Innovations

Development and Optimization of a Portable Filtration System for Sea Water Desalination to Transform Sea Water into Drinking Water

Dr. Chandan Adhikari[a], Souhridya Bhattacharjee[c], Dr. Prabir Kumar Das[b]
Department of Basic Science and Humanities
Institute of Engineering & Management, Kolkata, India
University of Engineering & Management, Kolkata, India

Correspondence Author: **Dr. Chandan Adhikari**

Abstract: *This paper describes the design, optimization and fabrication of a portable filtration system aimed for saltwater desalination into potable drinking water. The lab has built a fully functional prototype of the system to show it can desalinate seawater into low pH water safely worth between 7.4 and 7.8. This delivers alkaline water with a pH worth of around 7.3-7.6 both for healthier hydration and better body pH balance. Filtration system is designed for efficient desalination, and it has 3 liters per hour of seawater filtration capacity. Compact, mobile Architecture provides for applications in more remote areas and emergency services, maritime activities accompanied by limited access to fresh water. So overall a good cost analysis and initial investment for filtration system comes to about ₹65,000 -₹70,000. Initial investment covered but given the operational cost, it costs between ₹3 to ₹5 rupees per liter of drinking water. Since the cost is lower, this system can be a feasible solution for pure drinking water in numerous applications. Many aspects of the filter system required development work to ensure improved performance and durability. Important elements of the design feature and multi-layer filtration process with pre-filtration, reverse osmosis and post -filtrations that guarantee a very good output water. Technical specifications aside and pricing considerations made, the present work also explores potential health-promoting effects to be expected from drinking marginally alkaline water. Studies show that this type of water can aid in neutralizing acid in your blood stream and help metabolism the body absorbs nutrients. Results from the prototype testing are promising that suggest a sustainable and robust approach for portable filtration system to be utilized in human life-survival potable water generation using seawater. Future efforts will be directed toward refining the system to increase its efficiency and, therefore, reduce costs which hopefully will make water more accessible on a broader scale. In conclusion, this work provides an example of a* *practical approach to seawater desalination that could exhibit (i) compatibility with "on-site at the Point-of-Need" installation sites; and also affects destitute regions around the Globe where access to clean drinking water is still problematic or not available. This technology has great potential in assisting water shortages globally and improving the lives of those in water scarce areas.*

Introduction

The present water crisis in India as well as around the globe is an alarming issue that needs to be addressed at priority and sustainably. An emerging nation like India, with the fastest growing population in the world and urbanization trends that are outpacing most other countries, faces severe water scarcity due to inefficient management of its existing resources (groundwater over-extraction), unsustainable development, climate change etc. Water availability is confounded by the fact that India relies on monsoonal rains which are becoming more and more erratic. Cities experience acute water scarcity as the demand for municipal corporation-supplied water far exceeds availability. Loss of water resources plagues the rural belts as well, where agriculture (the predominant source of income) faces inadequate irrigation. Groundwater levels are plummeting rapidly, and major rivers have been reduced to a shadow of themselves or turned into sewers. Those pollutants range from industrial waste to agricultural runoff, also include untreated towns of the sewage that lead to water availability as unsafe for drinking. India has a serious issue of water quality which is related to health as well, and millions have been affected by unclean drinking water resulting in its high body count, which is a global catch, with almost two billion people lacking access to clean water worldwide as according to the WHO.[1-3] Water Stress is a universal problem, being projected that in 2050 the demand for water will increase by up to 55% on a global scale. The earth is burning into flames due to lives of human beings, life-threatening heatwaves and biodiversity loss are killing thousands where climate change wreaks on the natural systems that we all depend for food and water. However, most regions around the world - especially Africa and some parts of Middle East-Asia - are suffering severe water shortages which often leads to conflicts between different groups within or even migrations. Water security is a leading concern due to aging infrastructure and pollution in developed countries. This is a complex problem and can be attributed to industrial activities, pharmaceuticals in waste water, plastic pollution among other from the major factors that are creating havoc on most of our water resources.[4, 5] A vast array of demands on the few freshwater resources include 70% used in global agriculture - which feeds a growing and richer population that is also consuming increasing amounts of essence against predictions that with climate change, less water will be available across all catchments. The strain is further exacerbated if paired with ineffective irrigation practices and non-water-resilient crop choices. Solutions for the water crisis lie in advances in water management, conservation technology and fixing laws surrounding usage.

Naturally sustainable access to rainwater is needed; recycling and reusing soapy water should include biological wastewater treatment or UV/light investigation methods followed by further purification where technically possible (e.g. new techniques in desalination). For a thirsty planet on the verge of drying up, desalination - essentially removing salt and other impurities from seawater to make drinking water - provides hope for coastal regions that face freshwater deficits. That said, it takes a lot of money and energy plus careful mitigation to pull this off.[6-8] Portable filtration systems for desalination have the potential to greatly expand clean water availability in remote and disaster-prone regions. Such systems need to be efficient, they must also come at an affordable cost, and with a low environmental footprint. The most immediate need for intervention is in the case of policy measures such as stricter regulations on water use and pollution, rewarding technologies which minimize water usage with economic incentives or raising public awareness.[9-12] Collaboration across government and private agencies needed in adopting community intervention and education are vital in raising awareness of water conservation and its demand.[13, 14] Solving the water crisis, also requires protecting and restoring natural treasures which are at critical source for clean and fresh waters. The conservation of wetlands, forests and watersheds for long-term supplies continues to be necessary. In addition to challenges in securing water resources, major cities also face the obstacle of international cooperation on managing scarce water supplies across political boundaries. This is about more than whether there will soon be safe water to drink, and instead points to a crisis of governance, equity,and justice. Safe, sufficient and affordable water is a human right and essential to the realization of other rights under SDG. The challenges of the water crisis are too complex, demand a comprehensive or systemic solution and in an integrated way. Through innovative solutions, sustainable practices and cooperation we can manage our precious water resources in order to ensure secure availability for our future generations as well solve frequent that type of emergency.[15-18]

With global freshwater resources becoming increasingly limited by factors such as population growth, climate change and poor management practices, the need for seawater desalination is more urgent than ever. As the world population continues to expand - hitting 9.7 billion by midcentury, according to one United Nations estimate - pressure on already limited freshwater resources will ratchet up a notch from current water scarcity woes. On top of this, climate change is now playing a part haywire with precipitation patterns making drought periods even longer in some areas and scarcity water. Industrialization and urban growth are also putting the water supply under increased strain as they cause rivers, lakes, and aquifers to become over-extracted pollutants. This fast and growing demand makes traditional sources of freshwater such as rivers or groundwater insufficient, so the search for alternative solutions is imperative.[19, 20] As supplementary option, Seawater desalination pops up as a feasible and eco-conscious method to treat seawater-which is 97.5% of the total water sources in

