

Green Chemistry Solution for Water Treatment in a Changing Climate

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Abstract

As the impact of climate change on water resources intensifies, sustainable chemistry is emerging as a key player in comprehensive water management. Recent progress in advanced water treatment technologies, green technologies, and interdisciplinary collaborations are paving the way for innovative and more sustainable solutions. By integrating climate-responsive methodologies, adaptive strategies are being developed for dynamic water systems. A holistic approach that combines sustainable chemistry, policy frameworks, and social sciences is crucial to addressing current and future challenges. To ensure fair and just access to clean water for all, collaborative efforts between these fields are essential. This review emphasizes the urgent need for sustainable solutions and highlights the essential role of sustainable chemistry in addressing the water challenges amplified by climate change.

Keywords : Eco friendly approaches, plants based Biofloculant, Green Chemicals, Sustainable, Coagulation, Minimising ,Environment Impact, Reduced pollution, Sustainable water management, Less harmful byproducts

Introduction

By 2050, the number of people living in severely water-scarce areas is projected to rise from 1.9 billion (27 % of the global population) to around 3 billion. Additionally, the number of people at risk of floods is expected to increase from 1.2 billion to 1.6 billion by the same year . Moreover, only around 40 % of surface waters are in good ecological status, and only 38 % are in good chemical status . These facts, alongside the intensifying effects of climate change on water resources, emphasize the need to re-evaluate our approaches to multifaceted water-related issues . In this situation, sustainable chemistry and water management must converge for critical investigation and innovation. Innovations in sustainable water- related technologies have the potential to create a significant impact on the way we manage our water resources, and we must pay particular attention to their development and implementation. Recent innovations in sustainable water treatment technologies merit particular

attention. Innovative techniques, such as advanced oxidation processes, innovative membrane technologies, and nanotechnology-based filtration systems, have the potential to not only reduce chemical usage but also to strengthen the resilience of water treatment processes against climate-induced challenges. Moreover, the advancements in green chemistry and sustainable chemistry open the door to developing climate-responsive water management solutions. In this context, understanding the distinctions between green chemistry and sustainable chemistry is essential. While green chemistry primarily focuses on minimizing the environmental impact of chemical processes by reducing waste, energy consumption, and toxicity, sustainable chemistry adopts a broader perspective and seeks to develop solutions that are not only environmentally benign but also socially equitable and economically viable, thereby addressing the interconnected challenges of sustainability comprehensively. Sustainable chemistry prepares the framework for innovative approaches beyond green synthesis and environment only and aims to develop adaptable systems ready to face the complexities brought on by

a changing climate. Collaboration at local and global levels is an important aspect of this endeavor, where chemists, environmental scientists, engineers, and policymakers work together to formulate adaptive strategies for the current climate-induced water concerns. A holistic approach that builds on interdisciplinary expertise, could promise of comprehensive solutions capable of addressing the complex issues at hand.

Objectives

Minimize environmental impact of water treatment processes. Utilize renewable resources and green chemicals for water treatment. Reduce harmful byproducts and pollution from water treatment.

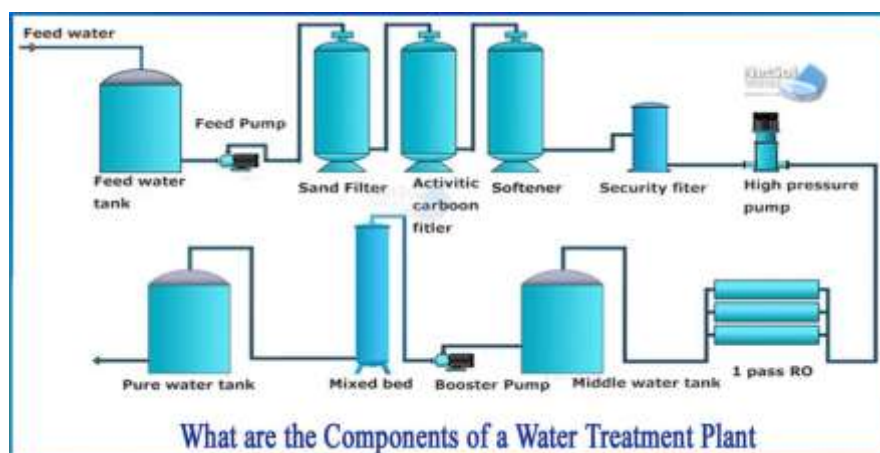
Enhance resilience of water treatment systems in the face of climate change.

