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Editorial

Advanced Technology for Desalination and Water Purification

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1. Introduction

Water scarcity stands as a critical challenge of our era, affecting approximately four billion individuals who confront severe water shortages for at least one month annually. Desalination, the process of removing salt from seawater, emerges as a viable solution that is increasingly being adopted to furnish potable water to expanding populations. Nonetheless, this trend underscores the imperative for energy-efficient desalination systems. Broadening the scope, desalination fundamentally entails extracting pollutants from a solution, encompassing the removal of heavy metal ions, colloidal particles, diverse chemical compounds, and organic matter from solutions or contaminated water. The methodologies employed can be categorized into physical and chemical approaches.

Physical methods encompass a diverse array of techniques, including distillation, freezing desalination, solvent extraction, membrane processes, solar desalination [1,2], and wave-powered desalination. Distillation, for instance, achieves liquid–dirt separation through selective boiling and subsequent condensation. Freezing desalination utilizes phase changes (freezing and melting) to isolate liquid from contaminants. Solvent extraction segregates contaminants based on their solubility in two immiscible liquids—one polar (water) and the other non-polar (e.g., organic solvent)—owing to gradients in chemical potential. Among these, membrane processes are the most prevalent, offering a wide range of options contingent upon the targeted pollutant for removal. These processes encompass subcategories, such as microfiltration, ultrafiltration, nanofiltration, reverse osmosis (RO), and forward osmosis (FO), which are distinguished primarily by the pore sizes of their respective membranes.

Chemical methods, in a preliminary classification, fall into two subclasses. The first comprises established techniques, such as precipitation, coagulation–fluctuation, adsorption [3,4], ultraviolet treatment, and ion exchange [5,6]. The second category involves emerging technologies, such as electrodeionization (EDI), capacitive deionization (CDI), and Faradeic electrosorption, leveraging electric fields to remove ions [7] or facilitate electrochemical reactions at electrodes. Hybrid approaches combine electric fields with established methods, including electrochemical oxidation and reduction, electrocoagulation, electroflotation, and electrodeposition.

Although these methods have demonstrated varying degrees of success across numerous industries, they are predominantly employed in large-scale installations, often outperforming other options. This Special Issue ‘Advanced Technology for Desalination and Water Purification’ (https://www.mdpi.com/journal/water/special_issues/N729IH77YQ (accessed on 25 March 2024)) focuses on alternative small-scale technologies addressing the need for solutions adaptable to individual or small group usage, potentially powered by small energy units or suitable for isolated environments. These technologies also hold promise for sustaining small population groups during emergency scenarios. The subsequent Table 1 outlines the articles featured in this Special Issue, followed by a succinct analysis and summary of each article in paragraph 2.

Table 1. The list of papers included in this Special Issue with their geographic coverage and main topics addressed.

First Author	Number of Authors	Area	Research Topic
K. Abdiyev et al. (2023)	9	International	slow sand filtration; microbes; turbidity
M. Zayed et al. (2023)	7	International	double-slope solar distiller; prismatic absorber; linen wicks; spraying nozzles; energic–exergic analysis; LCA
M. Mohammed et al. (2023)	4	International	direct evaporative; indirect evaporative; Maisotsenko evaporative; humidification–dehumidification; desalination; Köppen–Geiger climatic classifications
V. Bartzis et al. (2023)	7	International	anthocyanins; winery wastewater; electric field induced ion drift
M. Alomar et al. (2023)	8	International	solar evaporation; honokiol; self-regeneration; freshwater; salt collection

2. Summary of Contributions to This Special Issue

2.1. Review of Slow Sand Filtration for Raw Water Treatment with Potential Applications in Less-Developed Countries

Abdiyev et al. (2023) (contribution 1) explore a cost-effective and efficient method for obtaining potable water, namely the use of slow sand filters (SSFs). Their review delves into the construction, regeneration, and response time of SSFs, demonstrating their efficacy in providing safe drinking water to rural communities lacking centralized water supply. Particularly crucial for developing and underdeveloped regions is the biological filtration function of SSFs. Given that surface and shallow groundwater in such areas are frequently contaminated by domestic wastewater-carrying microbes and nutrients, SSFs play a vital role in treating raw water in the form of diluted wastewater. Even though there is high microbial and algal growth due to warm temperatures and nutrient accessibility, there is also high retention efficiency in removing contaminants using SSFs.

