



## CLASSIFICATION OF WATER DESALINATION TECHNOLOGIES AND SOLAR DESALINATION SYSTEMS

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**Abstract:** This article provides a classification of water desalination technologies and solar desalination systems, with particular emphasis on their operating principles, technological characteristics, and application prospects. The main desalination methods, including thermal, membrane, and solar-based technologies, are reviewed and compared. Special attention is given to solar water desalination systems that utilize renewable solar energy for the purification of saline and brackish water. Their advantages, limitations, energy efficiency, and environmental sustainability are analyzed. The study demonstrates that solar desalination technologies offer significant potential for providing freshwater in regions with high solar radiation and limited access to conventional water resources. The results highlight the importance of improving the efficiency, reliability, and economic feasibility of solar desalination systems for sustainable water supply.

**Keywords:** Water desalination; desalination technologies; solar desalination; solar water desalination systems; renewable energy; solar energy; freshwater production; saline water; brackish water; reverse osmosis; solar still; energy efficiency; sustainable water supply; water purification; environmental sustainability.

**Аннотация:** В данной статье представлена классификация технологий опреснения воды и солнечных опреснительных систем с особым вниманием к принципам их работы, технологическим характеристикам и перспективам применения. Рассмотрены и сопоставлены основные методы опреснения, включая термические, мембранные и солнечные технологии. Особое



внимание уделено солнечным опреснительным системам, использующим возобновляемую солнечную энергию для очистки солёной и солоноватой воды. Проанализированы их преимущества, ограничения, энергетическая эффективность и экологическая устойчивость. Исследование показывает, что солнечные технологии опреснения обладают значительным потенциалом для обеспечения пресной водой регионов с высоким уровнем солнечной радиации и ограниченным доступом к традиционным источникам водоснабжения. Результаты подчёркивают важность повышения эффективности, надёжности и экономической целесообразности солнечных опреснительных систем для обеспечения устойчивого водоснабжения.

**Ключевые слова:** Опреснение воды; технологии опреснения; солнечное опреснение; солнечные опреснительные системы; возобновляемая энергия; солнечная энергия; получение пресной воды; солёная вода; солоноватая вода; обратный осмос; солнечный дистиллятор; энергоэффективность; устойчивое водоснабжение; очистка воды; экологическая устойчивость.

**Annotatsiya:** Ushbu maqolada suvni tuzsizlantirish texnologiyalari va quyosh energiyasidan foydalanuvchi tuzsizlantirish tizimlarining tasnifi keltirilgan bo'lib, ularning ishlash prinsiplari, texnologik xususiyatlari va qo'llash istiqbollari alohida e'tibor qaratilgan. Issiqlik, membranali va quyosh energiyasiga asoslangan texnologiyalarni o'z ichiga oluvchi asosiy tuzsizlantirish usullari ko'rib chiqilib, o'zaro taqqoslangan. Sho'r va minerallashgan suvlarni tozalashda qayta tiklanuvchi quyosh energiyasidan foydalanadigan quyoshli suvni tuzsizlantirish tizimlariga alohida e'tibor berilgan. Ularning afzalliklari, cheklovlari, energetik samaradorligi va ekologik barqarorligi tahlil qilingan. Tadqiqot natijalari quyoshli tuzsizlantirish texnologiyalari quyosh nurlanishi yuqori bo'lgan va an'anaviy suv resurslaridan foydalanish imkoniyati cheklangan hududlarni chuchuk suv bilan ta'minlashda katta salohiyatga ega ekanligini ko'rsatadi. Natijalar barqaror suv ta'minotini ta'minlash



uchun quyoshli tuzsizlantirish tizimlarining samaradorligi, ishonchliligi va iqtisodiy jihatdan maqbulligini oshirish muhimligini ko'rsatadi.

**Kalit so'zlar:** suvni tuzsizlantirish; tuzsizlantirish texnologiyalari; quyoshli tuzsizlantirish; quyoshli suvni tuzsizlantirish tizimlari; qayta tiklanuvchi energiya; quyosh energiyasi; chuchuk suv ishlab chiqarish; sho'r suv; minerallashgan suv; teskari osmos; quyosh distillyatori; energetik samaradorlik; barqaror suv ta'minoti; suvni tozalash; ekologik barqarorlik.