Earth but unchecked so far because it saline nature-and use this for freshwater generation. The process, from the integration with technologies such as reverse osmosis and distillation removes salts and impurities in seawater making it potable to consumption by human beings Females used for growing crops. Arid countries such as those in the Middle East and North Africa have already realized that desalination is central to their water future, hence they are investing heavily in desal infrastructure. Countries like Saudi Arabia or the United Arab Emirates or Israel largely draw on as much water produced by sea-water-desalination to sate both household and agricultural needs. The improving dependability and efficiency of desalination technologies can offer an appealing chance for coastal regions or island communities with scarce water supplies or polluted.[21-23] In addition, developments in sustainable energy production (such as solar and wind power) could help to combat the typically high-energy nature of desalination processes that are associated with less environmentally friendly solutions. And as technology matures, combining energy recovery systems and advancing low-energy desalination methods continue to increase its possibility for implementation at large scale. The importance of seawater desalination does not stop at its influence on economic, infrastructural and ecological elements: it is also a lynchpin in the climate change field because competently providing stable internationally sourced water supply to reduced lower class communities that respond to their vulnerability towards due to regional changes. It also leads to a reduction in freshwater resource over-extraction, preserving ecosystems and biodiversity. As well as helping water-scarce regions to meet short-term needs, desalination has a place in supporting global water sustainability goals like the United Nations Sustainable Development Goal 6: ensure availability and sustainable management of water and sanitation for all. How seawater desalination can help your water infrastructure adapt and strengthenby drawing on alternative sources of water (such as the ocean) rather than burdened freshwater systems, thanks to modern technological advancements such as environment-friendly machines brought forward from what seems effortlessly abundant portable water supplies is starting to be more part.[24-27] Nevertheless, but adoption of desalination is not without its obstacles including environmental impacts relating to brine discharge and the substantial capital required for constructing infrastructure. It is important this technology continues to grow but in a sustainable manner and, since some of these concerns regarding environmental impact still hold true today improving new technical solutions will be a must - such as developing brine management practices that are more environmentally friendly along with optimizing the desalination process. In summary, seawater desalination is a must-have due to the increasing and pressing water scarcity worldwide as well as climate change and continual increase of freshwater demand. So, while it may take a little time for human ingenuity to catch up, the future of desalination is bright: as technology provides innovative new ways to improve both efficiency and ecological friendliness in

these systems - ensuring water security for us all can be that much more sustainable.[28-31]
Numerous water desalination technologies are available today that convert brackish or seawater into drinking quality fresh water, helping in meeting the growing global freshwater needs. Some of the most common technologies in use are reverse osmosis (RO), multi-stage flash distillation, multi-effect distillation and electrodialysis. The main method is reverse osmosis, which uses semi-permeable membranes under high pressure to separate salt and impurities from water for efficient desalination with relatively low energy costs. However, RO is not without its obstacles, and it does have some difficulty overcoming membrane fouling as well as requiring extensive pre-treatment to strip away the particulates like organic matter. Still, a historic and important technology for this is multi-stage flash distillation, which boils seawater to produce steam that cools and condenses into thousands of drops. As it constantly needs to be heated or cooled, this method is energy-intensive but highly reliable with a long-life span. Multi-effect distillation works on the same principles but has multiple stages of evaporation and condensation, where heat is reused from one stage to another. More efficient than MSF, but still consume a relatively large amount of energy. Unique technology-based on electrostatic - electrodialysis, the method is used less now but in future it will become more popular as it uses electric fields to drag and separate ions through special selective membranes that divide salt from water. It is extremely efficient for brackish water desalination producing relatively little waste, and costs less energy consumption compared with thermal ones. The other issue is that the salt levels are higher (less efficient) for seawater desalination.[32-35] In addition to these traditional technologies, new approaches such as forward osmosis; membrane distillation and capacitive deionization are being developed with the potential for increased efficiency while reducing energy input. Forward osmosis harnesses the natural pressure differential across a semi-permeable membrane to pull water through it rather than require an enormous input of energy as in reverse osmosis. Membrane distillation uses hydrophobic membranes and a temperature gradient to separate water from salt that could lead to energy savings while producing high purity water. CDI, which functions by extracting salt ions using electric fields (benefiting from this process with respect to energy consumption), can clearly offer improvements in terms of the low deployment costs and modular advantages for small-scale applications. That being said, all desalination technologies have common challenges such as high capital and operational expenditure, energy usage & environmental impacts through brine disposal. Brine contains a greater quantity of salt brine which endangers the environment if not properly thrown out that led scientists to invent an alternative method on how make use from it sustainably. Meanwhile, energy is still a major problem because most desalination operations are energy-intensive and contribute to greenhouse gas emissions. Various desalination processes try to incorporate renewable energy sources (like solar power, wind) and will push

efforts in the near future that are innocuous towards environment and sustainable.[36-39] Another focus is the advancement of novel materials and technologies to enhance membrane performance, decrease fouling effects, longevity as well as lower operational costs for higher productivity. This innovative new technology in nanotechnology and material science shows great potential to deliver stronger, more efficient membranes for desalination. Overall, even though the current desalination techniques can already significantly alleviate worldwide water scarcity, continuous research and development efforts are needed to tackle existing challenges in order to make these processes more sustainable and efficient. The incorporation of renewable energy sources with continued innovation can lead to promising prospects for the future of desalination technology in creating affordable and sustainable solutions to cater towards our ever-growing demand for fresh water worldwide.[40-43]

The global demand for fresh water is on the rise aided by a combination of scarce drinkable water resources and rising impact from climate change are pushing technological development such as portable desalination filter. Rivers, lakes and aquifers are being threatened by over-extraction, pollution and changes in precipitation patterns resulting from climate change. These include fast growing coastal and island communities vulnerable to chronic lack of water as they have no access or means for collecting clean rainwater, remote dry regions usually dependent only on subsurface sources in mountainous areas. In these locations, a large volume of seawater available through desalination has long been viewed as making water scarcity seem less acute. On the other hand, conventional desalination such as huge scale reverse osmosis plants is capital-intensive and requiring considerable infrastructure are energy-burning process which makes it unfeasible when subjected to resource-constrained settings. The problems are addressed with a portable desalination filter, which brings about decentralized water purification. In disaster-torn areas where supply chains for clean water are broken, this technology becomes essential. In addition to this, it is priceless for military activities as well as outside campaigns and marine-exercisessecuring that people in far off areas get safe water. With their portability and scalability, installation of these filters can cater to those with personal use requirements up to the entire community level. This is where the advancement in materials science and nanotechnology helped to create new, highly efficient filter systems that are smaller and easier for individuals to navigate. Finally, because portable desalination filters can be powered by renewable energy sources such as solar power, they have a very low carbon footprint compared to (the frequently polluting) conventional desalination processes. It also ensures that the water produced is of high quality, in addition to having real-time detection about its safety. The innovation of portable desalination filters reflects not just the maturation of new technologies but also a socio-economic necessity, as these tools enable the vulnerable to become more independent from external water-related threats. In addition, it is well in line with the global aspiration to realize

Sustainable Development Goal 6: ensure availability and sustainable management of water and sanitation for all. In so doing, portable desalination filters provide a dual-function strategy to water security: immediate need solutions for water-scarce regions as well progress in sustainable management of global freshwater resources.[12, 44]

