Chapter 58
Research Progress of Natural Polymer Coagulants in Water Treatment

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Abstract Water turbidity can be decreased through coagulation, effectively removing suspended particles and some dissolved solids from water. The coagulant employed has a significant impact on the outcome of the coagulation process. Inorganic and organic coagulants are the two primary divisions of commonly used coagulants. Due to their practical application and favour able economics, these flocculants are frequently used. However, these flocculants also have drawbacks, including organic synthetic monomers that can present health and safety issues and residual metal ions in the water. Natural polymer coagulants are economical, safe, non-toxic, practical and environmentally friendly. Developing green coagulants based on natural polymers is crucial since they have received widespread acclaim and have a wide range of potential applications.

Keywords Natural coagulants · Wastewater treatment · Coagulant

58.1 Introduction

The use of natural polymer coagulants to treat water and wastewater has been documented since ancient times and remains popular today (Vijayaraghavan et al. 2011). Natural polymers have been utilized for a long time as efficient flocculants and coagulants to cure excessive water turbidity (Anastasakis et al. 2009; Yin 2010). Natural polymer flocculants are derived from various sources (Hussain and Hydar 2019), primarily from plants, seeds, marine crustacean and shellfish (shrimp and crab) biomass, and microorganisms. Most research has concentrated on natural flocculants from plant and marine biomass, such as chitosan, cellulose, starch, and alginates. Natural coagulants are new, renewable, ecologically friendly, affordable, non-toxic, and easily degradable coagulants with good application potential (Choy et al. 2014). Natural POlymer flocculants are being researched at an unprecedented level under

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the environmental protection principle of "turning waste into treasure," which creates new opportunities for the recycling of natural waste but also addresses public demand for environmental protection.

Chemically powerful reactive groups, such as carboxyl and hydroxyl, are present in natural polymers. These groups form the nucleus of coagulation-inducing natural polymer coagulants. Currently, research on chemically altering the active groups of natural polymers to create coagulants is quite adequate, and the research findings have excellent outcomes for actual water treatment applications (Lee et al. 2014). However, research on producing coagulants from unaltered, pure natural raw materials is somewhat lacking. Most studies are still in the laboratory and have not been translated into actual technological applications (Ang and Mohammad 2020).

58.2 Application of Natural Polymer Coagulants in Water Treatment

Using natural polymer coagulants in treating different wastewaters is currently gaining much attention. Agricultural, food processing, aquaculture, beverage manufacturing, paint and varnish, adhesives, cement, soap and detergents, cosmetics, plastics, steel, leather, textile and dyeing, pulp and paper industries have all made extensive use of natural coagulants. In recent years, natural polymer coagulants have been studied to treat various wastewaters, as shown in Table 58.1.

Table 58.1 Application of natural coagulants in wastewater

Natural coagulant	Type of wastewater	Concentration	Removal performance	References
G. ulmifolia	Dairy wastewater	775 mg/L pH:5	Turbidity:95.8% BOD:81.2%	Muniz et al. (2020)
Guar gum	Landfill leachate	44.39 mL/L pH:8.56	COD:22.57%	Cheng et al. (2020)
Moringa seeds	Pharmaceutical wastewater	4 g/L	Turbidity:64% COD:38%	Omna et al. (2010)
Chitosan	Aquaculture wastewater	30 mg/L	Turbidity:96.3% Algae:98%	Fareza, et al. (2017)
Banana skin	Municipal wastewater	0.4 g/L	Turbidity:59.6%	Maurya and Daverey (2018)
Broad bean	Algal wastewater	0.5 g/L pH:5	Cyanobacterial cell removal rate: > 85%	Bouaidi et al. (2020)

58.2.1 Dairy Wastewater

The worldwide dairy business has grown due to the rising demand for milk and dairy products, making it one of the agricultural sector's most economically significant leaders (Ekka et al. 2022). Cheng et al. (2020) employed a brand-new all-natural coagulant from G. ulmifolia's stem bark to filter contaminants from dairy wastewater. It was discovered that the coagulant of G. ulmifolia removed 95.8, 76.0, 81.2, and 85.6% of turbidity, COD, BOD, and UV 254 compounds from dairy wastewater, respectively, at the optimum dose rate of 775.8 mg/L and pH 5.00. Additionally, the sludge created during the treatment process is safe and can be used on the soil to improve it and serve as fertilizer.

58.2.2 Landfill Leachate

Waste leachate post-membrane concentrate is a highly concentrated organic waste with a complex composition that is difficult to biodegrade due to its high chemical oxygen demand, high ammonia nitrogen, and high salt content produced during the treatment of waste leachate by membrane technology (Zouboulis et al. 2004). Landfill leachate can contaminate groundwater and streams by leaching into the soil and subsoil layers. Because of the complexity of waste leachate and the high variability of its content, it is critical to treat waste leachate because it can pose serious environmental and health risks if not adequately treated (Gupta and Singh 2007). Wang's (2020) treatment of waste leachate with guar gum revealed that at a guar gum dosage of 44.39 mg/L, pH 8.56 (the natural pH of leachate), and a mixing rate of 79.27 rpm, the COD removal rate was maximized at 22.57%. Guar gum coagulant could be a future development path for waste leachate treatment because structural characterization using Fourier transform infrared analysis revealed that hydrogen bonds between guar gum and pollutant particles were involved in the coagulation and flocculation.

