

# Emerging Technologies in Water Purification: A Mini Tutorial Review

Suhail Abdullah Malik<sup>1</sup> and Bashir Ahmad Dar<sup>2\*</sup>

<sup>1</sup>Department of Environmental Science, Government Degree College, India

<sup>2</sup>Department of Chemistry, Government Degree College, India

ISSN: 2576-8840



**\*Corresponding author:** Bashir Ahmad Dar, Department of Chemistry, Government Degree College, Uri, Baramulla, 193123, J&K, India

**Submission:**  August 19, 2024

**Published:**  August 28, 2024

Volume 20 - Issue 5

**How to cite this article:** Suhail Abdullah Malik and Bashir Ahmad Dar\*. Emerging Technologies in Water Purification: A Mini Tutorial Review. Res Dev Material Sci. 20(5). RDMS. 000998. 2024.  
DOI: [10.31031/RDMS.2024.20.000998](https://doi.org/10.31031/RDMS.2024.20.000998)

**Copyright@** Bashir Ahmad Dar, This article is distributed under the terms of the Creative Commons Attribution 4.0 International License, which permits unrestricted use and redistribution provided that the original author and source are credited.

## Abstract

Recent years have seen major developments in the technology of water purification, addressing the global issues of water contamination and scarcity. This thorough analysis looks at the most recent developments in water treatment as of 2024, emphasizing major patterns that could lead to increased accessibility, sustainability, and efficiency. With their accuracy and efficacy, emerging technologies like aquaporin inside technology, acoustic nanotube technology, and nanotechnology are transforming the field. It is also mentioned that advanced oxidation processes, graphene-based filtration, and AI integration have the potential to outperform conventional purifying techniques. Additionally, modular water treatment systems provide scalable solutions that can be adjusted to different needs, and desalination techniques are continually improving and providing essential resources in arid locations. This article critically examines each technology's role in providing everyone with safe, clean drinking water by exploring its foundations, uses, and possibilities for the future.

**Keywords:** Water purification; Emerging technologies; Nanotechnology; Advanced oxidation processes

## Introduction

One of the most important aspects of environmental sustainability and public health is water purification. On this World Water Day in 2024, the pressing needs of an expanding world population and the tangible effects of climate change highlight the value of water filtration and reuse<sup>1</sup>. In addition to highlighting the critical role that water plays in promoting wealth and peace, the United Nations World Water Development Report 2024 argues that fair access to water services is a prerequisite for social stability [1]. Despite advancements, current purification methods grapple with challenges such as limited accuracy, real-time monitoring capabilities, and cost-efficiency [2]. Even though they are somewhat effective, traditional methods like filtration, sedimentation, and disinfection are becoming less and less suitable to deal with new pollutants and rising water demands. The constant threat of micropollutants and outdated infrastructure aggravate this insufficiency [3].

Thus, it is evident how urgently new technologies for water purification are needed. Not only are innovations like nanotechnology and sophisticated membrane systems increasing efficiency, but they are also essential for guaranteeing the elimination of contaminants at the microscopic level [4]. Urbanization rates, widespread water body contamination, and the necessity for water safety are driving these technologies. Innovations like digital twin technology are also emerging to minimize water losses and improve utility operations as we move toward a future with zero water waste [5]. The concepts, uses, and revolutionary possibilities of these new technologies are explored in this brief article that focuses on water purification. It seeks to offer a thorough grasp of how these developments can resolve present issues and satisfy the need for clean water on a global scale.

## Traditional water purification technologies

Traditionally, the search for pure water has depended on conventional purifying techniques. Boiling, chemical treatment, filtration, distillation, and reverse osmosis are a

few of the techniques that have helped reduce the incidence of waterborne illnesses and provide safer drinking water. Traditional methods such as filtration using linen, plant materials, clay pots, and winnowing sieves have been profoundly embedded in the social approach to water purification in many cultures, most notably in India [6].

These conventional techniques have significant drawbacks even with their extensive application. They frequently fall short of completely eliminating new contaminants that are showing up in our water sources, such as microplastics and pharmaceutical residues. Furthermore, techniques that use chemical coagulants have the potential to add new impurities and change the pH balance of the water [7].

Moreover, certain conventional techniques require a lot of resources. Reverse osmosis systems, for instance, have come under fire for being inefficient because of their propensity to squander large amounts of water and energy. While developments in 2024 have resulted in waste reduction and increased efficiency in membrane technology, the drawbacks of conventional approaches highlight the need for innovation in water purifying technologies [8]. It's clear that these traditional approaches need to change as we move farther into the twenty-first century in order to satisfy the rising expectations for sustainability and water quality. The parts that follow will go over how new technologies are trying to solve these problems and usher in a new era of water purification [9].