Within the commercial sector, portable desalination filters are witnessing major demand due to limited availability of freshwater sources in large parts across globe and this segment is growing at good pace. The Portable Desalination Market was valued at USD 1.2 billion in 2020 and is further expected to grow from here and reach around USD 2. This demand is common in disaster areas, wildernesses barring the pan Iberian access control area. The filters can be easily carried anywhere a person needs fresh water by converting seawater and making it drinkable, thus satisfying immediate as well as long-term requirements. The evolution of technology has improved the efficiency, affordability and user-friendliness of these systems,

making them ever more accessible to a wider audience. The market is also defined by a wide array of capacities, filtration technologies and looks to satisfy different consumer needs. Leading players are concentrating on innovating and including superior materials as well as energy-efficient operations to optimize the performance of portable desalination systems encouraging its remaining power proficient. In addition, increasing awareness regarding water scarcity and sustainable management of water is augmenting the growth of these systems in a bid to reduce wastage. Portable small sized desalination is one of the emerging trends in water scarcity management along with disaster preparedness and response strategies from government & non- governmental organizations thereby surge demand for portable unit, as a result expected to create huge opportunity window to fuel growth over forecast period. For example, investments in portable water purification systems have grown 15% annually over the past five years.[45-47] Moreover, the introduction of solar and hybrid based desalination systems is creating opportunities for market growth mainly in off-grid & energy stressed regions. Smart features including real-time water quality monitoring and automatic maintenance alerts are improving user experience, reliability as well leading to higher consumer confidence and adoption. Market trends suggest that manufacturers are now creating devices in smaller and lighter forms to make it easier for users to transport and install the device as needed.[48-50] In addition, competition is characterized by key business events like partnerships, mergers and acquisitions (M&A s) that allowed over 30 deals in the past two years to gain unique strategic capabilities across their products as well as geographical footprints. Regulatory backing and supportive policies benefiting the adoption of sustainable water solutions are also contributing towards market expansion. Nonetheless, the high upfront costs of the systems as well as technical complexities and regular maintenance requirements still represent hurdles to broad implementation. However, despite these challenges facing the market for portable desalination filters is likely to grow as continuous research and development work are ongoing to address existing constraints while also improving economic feasibility & durability of their product. The global commercial market for handheld desalination filters is expected to grow at a strong rate due to the various forces pushing and pulling technology, regulation that favors drinking water more security-enabled, available conservation of portable water. Continuing to evolve with the market, it is anticipated that ceramic membrane technology will play an essential role in helping solve global water issues and serve as a healthy alternative for producing clean drinking water from any kind of difficult feed.[51-53]

There is great potential to deploy a portable desalination filter system in areas located right along the coastlines with continuous water all around, given the urgent problem of supplying reasonable and interesting drinking water. More often than that there is a rare water scarcity in coastal regions where the population has access to seawater just outside their door but lacks affordable and efficient desalination technologiesentirely. One transformative answer is a portable filtration system-a mobile, user-friendly way to convert seawater into potable water on demand. This technology is more advantageous for isolated and disaster-prone coastal areas where infrastructure can be scarce, whilst conventional water supply systems are often not available due to inaccessibility of resources. For use in an emergency response capacity or humanitarian aid, as well as everyday community freshwater needs, the portability and flexibility of deployment for these filtration units allows them to be hauled around quickly - making it much different than other traditional RO purification systems. The system operates more efficiently and uses less energy as well, which improves its overall footprint in line with global sustainability targets, lowering the embodied carbon of water production. On top of that, the filtration system can be adapted to local environment features and water quality requirements at different locations guaranteeing a safe drinking water output for human consumption. The use of such systems will not only be good for public health, as a renewable source of clean water can impact global disease rates by cutting down on the problem of unsafe sanitation and its negative repercussions in the form diseases related to unclean drinking water. Moreover,technology also gives economic benefits as it can cut water buy long by procuring and taking assistant of bottled in a mess, which are not solitary costly but plus biodiversity damaging. Given that freshwater access can be an asset in coastal tourist destinations, we should do more to provide this service not only for the visitor experience but also to support local economies. It can be used in minimum operations and maximum operations, so it caters to individual households as also for larger wider communities. By working together with local governments, non-governmental organizations and private sectors to enable large scale implementation of water smart agriculture this technology can benefit the most vulnerable part of the population. By training and educating people on how to utilize portable filtration systems, local communities will become self-sufficient in managing water their resources. Offering a solution tailored to the challenges faced by coastal regions, deployment of portable filtration can help achieve water security and bring better quality of life to millions worldwide. As such, this holistic approach of integrating these innovative solutions offers a bright future for the world to counter with overall water scarcity at a global level especially in coastal as well as remaining places over there and people are dying because they do not have access just safe drinking water. The strategic integration of portable filtration systems could bode well for a more sustainableplanet, where clean water is not something you are lucky enough to access but instead simply entitled to. This work proposes a portable desalination filtration system for obtaining drinking water from sea water.

In our current work, we have developed and optimized a portable filtration system specifically designed for sea water desalination to produce potable water. This innovative system has successfully transitioned from concept to a working prototype, demonstrating its potential to address the critical need for accessible drinking water in coastal and water-scarce regions. The core functionality of our prototype lies in its ability to efficiently convert sea water into drinking water, achieving a pH level of approximately 7.4 to 7.8. This pH range not only ensures the water is safe for consumption but also offers the added benefit of alkaline water, which is known for its potential health benefits such as improved hydration, neutralization of acid in the bloodstream, and enhanced immune function. The filtration capacity of our system is 3 liters per hour, making it a viable solution for both individual and community use. This capacity ensures that the system can meet the daily drinking water needs of a small community, making it an effective tool in emergency situations or in areas with limited access to fresh water. From an economic perspective, our portable filtration system is designed to be cost-effective. The initial investment required for the filter is approximately Rs 65,000 to Rs 70,000. This one-time cost is offset by the long-term benefits and the affordability of the produced water, which costs only Rs 3 to Rs 5 per liter. This price point is competitive and makes the system a sustainable option for continuous use, particularly in regions where bottled water or traditional desalination methods are prohibitively expensive. The importance of this work cannot be overstated. With the increasing scarcity of freshwater resources and the growing impact of climate change on global water supplies, innovative solutions like our portable filtration system are crucial. This technology not only provides an immediate solution for clean drinking water but also contributes to long-term water security and resilience. By enabling access to safe drinking water from abundant sea water sources, we can significantly improve the quality of life in affected regions, reduce the dependency on limited freshwater supplies, and promote sustainable water management practices. Our portable filtration system represents a significant advancement in the field of desalination technology, offering a practical, cost-effective, and sustainable solution to one of the world's most pressing challenges.

Materials and Methods

Procurement of the Required Materials

All the necessary materials for the desalination system were sourced locally from various suppliers, including AC spare part stores, robotics stores, hardware shops, and electrical supply outlets. These materials were carefully selected based on their quality and compatibility with the desalination system's design. The primary components include a 12V DC high-pressure pump, heating coil, 2-ton compressor, evaporator, condenser, UVC chamber, alkaline filter, and sediment/carbon filters. Additionally, electrical components such as Arduino boards, relays, and temperature probes were sourced to enable the automation and control functions. For the construction and assembly, mechanical parts like copper pipes, PVC pipes, and a fiber hard glass sheet were procured to ensure durability and efficiency in the desalination process.

Preparation of the Desalination System

The construction of the desalination system began with the preparation of a sturdy wooden base to support the entire setup. A cage was constructed from PVC pipes above this base to secure the evaporator and high-speed radial fans. A 2-ton compressor was then mounted onto the base and connected to the evaporator and condenser through copper pipes, capillary tubes, and Steiner valves. The connections were carefully soldered to prevent leakage and ensure a closed-loop system. To initiate the desalination process, a copper coil was inserted inside a copper jar filled with water. As the compressor was activated, it cooled the copper coil, leading to the condensation of steam. This condensed steam, now water, was pumped through a UVC chamber using a 12V high-pressure pump for sterilization. The water was further processed through an alkaline treatment chamber, which housed an alkaline filter, before being boosted by a 24V pump into sediment and carbon filters to ensure purity. This multi-stage system effectively converts saltwater into potable water, with the components arranged to optimize flow and minimize energy consumption.

Electrical Connections of the Project

The system's electrical requirements were met by dividing the load across three separate circuits: heating, cooling, and electronics. A 16A 3-pin extension was used to supply power to these circuits. The heating and cooling components were powered directly by the 230V 50Hz AC supply, while the electronic components, such as motors and fans, operated on a converted DC supply. This DC power was generated using three 12V SMPS units, each rated at 10A, with the input being a 30V 50Hz AC source. The electrical connections were made using standardized jack-to-jack connections to ensure polarity consistency (positive to positive, negative to negative). The power supply for the motors and fans was maintained at 12V DC, while the heating coil and compressor were connected to the AC supply. This hybrid power setup allowed for efficient operation of the system, with the heating and cooling elements utilizing high voltage AC, while the electronics operated on low voltage DC.

