads	7.32	7.0	Langmuir, Freundlich	Viswanathan et al. (2009a)
Carboxylated cross-linked chitosan beads	11.11	7.0	Langmuir, Freundlich	Viswanathan et al. (2009b)
MgO–chitosan composite	11.23	3.0–11.0	Langmuir, Freundlich	Sundaram et al. (2009)
Nanohydroxyapatite–chitosan	2.04	3.0	Langmuir, Freundlich	Sundaram et al. (2008)
Aluminum–chitosan composite	10.42	7.0	Langmuir, Freundlich	Viswanathan and Meenakshi (2010a)
Zr(IV)-entrapped carboxylated chitosan beads	13.69	7.0	Freundlich, Langmuir and Dubinin–Radushkevich	Viswanathan and Meenakshi (2009a)
Chitosan-supported zirconium(IV) tungstophosphate composite	7.63	3.0	Langmuir, Freundlich	Viswanathan and Meenakshi (2010b)
Neodymium-modified chitosan	22.38	7.0	Langmuir	Yao et al. (2009)
Cerium (III)-encapsulated carboxylated chitosan beads	9.00	7.0	Langmuir, Freundlich	Viswanathan and Meenakshi (2009b)

TABLE 38.4

Removal of Cadmium (II)

Adsorbent	Adsorption Capacity (mg/g)	pH	Isotherm	References
Xanthated chitosan	357.14	8.0	Langmuir	Sankararamakrishnan et al. (2007)
Thiocarbamoyl chitosan flakes	666.70	7.5	Langmuir	Chauhan et al. (2012)
Chitosan–graft-γ-cyclodextrin	833.33	8.5	Langmuir	Mishra and Sharma (2011)
Chitosan–cellulose acetate blend membrane	17.88	8.0	Langmuir	Zhang et al. (2011)
5,10,15,20-Tetrakis (1-methyl-4-pyridinio) porphyrin tetra (p-toluenesulfonate) immobilized chitosan–cellulose acetate blend membrane	43.77	8.0	Langmuir	Zhang et al. (2011)
Procion Brown MX 5BR immobilized poly(hydroxyethylmethacrylate–chitosan) composite membranes	18.50	5.0	—	Genc et al. (2002)
Chitosan hydrogel beads	61.35	6.3	Freundlich	Beigi et al. (2009)

TABLE 38.5

Removal of Nickel (II)

Adsorbent	Adsorption Capacity (mg/g)	pH	Isotherm	References
Reactive blue 2 dye immobilized chitosan	11.20	8.5	Langmuir	Vasconcelos et al. (2007)
Chitosan-grafted acrylonitrile	358.54	5.5	Langmuir	Ramya et al. (2011)
Chitosan-grafted-poly(2-amino-4,5-pentamethylene-thiophene-3-carboxylic acid N′-acryloyl-hydrazide) chelating resin	49.40	6.0	Langmuir	Bekheit et al. (2011)
Chitosan/magnetite nanocomposite beads	52.55	6.0	Langmuir	Tran et al. (2010)
Chitosan-coated polyvinyl chloride beads	120.50	5.0	Langmuir and Freundlich	Popuri et al. (2009)

TABLE 38.6

Removal of Chromium (VI)

Adsorbent	Adsorption Capacity (mg/g)	pH	Isotherm	References
Chitosan	166.00	4.0	Langmuir-Freundlich	Kyzas et al. (2009a)
Fe-cross-linked chitosan	295.00	4.8	Langmuir–Freundlich	Zimmermann et al. (2010)
Chitosan-grafted poly(acrylamide)	935.00	4.0	Langmuir-Freundlich	Kyzas et al. (2009a)
Chitosan-grafted poly(acrylic acid)	518.00	4.0	Langmuir-Freundlich	Kyzas et al. (2009a)
Chitosan-grafted polyacrylonitrile	218.82	5.5	Langmuir	Shanmugapriya et al. (2011)
Glutaraldehyde-cross-linked grafted chitosan beads	4057.00	4.0	Langmuir	Kousalya et al. (2010)
Glutaraldehyde-cross-linked protonated chitosan beads	3239.00	4.0	Langmuir	Kousalya et al. (2010)
Glutaraldehyde-cross-linked carboxylated chitosan beads	3647.00	4.0	Langmuir	Kousalya et al. (2010)
Glutaraldehyde-cross-linked chitosan-xanthated beads	256.40	3.3	Langmuir	Sankararamakrishnan et al. (2006)
Glutaraldehyde-cross-linked chitosan-xanthated flakes	625.00	3.0	Langmuir	Sankararamakrishnan et al. (2006)
Xanthated chitosan column	202.25	3.0	—	Chauhan and Sankararamakrishnan (2011)
Thiocarbamoyl chitosan flakes	434.80	2.0	Langmuir	Chauhan et al. (2012)
Chitosan coated with poly 3-methylthiophene	127.62	2.0	Langmuir	Hena (2010)
Alumina–chitosan composite	8.62	4.0	Dubinin–Radushkevich	Gandhi et al. (2010)

TABLE 38.7

Removal of Copper (II)