Methodology

- **Use of Plant-Based Biofloculants:** Utilizing natural substances like Moringa oleifera or cactus (Opuntia ficus-indica) for water purification.
- **Green Chemicals and Solvents:** Employing eco-friendly chemicals like citric acid, hydrogen peroxide, or bio-based polymers for water treatment.
- **Sustainable Coagulation and Flocculation:** Using organic coagulants that produce biodegradable sludge.
- **Design for Degradation:** Designing chemicals and processes that break down into harmless byproducts.
- **Minimizing Auxiliary Substances:** Reducing the use of harmful substances in water treatment.
- **Using Renewable Feedstocks:** Preferring renewable resources in water treatment processes.
- **Energy Efficiency:** Designing processes for energy efficiency to reduce environmental impact.

Water Treatment :

Water treatment is the process of removing undesirable chemical, physical and biological contaminants from raw or contaminated water. The purpose is to produce water suitable for a specific application. Water treatment may be designed for a variety of applications, including meeting the requirements of human consumption (potable water), medical and pharmacology, chemical and industrial applications. The common stages of treatment include pre-chlorination, coagulation and flocculation, sedimentation, filtration, disinfection, post-chlorination and fluoridation. The main purpose of pre-chlorination is to remove odor, taste and smell of raw water in particularly those containing organic substances such as humic acids. Coagulation and flocculation is a chemical process that removing fine and suspended solids in the water. The flocculated solids are removed via the sedimentation tank. Fines particulates that escape the coagulation-flocculation-sedimentation process will be trapped in the downstream sand filter beds. Some modern treatment plants adopt unconventional green technology to increase the filtration efficiency, such as the use of membrane filtration. The water after filtration needs to be disinfected using chlorination to eliminate pathogenic microorganisms such as parasites, bacteria, algae, viruses, fungi. Because of the concern of formation of carcinogenic trihalomethane in drinking water arising from the use of chlorination, more and more treatment plants are switching to ozonation as the disinfection method, albeit ozonation is relatively more expensive in the first and running costs. As ozone is highly unstable and it reverts to oxygen soon after it is produced, it has no residual disinfection effect as chlorination does. To provide residual disinfection capability, post-chlorination is still being practiced in many treatment plants. To complete the water treatment process, the last step of treatment is fluoridation with an objective of preventing teeth decay of the population.



The rising cost of water as natural resources and increasing environmental awareness have driven many businesses to deploy green technologies to reduce carbon footprints and to minimize wastewater production. Coupled with an increasing demand for high purity water from other industries, several industries are forced to seek out technological solutions, such as seawater desalination and process/wastewater recycling, to fulfill their water needs (such as seawater desalination, or process/wastewater recycling). Using advanced green technology, it is now possible to reclaim wastewater effluent for reuse purposes including drinking water. Water scarcity issues have made treated wastewater an attractive source for some industries (for example, livestock watering and irrigation) in some arid areas. Many industries are taking effort and initiatives to reduce production costs by establishing closed-loop recycling systems within the plants. In many cases, the costs associated with production are directly related to the production of ultra-pure water that is used in the manufacturing process. The consensus is that in many instances throughout the process at manufacturing facilities, it is far more beneficial to treat water through recycling of used water. This gives these facilities a water quality that is much higher than a traditional water source. In turn, the reclaim water produces a product quality that is much more enhanced, while in effect curtailing expenses at the manufacturing facility. It is simpler to recycle water with known constituents, such as the process water, than to formulate a plan to produce pure and ultra-pure water from raw groundwater sources. Efficiency gains and revolutionary technological developments are expected to make recycled water costcompetitive with other water provision options. Advancements in membrane technologies, for

example, have increased the potential uses for membranes in treating both process water and wastewater streams achieving both cost and quality competitiveness. As competition intensifies, price cuts will provide some respite to costconscious customers and further boost the uptake of water recycling equipment.

Limitations:

- Scalability: Some green chemistry methods might not be scalable for large-scale water treatment plants.
- Cost: Green alternatives can sometimes be more expensive than traditional methods.
- Effectiveness: In some cases, green chemistry solutions might not match the effectiveness of conventional methods for certain contaminants.
- Infrastructure Adaptation: Implementing green chemistry solutions might require adjustments to existing water treatment infrastructure.
- Limited Availability of Green Alternatives: For some treatment processes, green alternatives might not be readily available or well-developed.

Results and Case Studies

Green chemistry is making waves in water treatment, especially in the face of climate change. By utilizing eco-friendly methods and materials, green chemistry minimizes environmental harm while ensuring effective water purification.

Case Studies Highlighting Green Chemistry in Water Treatment

Novozymes' Enzyme-Based Detergents:
Novozymes developed enzyme-based detergents

using natural catalytic proteins. These biodegradable detergents reduce energy requirements for laundering and minimize harmful chemical release into wastewater systems ¹.

Dow Chemical's Eco-Friendly Plasticizers: Dow developed DOW ECOLIBRIUM™ bio-based plasticizers for flexible PVC applications. Derived from renewable plant-based feedstocks, these plasticizers reduce environmental impact while meeting regulatory standards ¹.