Heating

A tungsten coil heater was used as the primary heat source for generating steam in the desalination chamber. This heater was designed to withstand high temperatures and rapidly heat the water to its boiling point. The steam produced was channeled through a flexible heat-resistant pipe towards the cooling chamber. Inside the cooling chamber, the steam was condensed back into water through contact with the cooled copper coil. The choice of a tungsten coil heater ensured rapid and consistent heating, contributing to the overall efficiency of the desalination process.

Automation of the System

The system was automated using a combination of Arduino-based control circuits and relay modules. A temperature probe was integrated into the system to monitor the heat levels within the desalination chamber. When the temperature reached 100°C, the control circuit would trigger the compressor, initiating the cooling process. As the temperature decreased, the relay would automatically deactivate the compressor, conserving energy. The system was also equipped with a timer circuit that regulated the duration of each stage of the desalination process, reducing the need for manual intervention. This automation ensured precise control over the heating and cooling cycles, improving system efficiency and reducing energy consumption.

Integration of the Alkaline Filter

The alkaline filter was integrated into the desalination system after the UVC sterilization chamber to enhance the quality of the processed water. The integration was achieved by connecting the outlet of the cooling chamber's steam pipe to the inlet of the alkaline filter. The filter was equipped with a standard inlet and outlet, allowing for seamless integration with the other components of the system. A booster pump was installed after the alkaline filter to create sufficient pressure for the water to pass through the sediment and carbon filters. This step ensured that the final water product not only met purification standards but also had improved pH levels, making it suitable for consumption.

