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Functions of chitin fibre in water pollution control

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ABSTRACT

This paper aims to disclose the importance of chitin fibre in water pollution control. For this purpose, the cleaning function of chitin fibre in water environment was explored in difference scenarios, including the purification of drinking water, the treatment of wastewater containing metal ions, the treatment of printing and dyeing wastewater, the treatment of acid mine drainage, the treatment of high protein wastewater, the treatment of toxic organic compounds, and the treatment of papermaking wastewater. It is concluded that chitin fibre can remove the acidity and heavy metal ions from wastewater. Meanwhile, the optimal effect of ferric and manganese ion removal can be achieved at the pH of 4.2. The research findings lay the basis for further application and development of chitin fibres.

Keywords: Chitin fibre; Water pollution; Textile industry; Sustainable development

1. Introduction

The textile industry has created two sources of water pollution: the production of chemical fibre garments and the abandonment of unwanted clothes [1,2]. With these pollution sources, the water environment in water-scarce countries has gone from bad to worse. Taking China, for example, as many as 70% of its rivers, lakes and reservoirs are polluted. A national survey in 2007 shows that, among the organic pollutants discharged to water bodies, nearly 20% were from textile and other export-oriented industries; Most of the products in these industries were sold to the United States and Europe. In fact, about 20%–30% of water pollution in China is attributable to the production of export commodities such as clothes and fabrics.

The Chinese government has made great efforts to curb industrial water pollution. For instance, many factories were relocated to sparsely populated areas. Despite these efforts, there is no sign of decrease in the industrial emission of toxic and hazardous substances. In 2006, the State Environmental Protection Administration (SEPA) admitted that water pollution had endangered people's health, social stability and international image of China. According to the data released by the Ministry of Environmental Protection, the number of mass water pollution incidents increased by 1/3 each year. In 2007, the SEPA and the World Bank issued a report claiming that the use of polluted water incurs an annual loss of USD 7.5 billion in industry, and USD 1 billion in agriculture. This report does not mention the impact of water pollution on human health, because the impact is difficult to assess.

Facing severity of water pollution, it is highly necessary to apply new green raw materials in the textile industry. One of the viable candidates is chitin, a positively charged polysaccharide that comes from an animal source. The chemical structure of chitin is shown in Fig. 1. Chitin fibres can neutralize bacteria and microorganism. There will be fewer water pollution if this type of fibre is introduced to clothmaking [3,4].

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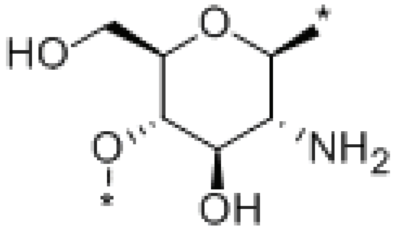

Fig. 1. Chemical structure of chitin.

Considering the above, this paper explores the cleaning function of chitin fibre in water environment. The goal is to disclose the importance of chitin fibre in water pollution control [5].

2. Experimental analysis

2.1. Preparation of chitin

In developed countries, chitin fibre is usually produced by the following advanced method: first, weigh a proper amount of raw materials and soak them in HCl at room temperature for 1 d; second, wash the treated materials, remove the calcium from the peel, and wash the remaining materials again; third, add a certain amount of NaOH into the materials and cook for 6 h to remove protein, forming the initial extraction of chitin; fourth, add 0.7% $KMnO_4$ solution into the extracts, stir the mixture and soak it for 1 h for initial fading; fifth, relocate the mixture into 10% $H_2C_2O_4$ solution and heat up the mixture while stirring for 1 h; sixth, wash the mixture sufficiently with water and dry it to obtain the white chitin product.

The chitin thus prepared is a translucent or white flake. It is insoluble in water but soluble in organic solvents, dilute acids and bases. Chitosan is produced commercially by deacetylation of chitin; chitosan is soluble in water. The chemical structure of chitosan is given in Fig. 2.

2.2. Purification of drinking water

The main pollutants in water include particulate matters, ferromagnesium ions, toxic organic substances and water-borne pathogens. With the growing demand of drinking water, more and more flocculants are needed for traditional methods of water purification. The chitin fibre has unique superiority in the treatment of drinking water, thanks to its naturality, nontoxicity and safety.