Aquacycl's Wastewater Treatment: Aquacycl's onsite wastewater treatment system for swine waste achieves net-zero energy requirements. Their BioElectrochemical Treatment Technology (BETT) reduces greenhouse gas emissions by 80-90% in food and beverage processing wastewater.

Results and Benefits of Green Chemistry in Water Treatment

Reduced Environmental Impact: Green chemistry minimizes hazardous waste, emissions, and resource consumption.

Improved Safety: Eco-friendly chemicals and processes reduce risks for workers and consumers.

Sustainable Solutions: Green chemistry promotes the use of renewable feedstocks, energy efficiency, and degradable products ³.

Discussion

Green chemistry is playing a pivotal role in addressing water treatment challenges in the face of climate change. By utilizing eco-friendly methods, green chemistry minimizes environmental harm while ensuring effective water purification.

Environmental Impact:

- **Reduced Pollution:** Green chemistry minimizes hazardous byproducts and promotes biodegradable substances.
- **Sustainable Resource Use:** Utilizes renewable feedstocks and reduces resource consumption.

Economic Impact:

- **Cost Considerations:** Green alternatives might have different cost implications compared to traditional methods.
- **Long-Term Benefits:** Green chemistry can lead to cost savings through reduced waste treatment and environmental remediation.

Social Impact:

Improved Safety: Eco-friendly chemicals and processes reduce risks for workers and communities.

Community Benefits: Sustainable water treatment supports community health and environmental well-being.

Challenges and Limitations:

Scalability and Effectiveness: Ensuring green chemistry solutions are scalable and effective for diverse water treatment needs.

Cost and Infrastructure: Balancing costs and adapting existing infrastructure for green chemistry implementation.

Regulatory Considerations: Meeting regulatory standards with green chemistry approaches.

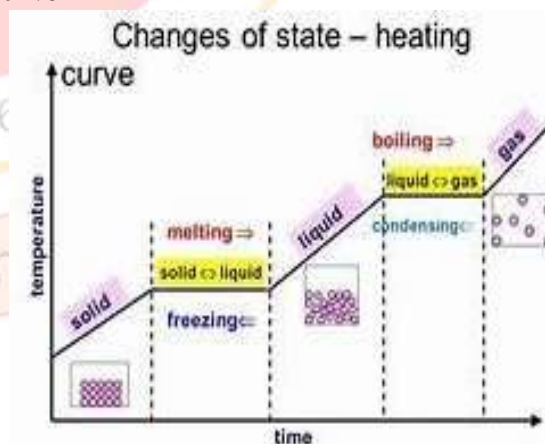
Policy Implications:

Regulatory Frameworks: Governments establish regulations requiring industries to adopt safer chemicals and processes.

Incentives for Green Innovation: Governments provide financial incentives for research and development in green chemistry.

International Cooperation: Global agreements promote green chemistry practices for environmental protection and public health ^{3 1}.

Curve



Emerging Innovations

Advanced Green Materials: Researchers are developing green materials like aerogels, nanoparticles, membranes, and biofilms from sustainable feedstocks such as agricultural waste and expired oils. These materials show outstanding efficiencies in removing contaminants like Cr(VI) (97%), Cd²⁺ (98.46%), and Pb²⁺

Biopolymer-Based Nanocomposites: Biopolymers like cellulose, chitosan, and alginate are being used in adsorption and membrane filtration for effective water treatment.

Green Nanoparticles: Green synthesis of nanoparticles using plant extracts is gaining attention for wastewater treatment, offering effective removal of heavy metals and organic pollutants

Membrane Filtration: Techniques like nanofiltration and reverse osmosis provide efficient removal of pollutants.

Advanced Oxidation Processes (AOP): AOPs use hydroxyl radicals to decompose organic contaminants in water.

Bioremediation: Using microorganisms to degrade water pollutants offers an eco- friendly alternative

Future Directions

Nanotechnology for Filtration: Development of nanomaterials for efficient filtration of contaminants at a microscopic level without harsh chemicals.

Microbial Treatments: Using specific bacteria to break down pollutants naturally in water systems.

Bio-based Polymers: Increasing use of bio-based polymers for flocculation in water treatment processes

Renewable Resources: Utilizing renewable feedstocks like plant-based chemicals reduces environmental impact.

Energy Efficiency: Green chemistry promotes energy-efficient processes to minimize the carbon footprint of water treatment.

Waste Minimization: Designing processes that minimize waste aligns with green chemistry principles

Conclusion

By examining advanced water treatment technologies, interdisciplinary collaborations, and the integration of sustainable chemistry, the review stresses the urgent need for transformative and adaptive strategies. The synergistic intersection of sustainable chemistry and emerging technologies, including artificial intelligence, holds promise for creating resilient water management approaches.

However, despite advancements, challenges and limitations remain.

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