58.2.3 Pharmaceutical Wastewater

Pharmaceutical manufacturing generates large volumes of highly concentrated organic waste with a complex composition, and its release into the environment endangers human and environmental systems (Alazaiza et al. 2022). The effectiveness of a natural coagulant made from Moringa seeds in treating hospital wastewater was examined by Nonfodji et al. (2010). According to the findings, the coagulant was 64 and 38% effective at removing turbidity and COD, respectively. In a subsequent study, Thirugnanasambandham and Karri (Riaz et al. 2018) compared the coagulant between a natural coagulant derived from Moringa seeds and a typical chemical coagulant, aluminum sulfide. According to the findings, natural-based coagulants may not only be efficient for removing COD, turbidity, and color but may also be economically viable. For hospital wastewater, moringa seed polymers are promising bio-coagulants.

58.2.4 Aquaculture Wastewater

Aquaculture is expanding quickly, and at the same time, more and more farm effluent is being discharged. Aquatic excrement, leftover bait, and other solid particle waste, as well as other contaminants such as pesticides, anti-microbial agents, and antibiotics used in aquaculture, are the main constituents of farm wastewater. In addition to seriously degrading the environment and disrupting the ecology, these pollutants contaminate aquatic products, spread viruses and epidemics, cause fish and shrimp to grow slowly or even die, and eventually destroy the farming business (Riaz et al. 2018). Fareza et al. (2017) investigated the use of chitosan papaya as a natural coagulant in the treatment of aquaculture wastewater. They found that at an optimum coagulant dose of 30 mg/L, the algae removal efficiency was 98%, the turbidity of the treated wastewater was reduced from 60 NTU to 2.2 NTU, and the further discharged supernatant water could be used as recycled water or removed into the water body.

58.2.5 Municipal Wastewater

Banana peel powder, banana stem juice, papaya seed powder, and neem leaf powder were the four natural plant coagulants that Maurya (2018) investigated for their effects on the treatment of municipal wastewater. The results revealed that the best turbidity removal rate was achieved at 0.4 g/L dosages of banana peel powder coagulant; the best COD removal rate was 66.7% for banana stem juice coagulant; and the best COD removal rate for papaya seed powder mix. The coagulant achieved the best removal of total suspended particles, which had a removal rate of 66.66%. This result shows that low-cost natural plant coagulants have a lot of potential for treating municipal wastewater in this study.

58.2.6 Algae Wastewater

With the expansion of agriculture and industry, a significant amount of organic or inorganic nitrogen and phosphorus enter lakes and reservoirs, resulting in eutrophication of water bodies and algal blooms (Teixeira et al. 2022). Of the complicated species, vast number, low specific gravity, and significant negative charge of the water's algae cells. However, the prevalent treatment methods used today rely on pricey membrane filtering or chemicals. According to ElBouaidi et al. (2020), broad bean seed and cactus coagulants were employed to treat algal wastewater, and both could eliminate 85% of Pseudomonas aeruginosa at 0.5 g/L and 1 g/L dosage and pH 5, respectively.

58.3 Limitations and Potential Study in the Use of Natural Coagulants

There haven't been detailed studies on the specific coagulation mechanisms each plant-based procoagulant uses (Kannankai and Devipriya 2022). One or more coagulation mechanisms may bring colloidal particle accumulation during water clarification. Because of the complexity of the process and the potential for synergistic effects between the components present, it is challenging to pinpoint the precise chemical composition that causes particle aggregation (Oladoja 2015). Additional research is required to characterize the active substances that would be useful in identifying the essential substances that are important in the coagulation-flocculation process.

Due to barriers to commercialization, natural polymer coagulants have not been commonly utilized in studies on industrial-scale wastewater treatment. Funding, R&D, market awareness, and regulatory approval requirements hinder commercialization. Market reaction and demand will also impact the outlook and demand for natural coagulants as a potential replacement for chemical coagulants. Target market estimates may be incorrect due to consumer and supplier misconceptions about the viability of natural coagulants (Hewawasam 2021). With the aid of pilot plant studies, it is possible to evaluate elements that may act as sustainability indicators in the economic, social, and environmental spheres. Any new product's successful commercialization will also need the support of local regulatory bodies (Btia et al. 2021).

58.4 Conclusion and Further Works

The main goal is to increase the coagulation effect of coagulants and treatment efficiency, so water treatment coagulants need to be more efficient and environmentally friendly. The creation of a non-toxic, non-hazardous water treatment coagulant should be done as part of the process of developing the future application of natural coagulants. Based on the concept of green and sustainable development, natural polymer coagulants will likely develop in one of two main ways: on the one hand, research and development of coagulants will gradually favor secure, non-toxic, non-polluting natural types and composite types (Jiang et al. 2021); on the other hand, this will be combined with in-depth research and analysis of the coagulation mechanism to prepare a new kind of effective coagulant. In comparison, more research on natural polymer coagulants has been conducted abroad, while the development in China has started a little later and is slower. In the future, the development of natural polymer coagulants will develop in the following directions.

(1) Enhancing and stabilizing the coagulation performance of current coagulants by combining the characteristics of natural polymer coagulants to expand the scope of application;
(2) Inoculating bacterial strains and cultivating them into microbial flocculants that can treat specific wastewaters;
(3) Continuing research and development of cationic or amphoteric coagulants.

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