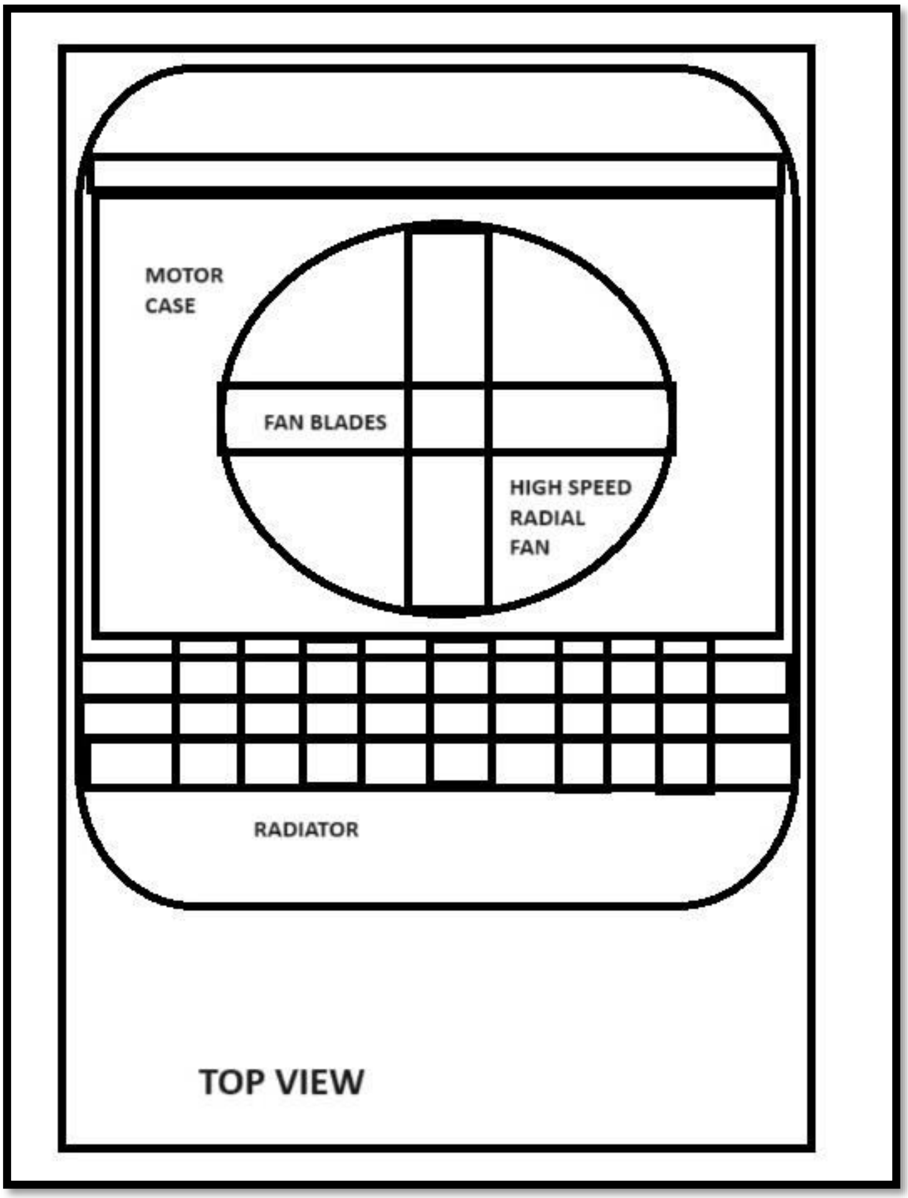

Figure 1: Schematic diagram of top view of the desalination Filter

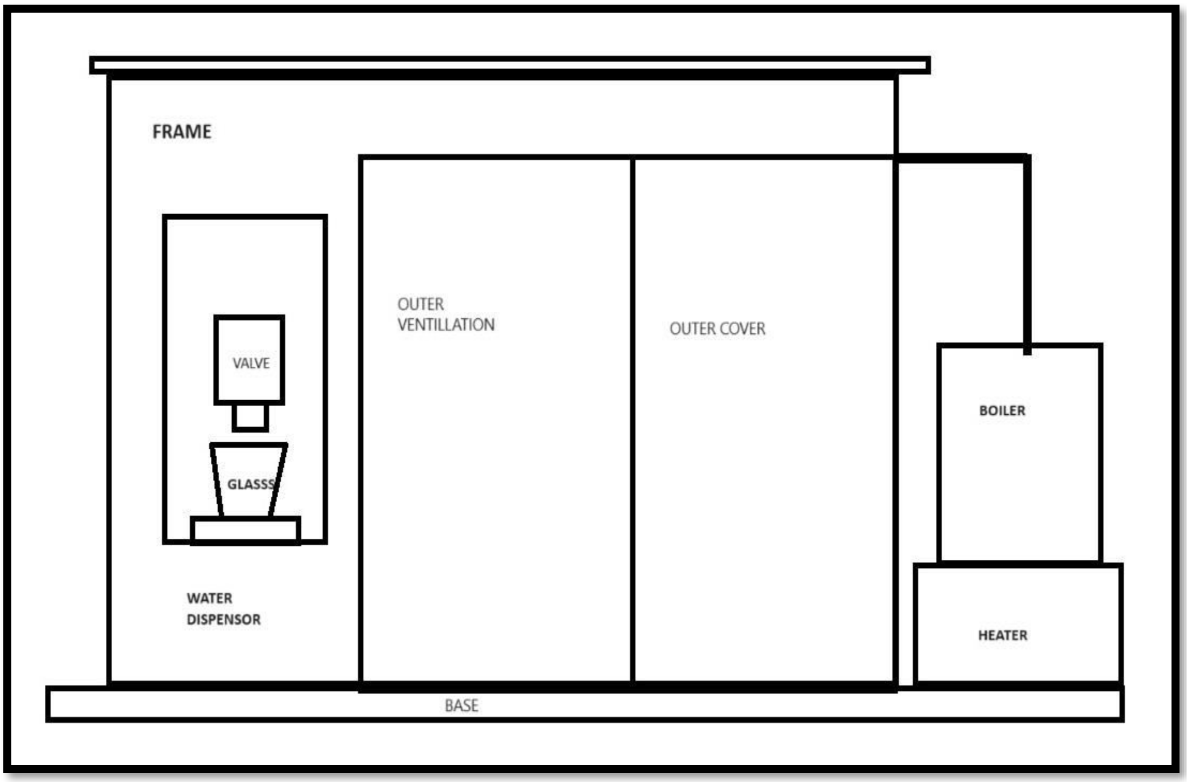

Figure 2: Side view of the Desalination Filter

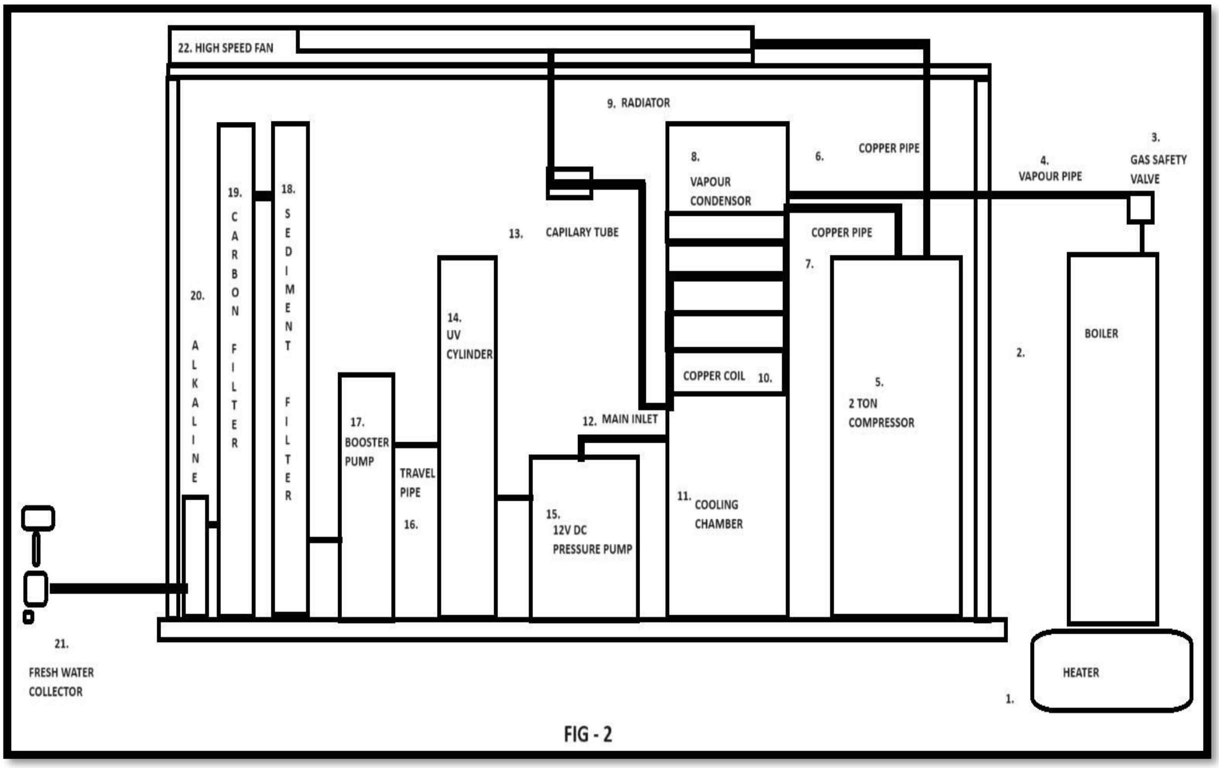

Figure 3: Schematic representations of the various components used in the desalination filter