### Advancements in physical purification methods

The field of water purification has seen significant advancements in physical methods, with innovations enhancing efficiency and effectiveness.

**Filtration innovations:** 2024 has seen a significant advancement in filtration technologies thanks to the incorporation of sophisticated membrane systems and applications of nanotechnology. These developments are essential for guaranteeing cleaner water flow by eliminating impurities at the microscopic level. The integration of membrane filtering with additional procedures like sophisticated oxidation and biological treatment has also been made possible by the advancement of modular technology [10].

**Ultraviolet disinfection improvements:** Significant advancements in water treatment have resulted from recent innovations in UV disinfection technology. An important development is the investigation of far-UVC light. Far-UVC light has shorter wavelengths than regular UV-C light, which is harmful to people's health but successfully inactivates germs. Studies in science have shown that it is effective against germs and viruses. Incorporating UV systems with HVAC systems also improves the quality of indoor air. Airborne infections are neutralized by adding UV-C lamps to HVAC ducts, improving general health and safety. The efficacy of this strategy in lowering microbial contamination is supported by research. Despite these developments, there are still issues, such as the high startup expenditures and the requirement

for regular maintenance. Adopting UV disinfection technology successfully requires educating users on safe handling and safeguards. Subsequent investigation and real-world application will propel additional advancements in this domain [11].

**Distillation technology enhancements:** Improvements in the design and texturing of condenser and reboiler tubes have helped distillation technology by increasing surface temperature control and heat transmission rates. Furthermore, developments in distillation models and technology that are directly applicable to distillation operations have been sparked by the interest in carbon dioxide removal methods [12].

These advancements reflect a commitment to addressing the limitations of traditional methods and pushing the boundaries of what's possible in water purification.

### Chemical purification breakthroughs

**Advanced Oxidation Processes (AOPs):** Recent developments in AOPs have concentrated on optimization techniques and sustainable water use. Sono chemical processes, hydro cavitation, ozone-based, sulphate radical-based, and UV-based processes are among the noteworthy advancements [13].

**Novel coagulation and flocculation agents:** Advances in coagulation-flocculation methodologies have ushered in the use of hybrid materials as coagulants-flocculants, hence providing enhanced efficacy in the treatment of wastewater with an industrial hue. To encourage the quick aggregation of stable particles in water, enhanced coagulation techniques are also being investigated [14].

**Enhanced adsorption materials:** The design of adsorption materials has seen significant progress with the introduction of amorphous-crystalline heterointerfaces providing oxygen vacancies and unsaturated coordination bonds for improved adsorption. Transition metals modified activated carbons and double alkali activation approaches are among the latest techniques enhancing adsorption capabilities [15].

### Biological purification developments

**Biofiltration and bioremediation techniques:** Advancements in biofiltration have recently improved the removal efficiency for a variety of pollutants, such as hydrogen sulfide (H<sub>2</sub>S) and volatile organic compounds (VOCs). Enhancing bioremediation of contaminated habitats through bioaugmentation, or seeding with enhanced microbial consortia, has demonstrated potential [16].

**The role of Microbial Fuel Cells (MFCs):** As bio-electrochemical devices that use microbial activity to transform chemical energy from organic molecules into electricity, MFCs are becoming more and more popular. They are useful in applications like wastewater treatment and bioenergy generation because they provide the twin benefits of pollution removal and energy production [17].

### Nanotechnology in water purification

**Nanofiltration membranes:** By 2024, the global market for nanofiltration membranes is projected to develop at a compound

yearly growth rate of 18.2 percent from 2019 to a value of over 1.2 billion US dollars. The invention of two-dimensional (2D) laminated membranes, which combine outstanding solvent permeance and solute rejection with the energy-saving property of Organic Solvent Nanofiltration (OSN) to enhance methanol recovery and other applications, is one of the recent successes [18].

**Nanoparticles for contaminant removal:** Nanoparticles, nanofibers, and Metal-Organic Frameworks (MOFs) are being investigated for their special properties and applications in wastewater treatment. Biocompatible nanoparticles with magnetite cores coated in hydroxyapatite have been developed for metals removal from fresh water, allowing easy retrieval due to their magnetic nature while minimizing toxicity. Advances in nanomaterials (NMs) have greatly enhanced environmental pollution remediation [19].

### Smart water purification systems

**Integration with IoT devices:** In order to improve efficiency and customer experience, smart water purification systems are progressively connecting with Internet of Things (IoT) devices. These systems precisely measure, monitor, and control water distribution networks and water quality through the use of sensors, big data, and artificial intelligence. IoT-integrated smart Reverse Osmosis (RO) purifiers provide remote management and real-time monitoring, resulting in better water quality, cost savings, and data-driven insights [20].