Chitin fibre has good removal effect on some algae in water. Adding 0.5 mg/L chitin fibre can reduce the algae-induced turbidity from 9.2 to 1 NTU. In addition, chitin fibre also enjoys excellent bactericidal effect. The previous studies have shown that the application of chitin fibre as flocculant in water purification can achieve the same effect with fewer flocculants in traditional methods. Thus, chitin fibre has been widely adopted for water purification in developed countries.

2.3. Treatment of wastewater containing metal ions

The ammonia in chitin fibre can easily form ammonia cations, which have a good chelating effect on transition metals. Hence, chitin fibre can remove heavy metals from wastewater, such as copper, cadmium, mercury, zinc and lead. Added at 0.1–5 times the mass of metal ions, the fibre enables metal ions in aqueous solution to form water-insoluble substances at certain pHs, making them easier to be separated from water. Chitin fibre is particularly good at removing heavy metal ions from water. The removal is achieved mainly through the reaction between modified chitosan polymer and heavy metal ions and the chelation of the ions by ammonia cations.

When chitin fibre is used as flocculant to remove cadmium in Na_2SO_4 electrolyte, the removal rate depends on the acidity, ion concentration and the amount of chitosan. The removal rate exceeds 99.95% if the cadmium content is less than 40 mg/L, the pH falls in the range 8–9 and chitosan content is 1%. Under the same conditions, the residual contents of copper, zinc and lead are 0.053, 0.058 and 0.01 mg/L, respectively. All of these are below the national emission standard of China. When chitin fibre is used as flocculant to remove lead from wastewater, the removal rate hinges on the addition, adsorption time and pH. The removal rate reaches 98%, if the chitin content is 0.4 m/L, adsorption time is 30 min, the pH is 5–6, and the lead content is 1×10^4 m/L. Under the same conditions, the removal rate of lead stands at 92.6% for wastewater of printing and dyeing processes.

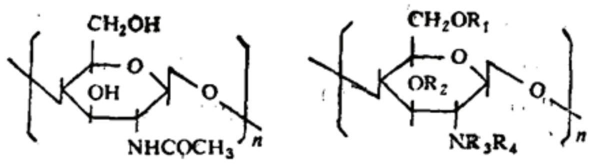

Fig. 2. Chemical structure of chitosan.

2.4. Treatment of printing and dyeing wastewater

Printing and dyeing wastewater refers to the wastewater generated in the pretreatment, dyeing, printing and finishing of textile products made of cotton, wool and chemical fibre. With a large chemical oxygen demand (COD), the wastewater is highly chromatic, hard to oxidize and difficult to degrade. It has become a major source of pollution to water bodies across the globe.

If treated with traditional flocculants, the printing and dyeing wastewater must be processed 20 times, and be placed for 1 or 2 d each time to ensure discolouration. If treated with chitin fibre and activated carbon, the printing and dyeing wastewater can be cleaned through one treatment and a placement of 1–2 months; the processed water is discoloured and free of suspended solids.

2.5. Treatment of acid mine drainage

The chitosan, a product from chitin fibre, can effectively remove the metal ions and reduce the acidity in acid mine drainage. Suppose the raw water has a pH of 2.58 and Fe^{3+} content of 112 m/L, and the H_3O^+ to be neutralized is 0.5–1.2 ml/kg. Then, the pH can be increased from 2.5 to 6.5 and almost 100% of Fe^{3+} can be removed after adding 1 g chitin fibre. If the H_3O^+ to be neutralized is 0.4 mL/kg per 100 mL of raw water, nearly 98% of Fe^{3+} can be removed by 1 g chitin fibre and almost 100% by 2 g chitin fibre.

2.6. Treatment of high protein wastewater

Through protonation, the amide, amino groups and hydroxyl groups in chitin fibre form a cationic polyelectrolyte, which can chelate heavy metals and absorb negatively charged particles in water. Particularly, chitin fibre is good at flocculating protein, starch and other organics from wastewater containing high amounts of protein and starch. That is why this kind of fibre is widely used in the processing of food waste. If used as flocculant, chitin fibre can achieve high flocculation and sedimentation rates in high protein wastewater. The COD removal rate and protein recovery rate could reach 68% and 81%, respectively. The flocculation effect is optimal at the pH of 6.5–8.5, while the sedimentation effect is optimal when the wastewater is boiled.