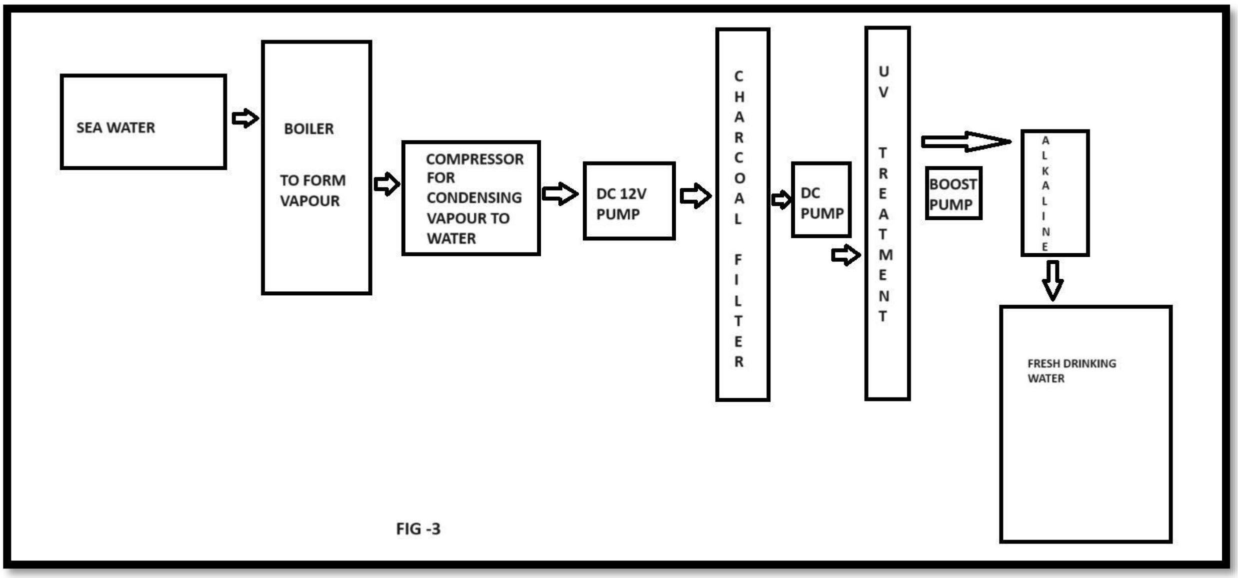

Figure 4: Block Diagram of the Filter

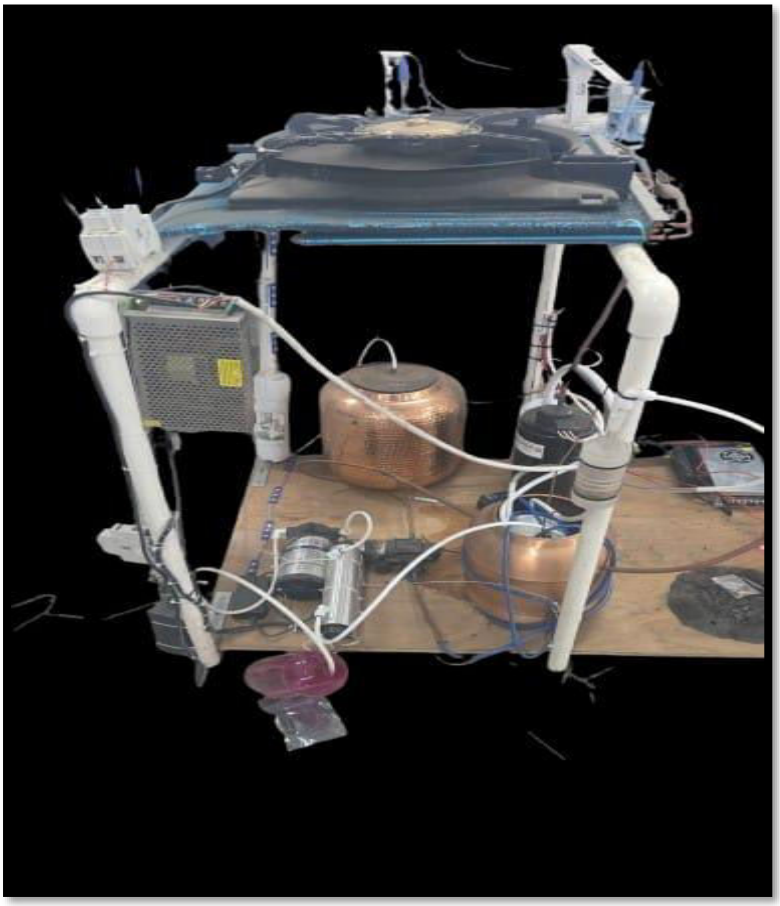

Figure 5: Prototype of the Desalination System

Results and Discussion:

TDS Analysis

Total Dissolved Solids (TDS) is a key parameter in evaluating water quality, particularly in the desalination of seawater to make it safe for human consumption. Seawater naturally contains high levels of dissolved salts and other solids, typically between 35,000 mg/L and 45,000 mg/L. Consuming water with high TDS levels can lead to various health issues, including kidney stress and the accumulation of toxic substances. The World Health Organization (WHO) recommends a maximum TDS concentration of 500 mg/L for potable water. In our study, raw seawater showed a TDS value of approximately 37,000 mg/L. After the desalination process, the TDS was reduced to 120 mg/L, well within the WHO guidelines. The significant reduction demonstrates the system's efficiency in removing not only salts but also other potentially harmful dissolved substances, thereby producing water that supports overall health by preventing dehydration and maintaining the body's electrolyte balance.[54, 55]

pH Measurement

pH plays a critical role in water safety and human health. Seawater typically exhibits a slightly alkaline pH range of 7.5 to 8.4, whereas the WHO recommends that safe drinking water should have a pH between 6.5 and 8.5. pH outside of this range can lead to adverse health effects, such as skin irritation, digestive issues, or the leaching of harmful metals like lead from plumbing. In our study, the raw seawater had a pH of 8.2, which is consistent with typical oceanic measurements. Following desalination, the pH of the water was adjusted to 6.7, placing it within the ideal range for human consumption. This adjustment is important as water with a balanced pH is essential for maintaining cellular function, metabolic processes, and overall health by ensuring that the body's natural acid-base balance remains stable.[56]

Alkalinity Analysis

Alkalinity, which measures the water's capacity to neutralize acids, is an important factor in ensuring water quality and overall health. It is largely governed by the presence of bicarbonates, carbonates, and hydroxides. Alkaline water is believed to offer several health benefits, such as enhanced hydration, improved acid-base balance in the body, and antioxidant properties. Seawater typically exhibits high alkalinity levels due to its bicarbonate content, with values between 120 to 150 mg/L as $CaCO_3$. High alkalinity in drinking water, however, may lead to unpleasant taste and scaling. According to WHO guidelines, alkalinity should not exceed 200 mg/L. Our study revealed that raw seawater had an alkalinity of 135 mg/L, which was reduced to 80 mg/L post-desalination, well within the safe limits for drinking water. The reduction in alkalinity reflects the desalination system's effectiveness in removing excess bicarbonates, resulting in water that not only tastes pleasant but also supports proper hydration and helps maintain the body's acid-base equilibrium, essential for metabolic health and preventing conditions like acidosis.[57, 58]

Hardness Analysis

Water hardness is caused by the presence of calcium and magnesium ions, and excessive hardness can result in negative health effects and scaling in water systems. WHO recommends a hardness level below 300 mg/L for drinking water. Elevated hardness can contribute to kidney stones, scale build-up in plumbing, and skin irritation. Seawater generally has a hardness level ranging from 6,000 to 7,000 mg/L due to its high concentration of dissolved salts. In our analysis, the raw seawater exhibited a hardness of 6,500 mg/L. After the desalination process, the hardness level was reduced to 85 mg/L, well within acceptable drinking water limits. This significant reduction ensures that the filtered water is not only free from scaling issues but also safe for consumption, reducing the risk of kidney stones and improving overall water palatability.[59, 60]

Chloride Content Analysis

Chloride is a major ion present in seawater, with concentrations as high as 19,000 mg/L. High chloride levels in drinking water can lead to corrosion of pipes, a salty taste, and potential adverse health effects such as hypertension and dehydration. WHO sets the maximum allowable chloride concentration in drinking water at 250 mg/L. In our study, the raw seawater had a chloride concentration of 18,500 mg/L, consistent with typical seawater levels. Following desalination, the chloride content was reduced to 55 mg/L, well below the permissible limit. This significant reduction ensures that the water is safe for consumption and devoid of the salty taste associated with high chloride levels, promoting better hydration and preventing potential long-term health complications, such as increased blood pressure.[61, 62]

Instrumentation

The instrumentation used for the water quality analysis in this study was carefully selected to ensure precise measurements of key parameters, including Total Dissolved Solids (TDS), pH, alkalinity, hardness, and chloride content. A digital TDS meter was used to measure TDS levels, providing accurate readings in mg/L to assess the effectiveness of the desalination process. The pH of water samples was measured using a calibrated benchtop digital pH meter with standard buffer solutions for accuracy within the required range. Alkalinity was determined through titration using sulfuric acid and a phenolphthalein indicator, following the ASTM D1067 method, with results expressed in mg/L as $CaCO_3$ equivalents. Hardness was measured using complexometric titration with EDTA to quantify calcium and magnesium concentrations. For chloride content, the argentometric method was applied, with silver nitrate as the titrant in the Mohr titration procedure. All instruments were calibrated regularly to maintain precision, and each measurement was repeated three times to ensure reliability.

Table 1: Comparison of Seawater and Filtered Desalinated Water Quality Parameters with WHO Standards

Parameter	Seawater	Filtered Desalinated Water	WHO Standard for Drinking Water
Total Dissolved Solids (TDS) (mg/L)	37,000	120	≤ 500
pH	8.2	6.7	6.5 - 8.5
Alkalinity (mg/L as $CaCO_3$)	135	80	≤ 200
Hardness (mg/L)	6,500	85	≤ 300
Chloride (mg/L)	18,500	55	≤ 250