**Real-time monitoring and control:** Through synced smartphone apps, consumers may monitor consumption habits and purifier health thanks to these systems' real-time monitoring capabilities. AI systems forecast maintenance requirements and optimize servicing plans. Startups are overcoming the accuracy and cost-efficiency constraints of traditional water quality monitoring by utilizing machine learning algorithms, IoT devices, and remote sensing [21].

### Sustainability and Environmental Impact

**Energy-efficient technologies:** Water treatment technologies will still be developing in 2024, with a focus on energy efficiency. Vacuum distillation, multi-effect distillation, and advanced oxidation processes are examples of innovations that are becoming more common. These techniques guarantee the production of high-purity water, save operating costs, and improve energy efficiency. Another innovation in water treatment is the use of nanobubble technology, which provides effective gas transport and lowers energy use [22].

**Waste reduction strategies:** Additionally, the industry is concentrating on waste reduction techniques, with Zero Liquid Discharge (ZLD) systems becoming more and more well-liked, particularly in sectors like semiconductor fabrication. Eliminating liquid waste and maximizing water reuse are the goals of these systems. The move towards more sustainable water management approaches also includes modular water treatment systems and bio-based water remediation [23].

### Case studies and real-world applications

**Success stories of technology implementation:** Innovative water purification technologies have been successfully implemented across various regions, showcasing significant improvements in water quality and resource management. For instance, Smart Terra in India is utilizing digital twin technology to reduce water losses and enhance revenue streams through its cloud-hosted software, which is adept at handling intermittent water supply and enables utilities to swiftly detect leaks across networks. Other success stories include companies that have developed advanced filtration systems capable of removing bacteria, viruses, and heavy metals from contaminated water sources [24].

**Comparative analysis of different regions:** Comparative analyses of water purification systems reveal diverse approaches and effectiveness across regions. In Bangladesh, for example, studies have highlighted issues like excessive microorganisms and contaminants in tap water, prompting the adoption of various purification methods to ensure safe drinking water. A systematic review of water sustainability indices provides insights into how different regions prioritize and measure their progress towards sustainable water management [25].

### Future directions and research opportunities

**Potential for scalability:** Recent advancements in water purification technology have demonstrated significant potential for scalability. For example, a roll-to-roll prototype has been developed for the photochemical modification of membranes, employing robust chemistries and scalable methods to bring new solutions closer to real-world applications<sup>1</sup>. Additionally, green and sustainable in situ water treatment methods are being reviewed for their scalability, stability, and selectivity<sup>2</sup>. Modular water treatment systems are also gaining traction due to their flexibility and scalability, improving access to fresh water in water-scarce regions [25].

**Interdisciplinary collaboration prospects:** Interdisciplinary collaboration continues to be a driving force in the field of water purification. The International Conference on Future of Water Resources (ICFWR-2024) and the Roorkee Water Conclave are examples of platforms that promote interdisciplinary dialogue among various stakeholders. The EU-India Research Collaboration on Water Challenges has brought forth innovative solutions like SPRING's cost-effective wastewater treatment technology [26].

### Conclusion

This review has highlighted the remarkable strides made in water purification technologies, underscoring the critical role of innovation in addressing global water challenges. Key findings reveal that advancements in filtration, desalination, and sustainable treatment methods are revolutionizing our approach to water purification, offering scalable and efficient solutions. Emerging technologies, such as advanced membrane systems and green chemistry approaches, are not only enhancing the efficacy of water treatment but also contributing to environmental sustainability.

The interdisciplinary collaboration has proven to be instrumental in driving these innovations forward, fostering a synergistic exchange of knowledge and expertise. In conclusion, the impact of these technologies is profound, promising a future where access to clean water is not a luxury but a reality for all. As we continue to navigate the complexities of water management, it is clear that the fusion of technology and collaborative effort will be pivotal in ensuring water security for generations to come.