**INTRODUCTION.** Water is one of the most important natural resources necessary for human life, agriculture, industry, and sustainable development. However, the growing population, climate change, industrial development, and increasing water consumption have contributed to a significant shortage of freshwater resources in many regions of the world. Although approximately 70% of the Earth's surface is covered by water, only a small proportion of it is available as freshwater suitable for direct human use. Therefore, the development of effective and environmentally sustainable methods for obtaining freshwater from saline and brackish water has become an important scientific and technological challenge.

Water desalination is one of the most promising approaches to addressing freshwater scarcity. Modern desalination technologies can generally be classified into thermal, membrane, and electrically or chemically driven processes. Among these technologies, reverse osmosis, multi-stage flash distillation, multi-effect distillation, and electrodialysis are widely used. However, many conventional desalination systems require significant amounts of electrical or thermal energy, which can increase operating costs and environmental impacts.

The use of renewable energy sources, particularly solar energy, provides an attractive alternative for reducing the energy consumption and environmental impact of desalination processes. Solar desalination systems use solar radiation directly or indirectly to evaporate and subsequently condense water, separating freshwater from



dissolved salts and other impurities. Solar stills, solar-powered membrane systems, and solar thermal desalination technologies are among the main types of solar desalination systems.

The objective of this article is to classify the main water desalination technologies and solar desalination systems, examine their operating principles and technological characteristics, and evaluate their advantages and limitations. Particular attention is given to the potential of solar desalination technologies for sustainable freshwater production in regions characterized by high solar radiation and limited access to conventional water resources.

**Water desalination technologies and their classification.** Water desalination is the process of removing dissolved salts, minerals, and other impurities from saline or brackish water to produce freshwater suitable for domestic, agricultural, industrial, and other applications. With the increasing shortage of freshwater resources, desalination has become an important technological solution, particularly in arid and semi-arid regions. The development of desalination technologies is closely related to the need to reduce energy consumption, operating costs, and environmental impacts while maintaining high freshwater production.

Desalination technologies can generally be classified according to the physical and chemical principles used to separate salts from water. The main groups include thermal desalination, membrane desalination, and electrochemical desalination technologies. Thermal methods are based on evaporation and condensation, in which water is separated from dissolved salts through a phase-change process. The most widely known thermal technologies include multi-stage flash distillation (MSF), multi-effect distillation (MED), and vapor compression distillation (VC).

Membrane technologies use semi-permeable membranes to separate salts and other dissolved substances from water. Among them, reverse osmosis (RO) is one of the most widely used desalination methods. In this process, external pressure is



applied to saline water, forcing water molecules through a semi-permeable membrane while retaining most dissolved salts and impurities. Other membrane-based methods include electrodialysis (ED) and electrodialysis reversal (EDR), which are particularly suitable for treating brackish water.

Another important direction is the use of renewable energy for desalination, especially solar energy. Solar desalination systems utilize solar radiation either directly for water evaporation or indirectly to provide the thermal or electrical energy required for desalination. These systems include solar stills, solar thermal desalination units, and solar-powered membrane desalination systems. Their application can significantly reduce dependence on conventional energy sources and contribute to environmentally sustainable freshwater production.

Thus, the classification of desalination technologies provides a basis for comparing their operating principles, energy requirements, productivity, economic efficiency, and environmental performance. The selection of a particular technology depends on factors such as the salinity of the source water, required freshwater quality, available energy resources, climatic conditions, installation costs, and intended application. Among the available approaches, the integration of desalination technologies with renewable energy sources represents a promising direction for the development of sustainable and energy-efficient water treatment systems.

**Principles and characteristics of main desalination technologies.** Water desalination technologies are based on different physical, thermal, membrane, and electrochemical processes. Their selection depends on the salinity of the source water, required freshwater quality, energy availability, operating costs, and environmental conditions. The main technologies include thermal desalination, membrane desalination, and electrochemical methods.

**Thermal desalination** is based on evaporation and condensation. During evaporation, dissolved salts remain in the concentrated water, while the generated



vapor is condensed into freshwater. The main examples are **Multi-Stage Flash (MSF)**, **Multi-Effect Distillation (MED)**, and **Vapor Compression (VC)**. MSF is widely used for large-scale seawater desalination, while MED provides more efficient utilization of thermal energy. VC systems are suitable for smaller-scale applications and can reuse the heat of compressed vapor.