Conclusions

The development and optimization of a portable filtration system for seawater desalination, as explored in this research, demonstrated the potential to transform seawater into potable drinking water that meets international safety standards. By employing a multi-stage filtration and desalination process, significant reductions were observed in key parameters such as Total Dissolved Solids (TDS), pH, alkalinity, hardness, and chloride content. These results underscore the effectiveness of the system in producing water that not only meets but exceeds the World Health Organization (WHO) guidelines for safe drinking water. The Total Dissolved Solids (TDS) level of the raw seawater, which was recorded at approximately 37,000 mg/L, was reduced to 120 mg/L post-filtration. This substantial reduction places the filtered water well below the WHO's maximum recommended TDS limit of 500 mg/L, indicating the system's proficiency in removing dissolved salts. TDS reduction is a critical factor in desalination since it directly impacts water salinity and overall quality. Achieving this level of TDS reduction demonstrates the effectiveness of the portable system in transforming highly saline seawater into drinkable water suitable for human consumption. Similarly, the pH of the seawater, which initially measured 8.2 (slightly alkaline), was adjusted to 6.7 after filtration, falling within the ideal range of 6.5 to 8.5 recommended for drinking water. This pH adjustment suggests that the filtration process not only removes impurities but also balances the water's pH, ensuring that it is neither too acidic nor too alkaline for safe use. Another significant achievement was the reduction in alkalinity and hardness. Seawater's high alkalinity, typically between 120 to 150 mg/L, was brought down to 80 mg/L, ensuring that the filtered water does not pose any risk of scaling or unpleasant taste, which are common concerns associated with high alkalinity. Additionally, the hardness of the water, initially measured at 6,500 mg/L due to high levels of calcium and magnesium, was reduced to 85 mg/L, which is far below the 300 mg/L limit set by WHO. This reduction ensures that the filtered water is soft and palatable, free from mineral deposits that could affect both taste and water utility in household applications. The reduction in chloride content was also significant. From an initial concentration of 18,500 mg/L in the raw seawater, the filtered water's chloride content dropped to 55 mg/L, well within the acceptable limit of 250 mg/L for drinking water. This demonstrates the system's capability to efficiently remove excess chloride, which is essential not only for preventing corrosion of household appliances but also for improving the taste and overall quality of the water. In conclusion, the portable filtration system developed in this study has proven to be highly effective in transforming seawater into safe, drinkable water. The system successfully met or exceeded all the key water quality standards set by WHO, highlighting its potential as a practical solution for addressing the global challenge of clean water scarcity. Its portability makes it particularly suitable for use in remote or disaster-stricken areas where access to clean drinking water is limited. Future work will focus on further optimizing the system's energy efficiency and cost-effectiveness, making it even more accessible for widespread use in various contexts.

Acknowledgments: The authors thank Institute of Engineering & Management Kolkata, Salt Lake Campus, University of Engineering & Management Kolkata for providing Financial Support and all necessary facilities required for carrying out the research successfully.

Funding: This work was financially supported by Institute of Engineering &Management, Kolkata, Salt Lake Campus, University of Engineering & Management, Kolkata through the Grant-in-Aid Project Grant (2024) ***[Grant No: IEMT(S)/2024/C/05-G04]***

Conflict of Interest: The authors declare no conflict of interest.

[a]Assistant Professor, Department of Basic Science and Humanities, Institute of Engineering & Management, Kolkata, Salt-Lake Campus. University of Engineering & Management, Kolkata
[b]Associate Professor, Department of Basic Science and Humanities, Institute of Engineering & Management, Kolkata, Salt-Lake Campus. University of Engineering & Management, Kolkata
[c]Research Assistant, IIFR Lab, Department of Basic Science and Humanities, Institute of Engineering & Management, Kolkata, Salt-Lake Campus. University of Engineering & Management, Kolkata

References

1. *Emran M. G. I., Barma R., Khan A. H., Roy M. -Reasons behind the Water Crisis and its Potential Health Outcomes. arXiv preprint arXiv:2403.07019,(2024)*
2. *Rais S., Salam M. A. -Water crisis in India: challenges and implications. India 2020: Environmental Challenges, Policies and Green Technology,(2020) 9.*
3. *Gulati A., Banerjee P. -Emerging water crisis in India: Key issues and way forward. Indian Journal of Economics, 96 (2016) 681-704.*
4. *Shemer H., Wald S., Semiat R. -Challenges and solutions for global water scarcity. Membranes, 13 (2023) 612.*
5. *Salehi M. -Global water shortage and potable water safety; Today's concern and tomorrow's crisis. Environment International, 158 (2022) 106936.*
6. *Milani D., Abbas A., Al Bakri D. -Sustainable solutions to our water crisis: generating freshwater from thin air. Water infrastructure for sustainable communities. China and the World IWA Publishing, London,(2010) 127-140.*
7. *Tay L.- Water and the climate crisis; Edward Elgar Publishing (2024) 480-494.*
8. *Wang Y., Xu S., Kathryn M. -Environmental Engineering Innovation to Tackle Water Crisis in Modern Era. Journal of Moeslim Research Technik, 1 (2024) 51-62.*
9. *Sun Q., Hong C., Tang X., Li J., Ma H., Zhang B. -Tailoring ultralow cost hopper-type 3D solar evaporator via dyeing paper for continuous real saline waters desalination. Chemical Engineering Journal, 496 (2024) 154127.*

10. *Baggio G., Adamowski J., Hyde V. J., Qadir M. -Small-scale desalination and atmospheric water provisioning systems in water-scarce vulnerable communities: status and perspectives. International Journal of Water Resources Development, 40 (2024) 686-717.*
11. *Usman A., Khan H., Tariq R., Atta M. S., Rehman A., Iqbal M. M. -Sustainable water solutions: a Six Sigma approach to membrane-based filtration system design. Frontiers in Environmental Science, 12 (2024) 1352210.*
12. *Jamil F., Ali H. M. -Sustainable desalination using portable devices: a concise review. Solar Energy, 194 (2019) 815-839.*
13. *Moglia M., Cook S., Tapsuwan S. -Promoting water conservation: where to from here? Water, 10 (2018) 1510.*
14. *Vazquez-Casaubon E. C., Cauberghe V., Van de Sompel D. -"I conserve more water than others, do I?" An exploratory study examining self-assessment misperceptions of water conservation. Environment, Development and Sustainability, 26 (2024) 7303-7317.*
15. *Scanlon B. R., Fakhreddine S., Rateb A., de Graaf I., Famiglietti J., Gleeson T., Grafton R. Q., Jobbagy E., Kebede S., Kolusu S. R. -Global water resources and the role of groundwater in a resilient water future. Nature Reviews Earth & Environment, 4 (2023) 87-101.*
16. *Mishra R. K. -Fresh water availability and its global challenge. British Journal of Multidisciplinary and Advanced Studies, 4 (2023) 1-78.*
17. *Savelli E., Mazzoleni M., Di Baldassarre G., Cloke H., Rusca M. -Urban water crises driven by elites' unsustainable consumption. Nature Sustainability, 6 (2023) 929-940.*
18. *Ssekyanzi G., Ahmad M. J., Choi K.-S. -Sustainable Solutions for Mitigating Water Scarcity in Developing Countries: A Comprehensive Review of Innovative Rainwater Storage Systems. Water, 16 (2024) 2394.*
19. *Ferreira C. S. S., Kašanin-Grubin M., Destouni G., Soares P. R., Harrison M., Kikuchi R., Kalantari Z.- Freshwater: Management Principles for Sustainability Under the Climate Emergency; Springer (2024) 113-148.*
20. *Watts G. -Global Environmental Pressures. Ecohydrological Interfaces,(2024) 331-353.*
21. *Elimelech M., Phillip W. A. -The future of seawater desalination: energy, technology, and the environment. science, 333 (2011) 712-717.*
22. *Khawaji A. D., Kutubkhanah I. K., Wie J.-M. -Advances in seawater desalination technologies. Desalination, 221 (2008) 47-69.*
23. *Cipollina A., Micale G., Rizzuti L. -Seawater desalination. Green Energy and Technology,(2009)*
24. *Qudah A., Almerbati A., Mokheimer E. M. -RO desalination powered by renewable energy sources: Optimized sizing with pumped storage hydropower system. Journal of Energy Storage, 97 (2024) 112854.*
25. *Kotb K. M., Elkadeem M. R., Sharshir S. W., Abido M. A., Elsayed M. M., Ghazala M. O. A., Younes A. -Harnessing solar and wind power for*

sustainable seawater desalination: A multi-criteria geospatial suitability analysis. Renewable Energy, 222 (2024) 119814.