## References

- United Nations World Water Development Report (2024) Water for Prosperity and Peace. UNESCO.
- Singh BJ, Chakraborty A, Sehgal R (2023) A systematic review of industrial wastewater management: Evaluating challenges and enablers. *Journal of Environmental Management* 348: 119230.
- Bhagavatula A, Rajagopalan A, Duncan B, Vimalchand P (2021) Evaluation and optimization of flocculation-sedimentation-filtration process for addressing water-energy nexus challenges at Kemper IGCC power plant: Bench and pilot scale studies. *Energy Nexus* 1: 100006.
- Kathi S, Mahmoud AED (2024) Trends in effective removal of emerging contaminants from wastewater: A comprehensive review. *Desalination and Water Treatment* 317: 100258.
- Pesantez JE, Alghamdi F, Sabu S, Mahinthakumar G, Berglund EZ (2022) Using a digital twin to explore water infrastructure impacts during the COVID-19 pandemic. *Sustain Cities Soc* 77: 103520.
- Adesina OB, Chirwa W, Oke EI (2024) Evolution in water treatment: Exploring traditional self-purification methods and emerging technologies for drinking water and wastewater treatment: A review. *World News of Natural Sciences* 53: 169-185.
- Talukdar A, Kundu P, Bhattacharya S, Dutta N (2024) Microplastic contamination in wastewater: Sources, distribution, detection and remediation through physical and chemical-biological methods. *Science of The Total Environment* 170254.
- Xu Y, Zhu Y, Chen Z, Zhu J, Chen G (2022) A Comprehensive review on forward osmosis water treatment: Recent advances and prospects of membranes and draw solutes. *Int J Environ Res Public Health* 19(13): 8215.
- Shayo GM, Elimbinzi E, Shao GN (2024) Water-based technologies for improving water quality at the point of use: A review. *Wiley Interdiscip Rev Nanomed Nanobiotechnol* 16(1): e1940.
- Issaoui M, Jellali S, Zorpas AA, Dutournie P (2022) Membrane technology for sustainable water resources management: Challenges and future projections. *Sustainable Chemistry and Pharmacy* 25: 100590.
- Memarzadeh F (2021) A review of recent evidence for utilizing ultraviolet irradiation technology to disinfect both indoor air and surfaces. *Appl Biosaf* 26(1): 52-56.
- Towler GP, Frey SJ (2019) Reactive distillation. *Reactive Separation Processes*. CRC Press, USA, pp. 18-50.
- Kumari P, Kumar A (2023) Advanced oxidation process: A remediation technique for organic and non-biodegradable pollutant. *Results in Surfaces and Interfaces* 11: 100122.
- Zaharia C, Musteret CP, Afrasinei MA (2024) The use of coagulation-flocculation for industrial colored wastewater treatment-(I) the application of hybrid materials. *Applied Sciences* 14(5): 2184.
- Jia B, Zhang B, Cai Z, Yang X, Li L, et al. (2023) Construction of amorphous/crystalline heterointerfaces for enhanced electrochemical processes. *eScience* 3(2): 100112.
- Pachaiappan R, Cornejo-Ponce L, Rajendran R, Manavalan K, Femilaa Rajan V, et al. (2022) A review on biofiltration techniques: recent advancements in the removal of volatile organic compounds and heavy metals in the treatment of polluted water. *Bioengineered* 13(4): 8432-8477.
- Mittal N, Kumar A (2022) Microbial fuel cell as water-energy-environment nexus: a relevant strategy for treating streamlined effluents. *Energy Nexus* 7: 100097.
- Baysal T, et al. (2024) Methanol recovery: potential of nanolaminated organic solvent nanofiltration (OSN) membranes. *Nanoscale* 16(7): 3393-3416.
- Zamel D, Khan AU, Waris A, Ebrahim A, El-Sattar N (2023) Nanomaterials advancements for enhanced contaminant removal in wastewater treatment: nanoparticles, nanofibers, and metal-organic frameworks (MOFs). *Results in Chemistry* 6:101092.
- Dada MA, Majemite MT, Obaigbena A, Daraojimba OH, Oliha JS, et al. (2024) Review of smart water management: IoT and AI in water and wastewater treatment. *World Journal of Advanced Research and Reviews* 21(1): 1373-1382.
- Alprol AE, Mansour AT, El-Din Ibrahim ME, Ashour M (2024) Artificial intelligence technologies revolutionizing wastewater treatment: Current trends and future prospective. *Water* 16(2): 314.
- Eniola JO, Kujawa J, Nwokoye A, Al-Gharabli S, Avornyo AK, et al. (2024) Advances in electrochemical membranes for water treatment: A comprehensive review. **Desalination and Water Treatment** 319: 100450.
- Date M, Patyal V, Jaspal D, Malviya A, Khare K (2022) Zero liquid discharge technology for recovery, reuse, and reclamation of wastewater: A critical review. *Journal of Water Process Engineering* 49: 103129.
- Rodríguez-Alonso C, Pena-Regueiro I, García Ó (2024) Digital twin platform for water treatment plants using microservices architecture. *Sensors* 24(5): 1568.
- Afzal L (2023) Comparative analysis between water purification systems. *Engineering Proceedings* 56(1): 110.
- Kotsampopoulos P, et al. (2022) Eu-India collaboration for smarter microgrids: Re-empowered project. 2022 IEEE PES innovative smart grid technologies conference Europe (*ISGT-Europe*). IEEE.