2.2. Novel Design of Double-Slope Solar Distiller with Prismatic Absorber Basin, Linen Wicks, and Dual Parallel Spraying Nozzles: Experimental Investigation and Energic–Exergic–Economic Analyses

M. Zayed et al. (2023) (contribution 2) explored the use of a prismatic absorber basin within a solar distiller (SD). More specifically, by expanding the evaporation area within a SD, there is an increase in freshwater output. This study introduces a novel design featuring a prismatic absorber basin with linen wicks, replacing the traditional flat absorber basin, to amplify the surface area of the vaporization zone in a double-slope solar distiller (DSSD). To increase the efficiency of the DSSD, dual parallel spraying nozzles were integrated beneath the glass cover to supply saltwater, reducing the thickness of the saltwater film on the wick. Two types of double-slope distillers were constructed and tested in outdoor summer conditions in Tanta, Egypt (31° E and 30.5° N): a double-slope solar distiller with a wick prismatic basin and dual parallel spraying nozzles (DSSD-WPB&DPSN), and a traditional double-slope solar distiller (TDSSD). A comparative energic–exergic-economic analysis of the two proposed solar stills was also conducted, in terms of the cumulative distillation yield, daily energy efficiency, and cost per liter of distilled yield for DSSD-WPB&DPSN and (TDSSD). The findings indicated that the cumulative distillation yield of the DSSD-WPB&DPSN was 8.20 kg/(m^2) per day, surpassing that of the TDSSD by 49.64%. Additionally, the energy and exergy efficiencies increased by 48.51% and 118.10%, respectively, compared to the TDSSD. Moreover, the life cost assessment revealed that the cost per liter of the distilled yield of the DSSD-WPB&DPSN was reduced by 11.13% compared to the TDSSD.

2.3. Evaporation-Assisted Humidification–Dehumidification Cycles for Desalination Application in Tropical and Subtropical Regions

Mohammed et al. (2023) (contribution 3) demonstrated that the Maisotsenko evaporative (ME-HDH) desalination system exhibits a higher water production rate (WPR) compared to direct evaporative (DE-HDH) and indirect evaporative (IE-HDH) systems, ranging from 0.01 to 7.92 g/s. The sensible cooling flux was notably high at a dry-bulb temperature (Tdb) of 50 °C and relative humidity (RH) of <0.2, with values of 5.26 kW for the DE-HDH system, followed by the ME-HDH system (3.23 kW) and the IE-HDH system (3.11 kW) due to higher mass flow rates. The latent heat flux was comparatively high in the ME-HDH system. The ME-HDH system exhibited the lowest specific energy consumption and consequently achieved the highest gain output ratio (3.32). Moreover, increasing air velocity and wet bulb effectiveness were found to significantly enhance the WPR. Considering the climatic conditions of the Saudi Arabian cities studied, Al-Hofuf and Riyadh were found to have relatively high WPRs with minimal energy consumption. Al-Hofuf had an average WPR of 185.51 kg/day, followed by Riyadh with 180.33 kg/day. The energy required was estimated to be 0.042 kWh/kg and 0.034 kWh/kg for Al-Hofuf and Riyadh, respectively.

2.4. Application of Electric Field Force for the Accumulation of Anthocyanins from Winery Wastewater

Bartzis et al. (2023) (contribution 4) proposed, in this theoretical study, a way to remove anthocyanins from winery wastewaters using an external electric field. The products of the method can be used as food colorants and nutraceutical ingredients. Also, clean water can be reused. It is based on the fact that anthocyanin is in an ionic form ($C17H15O7^+$); thus, by applying an electric field externally using a capacitor perpendicular to the wastewater flow inside a duct, anthocyanin ions will accumulate on one side of the duct from which they can be collected. Of course, the existence of a double layer prevents the accumulation of ions from a certain point onwards. This is why the method works for duct widths of less or equal to 1 mm, achieving more than 90% reduction in the concentration of anthocyanins in the main volume of the solution for applied potentials $\varphi(0)$ in the range of 0.2–0.4 V and target concentrations equal to 1.2×10^{-3} mol/m^3. The device that creates the electric field is also described theoretically, and essential parameters such as final spatial distribution of concentration, electric field intensity, surface charge density, potential and double layer width are calculated.

2.5. Self-Regenerating Solar Evaporation System for Simultaneous Salt Collection and Freshwater from Seawater

Alomar et al. (2023) (contribution 5) proposed a system that aims to generate freshwater in situ and collect salt from seawater. It is based on the successful synthesis of pyrolyzed honokiol biochar (HB) for the development of a self-regenerating solar evaporation system. The pyrolyzed biochar was applied onto a non-woven fabric (HB@NF), exhibiting outstanding solar absorption (96%) and stability in seawater. The device consists of two components: (1) the HB-printed fabric serving as a photothermal layer for efficient solar-to-vapor conversion (93%) under 1 kWm^{-2}, and (2) a centralized seawater supply mechanism resembling an umbrella, utilizing the Marangoni effect for water evaporation and salt collection on-site. Efficient thermal management was achieved with heat accumulation of 48.5 °C under one sun intensity (1 kW m^{-2}), validated through the COMSOL heat transfer simulation. Additionally, a series of experiments were conducted to evaluate salt collection over various time periods, evaporation stability across different cycles, and the removal of primary metal ions using inductively coupled plasma.

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