26. *Wen D., Kuo P.-C., Aziz M. -Novel renewable seawater desalination system using hydrogen as energy carrier for self-sustaining community. Desalination, 579 (2024) 117475.*
27. *Guo P., Liu Z., Huang S., Liu S., Han M. -Minimizing energy footprint of seawater desalination system via wind power generation in coastal areas. Journal of Environmental Management, 369 (2024) 122244.*
28. *Almasoudi S. M., Bassam J. -Desalination technologies and their environmental impacts: A review. Sustainable Chemistry One World,(2024) 100002.*
29. *Nurjanah I., Chang T.-T., You S.-J., Huang C.-Y., Sean W.-Y. -Reverse osmosis integrated with renewable energy as sustainable technology: A review. Desalination,(2024) 117590.*
30. *Alipoor F., Gilani H., Sahebi H., Ghannadpour S. F. -Renewable energy-powered water desalination and treatment network under wind power and water demand uncertainty: A possibilistic chance-constrained programming. Energy Strategy Reviews, 55 (2024) 101511.*
31. *Choi P. J., Lee J., Jang A. -Interconnection between renewable energy technologies and water treatment processes. Water Research,(2024) 122037.*
32. *Ali E., Orfi J., AlAnsary H., Baakeem S., Alsaadi A. S., Ghaffour N. -Advanced structures of reversal multi-stage flash desalination. Desalination, 571 (2024) 117095.*
33. *Harby K., Emad M., Benghanem M., Abolibda T. Z., Almohammadi K., Aljabri A., Alsaiari A., Elgendi M. -Reverse osmosis hybridization with other desalination techniques: An overview and opportunities. Desalination,(2024) 117600.*
34. *Peñate B., García-Rodríguez L. -Current trends and future prospects in the design of seawater reverse osmosis desalination technology. Desalination, 284 (2012) 1-8.*
35. *Jalihal P., Venkatesan R.- Advanced desalination technologies; Elsevier (2019) 93-131.*
36. *Kumar S., Aldaqqa N. M., Alhseinat E., Shetty D. -Electrode materials for desalination of water via capacitive deionization. Angewandte Chemie, 135 (2023) e202302180.*
37. *Collado-Capell C., Menon A. K. -Performance modeling and cost optimization of a solar desalination system using forward osmosis with energy storage. Renewable Energy, 230 (2024) 120866.*
38. *Andrianov A., Yantsen O., Efremov R. -State-of-the-art of forward osmosis technology: prospects and limitations. Membranes and Membrane Technologies, 5 (2023) 276-289.*
39. *Reddy S., Dey K., Rufuss D. D. W., Arulvel S., Akinaga T. -Forward osmosis desalination: A critical review focussing on recent advancements in draw*

solution recovery techniques for enhanced efficiency and regeneration. Journal of Environmental Chemical Engineering,(2024) 113968.

40. *Yalcinkaya F., Siekierka A., Yalcinkaya B., Dvořák L.- Nanomaterials in membrane technology; Elsevier (2024) 361-391.*
41. *Osman A. I., Chen Z., Elgarahy A. M., Farghali M., Mohamed I. M., Priya A., Hawash H. B., Yap P. S. -Membrane technology for energy saving: principles, techniques, applications, challenges, and prospects. Advanced Energy and Sustainability Research, 5 (2024) 2400011.*
42. *Aliyu U. M., Rathilal S., Isa Y. M. -Membrane desalination technologies in water treatment: A review. Water Practice & Technology, 13 (2018) 738-752.*
43. *Patel S. K., Ritt C. L., Deshmukh A., Wang Z., Qin M., Epsztein R., Elimelech M. -The relative insignificance of advanced materials in enhancing the energy efficiency of desalination technologies. Energy & Environmental Science, 13 (2020) 1694-1710.*
44. *Chatterjee S., Purty R. S., Asrani D., Kumar P., Panda S. R., Asthana S. Process design for a low cost portable green filter for water purification; AIP Publishing, 2024;*
45. *Kariman H., Shafieian A., Khiadani M. -Small scale desalination technologies: A comprehensive review. Desalination,(2023) 116985.*
46. *Ziolkowska J. R. -Desalination leaders in the global market–current trends and future perspectives. Water Science and Technology: water Supply, 16 (2016) 563-578.*
47. *Yoon J., Kwon H. J., Kang S., Brack E., Han J. -Portable seawater desalination system for generating drinkable water in remote locations. Environmental Science & Technology, 56 (2022) 6733-6743.*
48. *Rajesh S., Chiranjeevi C. -Hybrid thermal desalination systems for sustainable development–A critical review. Solar Energy, 270 (2024) 112364.*
49. *Fares M. M., Ju X., Elgendy E., Fatouh M., Zhang H., Xu C., Abd El-Samie M. M. -Hybrid desalination system driven by solar energy: Optimization and case study. Applied Thermal Engineering, 246 (2024) 122847.*
50. *Abdelrazik A., Sharafeldin M., Elwardany M., Abdulkawy N., Shboul B., Ezzat S. M., AlGalad A., Allam A. N., Abdulnasser R., Abdalbadea N. -Effect of design and operation parameters on solar-driven membrane-based desalination systems: An overview. Wiley Interdisciplinary Reviews: Energy and Environment, 13 (2024) e521.*
51. *Cai C., Sun W., He S., Zhang Y., Wang X. -Ceramic membrane fouling mechanisms and control for water treatment. Frontiers of Environmental Science & Engineering, 17 (2023) 126.*
52. *Akash F. A., Shovon S. M., Rahman W., Rahman M. A., Chakraborty P., Prasetya T. A. E., Monir M. U. -Advancements in ceramic membrane technology for water and wastewater treatment: A comprehensive exploration of current utilizations and prospective horizons. Desalination and Water Treatment,(2024) 100569.*

53. *Miao K., Song Y., Guan K., Liu J., Matsuyama H., Zou D., Zhong Z. -Robust hydrophobic ceramic membrane for high-salinity wastewater separation via membrane distillation. Desalination,(2024) 118091.*
54. *Hussain I., Shakeel M., Faisal M., Soomro Z. A., Hussain M., Hussain T. -Distribution of Total Dissolved Solids in Drinking Water by Means of Bayesian Kriging and Gaussian Spatial Predictive Process. Water Quality, Exposure and Health, 6 (2014) 177-185.*
55. *Rusydi A. F. Correlation between conductivity and total dissolved solid in various type of water: A review; IOP publishing, 2018;*
56. *Kulthanan K., Nuchkull P., Varothai S. -The pH of water from various sources: an overview for recommendation for patients with atopic dermatitis. Asia Pacific Allergy, 3 (2013)*
57. *Mills H. -Alkalinity And Mineral Concentration Estimation In Commercial Drinking Water.(2019)*
58. *Lou J.-C., Lee W.-L., Han J.-Y. -Influence of alkalinity, hardness and dissolved solids on drinking water taste: A case study of consumer satisfaction. Journal of environmental management, 82 (2007) 1-12.*
59. *Hardness in drinking-water: background document for development of WHO guidelines for drinking-water quality.*
60. *Boyd C. E. -Typical chemical characteristics of full-strength seawater. Boyd offers a guide for preparing artificial seawater,(2020)*
61. *Davis S. N., Whittemore D. O., Fabryka-Martin J. -Uses of chloride/bromide ratios in studies of potable water. Groundwater, 36 (1998) 338-350.*
62. *Parker A. -Potable water from sea-water. Nature, 149 (1942) 184-186.*