Adsorbent	Adsorption Capacity (mg/g)	pH	Isotherm	References
Chitosan beads	80.71	6.0	Langmuir	Ngah et al. (2002)
Chitosan cross-linked with glutaraldehyde beads	59.67	6.0	Langmuir	Ngah et al. (2002)
Chitosan cross-linked with epichlorohydrin beads	62.47	6.0	Langmuir	Ngah et al. (2002)
Chitosan-grafted acrylonitrile	230.79	5.0	Langmuir	Ramya et al. (2011)
Epichlorohydrin-cross-linked chitosan	35.46	6.0	Langmuir	Chen et al. (2008a)
Epichlorohydrin-cross-linked xanthate chitosan	43.47	5.0	Langmuir	Kannamba et al. (2010)
Chitosan cross-linked with ethylene glycol diglycidyl ether beads	45.94	6.0	Langmuir	Ngah et al. (2002)
Carboxylated chitosan-bound Fe3O4 magnetic nanoparticles	21.50	5.0	Langmuir	Chang and Chen (2005)
Chitosan-grafted poly(2-amino-4,5-pentamethylene-thiophene-3-carboxylic acid N′-acryloyl-hydrazide) chelating resin	137.64	6.0	Langmuir	Bekheit et al. (2011)
Chitosan-grafted polyacrylonitrile	239.31	7.0	Langmuir	Shanmugapriya et al. (2011)
Reactive blue 2 dye immobilized chitosan	57.00	7.0	Langmuir	Vasconcelos et al. (2007)
Chitosan-grafted polyacrylonitrile	239.31	7.0	Langmuir	Shanmugapriya et al. (2011)
Chitosan-grafted poly(acrylamide)	166.00	6.0	Langmuir-Freundlich	Kyzas et al. (2009a)
Chitosan-grafted poly(acrylic acid)	318.00	6.0	Langmuir-Freundlich	Kyzas et al. (2009a)
Chitosan	208.00	6.0	Langmuir-Freundlich	Kyzas et al. (2009a)
Chitosan-coated polyvinyl chloride beads	87.90	4.0	Langmuir and Freundlich	Popuri et al. (2009)

TABLE 38.8

Removal of Lead (II)

Adsorbent	Adsorption Capacity (mg/g)	pH	Isotherm	References
Chitosan	47.39	6.0	Langmuir	Asandei et al. (2009)
Chitosan–alginate beads	60.27	4.5	Langmuir	Ngah and Fatinathan (2010)
Glutaraldehyde-cross-linked chitosan-xanthated beads	322.60	4.0	Langmuir	Chauhan and Sankararamakrishnan (2008)
Epichlorohydrin-cross-linked chitosan	34.13	6.0	Langmuir	Chen et al. (2008a)
Chitosan/magnetite nanocomposite beads	63.33	6.0	Langmuir	Tran et al. (2010)
Pb(II)-imprinted chitosan biosorbent using diatomite as core material	139.60	7.0	Langmuir	Jiang et al. (2010)
Chitosan/TiO2 hybrid film	36.80	3.0	Freundlich	Tao et al. (2009)
Chitosan beads	34.98	4.5	Langmuir and Freundlich	Ngah and Fatinathan (2010)
Chitosan–glutaraldehyde beads	14.24	4.5	Langmuir and Freundlich	Ngah and Fatinathan (2010)
Procion Brown MX 5BR immobilized poly(hydroxyethylmethacrylate–chitosan) composite membranes	22.70	5.0	—	Genc et al. (2002)

TABLE 38.9

Removal of Arsenic

Adsorbent	Adsorbate	Adsorption Capacity (mg/g)	pH	Isotherm	References
Chitosan nanospheres	As (V)	270	5.2	Langmuir	Singh et al. (2011)
As(III)-loaded α-Fe_2O_3-chitosan composite	As (III)	6.18	5.0	Langmuir	Liu et al. (2011)
Iron-impregnated chitosan beads	As (III)	6.48	8.0	Freundlich	Gang et al. (2010)
Molybdate-impregnated chitosan beads column	As (III)	1.98	5.0	—	Chen et al. (2008)
Molybdate-impregnated chitosan beads column	As (V)	2.00	5.0	—	Chen et al. (2008)
3,4-Diamino benzoic acid functionalized chitosan	As (V)	82.00	3.0	—	Sabarudin et al. (2005)

38.3 Conclusion

In recent times, there is an increasing interest in the development of marine polysaccharides for various applications including water treatment because of its availability and low cost. The high reactivity against water pollutants has made them a potential candidate for

TABLE 38.10

Removal of Other Metal Ions

Adsorbent	Adsorbate	Adsorption Capacity (mg/g)	pH	Isotherm	References
Procion Brown MX 5BR immobilized poly(hydroxyethylmethacrylate–chitosan) composite membranes	Hg(II)	68.80	5.0	—	Genc et al. (2002)
Chitosan–montmorillonite composites	Se(VI)	18.40	—	Langmuir	Bleiman and Mishael (2010)
3,4-Diamino benzoic acid functionalized chitosan	Se(IV)	64.00	3.0	—	Sabarudin et al. (2005)
3,4-Diamino benzoic acid functionalized chitosan	Se(VI)	88.00	2.0 and 3.0	—	Sabarudin et al. (2005)
Chitosan-grafted poly(2-amino-4,5-pentamethylene-thiophene-3-carboxylic acid *N*′-acryloyl-hydrazide) chelating resin	Co(II)	102.51	6.0	Langmuir	Bekheit et al. (2011)
Epichlorohydrin-cross-linked chitosan	Zn(II)	10.21	6.0	Langmuir	Chen et al. (2008)

the water treatment. The modification of chitosan to its derivatives has shown that the marine polysaccharide chitosan can be tailor-made to any requirement. The multidimensional usage of chitosan and its derivative as water purifier has been well established and reviewed in this chapter.

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