2.7. Treatment of toxic organic compounds

In industrial wastewater, toxic organic substances such as chlorophenols and polychlorinated biphenyl are dominant pollutants. Here, the chitin fibre is compared with inorganic flocculants in terms of turbidity removal and organic compound removal. The inorganic flocculants include $Al_2(SO_4)^3$, $FeCl_3$ and the polymeric aluminum ferric chloride (PAFC). The results show that the composite flocculant of PAFC and chitosan had the best effect. Under the optimal conditions, the removal rates of turbidity, COD-Mn and UV254 reached 97%, 44% and 55%, respectively.

2.8. Treatment of papermaking wastewater

The wastewater of paper industry contains a lot of fibre, lignin and chemicals. The ensuing pollution has raised global concerns. The chitin fibre flocculant can outperform other synthetic flocculants in the removal of colour and total organic carbon (TOC), with a decolouration rate of 90% and the TOC removal rate of 70%.

3. Results and discussion

3.1. Heavy metal removal effect

When the dosage of chitin fibre is 12 g and the pH is 2.57, the adoption capacity of ferric and manganese ions reaches the maximum after 2.7 h of reaction. Thus, 2.7 h is the best reaction time. When pH = 3.69 and the reaction time is 2.4 h, the adoption capacity of ferric ions peaks when 5.6 g chitin fibre is added, while that of manganese ions peaks when 5.2 g chitin fibre is added. When the dosage of chitin fibre is 2.3 g and the reaction time is 2.9 h, the adsorption capacity of ferric ions is maximized at the pH of 4.2 and that of manganese ions is maximized at the same pH. Hence, 4.2 is the optimal pH for heavy metal removal.

3.2. Acidity removal effect

The chitin fibre has a small effect on wastewater acidity. The neutralization effect is not desirable at a low pH but improves when the pH increases to 4.2 and above. The fibre quality has less influence on neutralization than raw water pH. Therefore, the most economic way is to increase the pH of wastewater to 4.2 before applying chitin fibre.

3.3. Adsorption kinetics

Through the above analysis, it is clear that the ferric and manganese ion adsorption of chitin fibre belongs to isothermal adsorption. Considering the effect of pH on adsorption, the process can be identified as chemisorption. When the removal rate of Fe^{3+} reaches about 93%, 2.6 g chitin fibre can adsorb 99 mg Fe^{3+} from acidic wastewater. When the removal rate of Mn^{2+} reaches about 55%, 2.6 g chitin fibre can adsorb 3.4 mg Mn^{2+} from acid wastewater.

4. Conclusions

The previous analysis shows that chitin fibre can remove the acidity and heavy metal ions from wastewater. Meanwhile, the optimal effect of ferric and manganese ion removal can be achieved at the pH of 4.2. The research findings lay the basis for further application and development of chitin fibres. The future research will combine chitin fibre with other adsorbents to reduce the cost, perform dynamic tests on fixed and fluidized beds, and improve strength of regenerated chitin fibre.

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References

[1] C.K.S. Pillai, W. Paul, C.P. Sharma, Chitin and chitosan polymers: chemistry, solubility and fiber formation, Progr. Polym. Sci., 34 (2009) 641–678.
[2] C. King, R.S. Stein, J.L. Shamshina, R.D. Rogers, Measuring the purity of chitin with a clean, quantitative solid-state NMR method, ACS Sustain. Chem. Eng., 5 (2017) 8011–8016.
[3] S. Gorrasp, G. Izzo, G. Massing, A. Signorini, P. Barghini, M. Fenice, From polluting seafood wastes to energy. Production of hydrogen and methane from raw chitin material by a two-phase process, J. Environ. Protect. Ecol., 75 (2014) 526–536.
[4] C. Hongkulsup, V.V. Khutoryanskiy, K. Niranjan, Enzyme assisted extraction of chitin from shrimp shells (*Litopenaeus vannamei*), J. Chem. Technol. Biotechnol., 91 (2016) 1250–1256.
[5] V.L. Pachapur, K. Guemiza, T. Rouissi, S.J. Sarma, S.K. Brar, Novel biological and chemical methods of chitin extraction from crustacean waste using saline water, J. Chem. Technol. Biotechnol., 91 (2016) 2331–2339.