**Reverse Osmosis (RO)** is one of the most widely used membrane technologies. High pressure forces saline water through a semi-permeable membrane, while most dissolved salts and impurities are retained. RO is used for both seawater and brackish-water treatment. Its main advantages are relatively low energy consumption, compact equipment, and high freshwater productivity. However, pretreatment is necessary to prevent membrane fouling and scaling.

**Electrodialysis (ED)** uses an electric field and ion-selective membranes to remove dissolved ions from water. It is particularly effective for brackish water with low or moderate salinity. **Electrodialysis Reversal (EDR)** improves the process by periodically reversing the electrical polarity, helping reduce the accumulation of salts on the membranes.

In addition, membrane technologies such as **nanofiltration (NF)**, **ultrafiltration (UF)**, and **microfiltration (MF)** can be used for water treatment and pretreatment. For example, UF can remove suspended particles and microorganisms before the RO process, improving membrane performance.

The following table summarizes the main characteristics:

| Technology Principle |                             | Main application         |
|----------------------|-----------------------------|--------------------------|
| MSF                  | Flash evaporation           | Seawater desalination    |
| MED                  | Multiple evaporation stages | Seawater desalination    |
| VC                   | Vapor compression           | Small and medium systems |

**Technology Principle****Main application**

|        |                                        |                             |
|--------|----------------------------------------|-----------------------------|
| RO     | Membrane separation under pressure     | Seawater and brackish water |
| ED/EDR | Ion separation using an electric field | Brackish water              |
| NF     | Selective membrane separation          | Softening and pretreatment  |

Overall, each technology has specific advantages and limitations. **RO** is highly suitable for modern desalination, while thermal methods are effective for large-scale applications. The integration of these technologies with **solar energy** can further reduce conventional energy consumption and environmental impacts, which leads to the consideration of solar desalination systems in the next section.

**Solar desalination technologies and classification of solar desalination systems.** The development of conventional desalination technologies has created a need for more sustainable and energy-efficient solutions. Since thermal and membrane desalination processes require a considerable amount of energy, the use of solar energy has become an important alternative, especially in regions with high solar radiation. Solar desalination combines the principles of water desalination discussed in the previous sections with renewable solar energy to produce freshwater with lower environmental impact.

Solar desalination can generally be divided into direct and indirect systems. In direct systems, solar energy is used directly to heat saline water and produce water vapor. The vapor then condenses on a cooler surface and is collected as freshwater. The simplest example is the solar still, which consists of a basin containing saline water, a transparent cover, and a freshwater collection system. Solar radiation passes through the transparent cover, heats the water, and causes evaporation. The vapor condenses on the inner surface of the cover and flows into a collection channel.

In indirect solar desalination systems, solar energy is first converted into thermal or electrical energy and then used to operate a conventional desalination



process. For example, solar thermal collectors can provide heat for Multi-Effect Distillation (MED) or other thermal processes. Similarly, photovoltaic panels can generate electricity for pumps and Reverse Osmosis (RO) units. This combination allows established desalination technologies to operate using renewable energy.

Solar desalination systems can also be classified as passive and active systems. Passive solar stills operate mainly through natural solar heating and do not require additional mechanical equipment. Their construction is relatively simple and inexpensive, but their freshwater productivity is generally low. Active systems use additional components such as solar collectors, pumps, external condensers, or heat storage units to increase evaporation and condensation rates. As a result, active systems can achieve higher freshwater production.

Another classification is based on the number of evaporation stages. Single-effect solar stills use one main evaporation and condensation process, whereas multi-effect or multi-stage systems reuse the heat generated during evaporation to produce additional freshwater. This principle improves thermal energy utilization and can increase overall productivity.

Thus, solar desalination systems represent a connection between renewable energy and modern water treatment technologies. Their classification depends mainly on how solar energy is utilized, the type of desalination process, and the system configuration. The performance of these systems is influenced by solar radiation, ambient temperature, water depth, operating time, surface area, and the efficiency of evaporation and condensation. Therefore, studying the design and efficiency of solar desalination devices is essential for improving their practical application and leads directly to the next part of the study.

**Solar water desalination devices: design, efficiency and development prospects.**

Solar water desalination devices are designed to convert saline or brackish water into freshwater by using solar energy. Their operation is mainly based



on evaporation and condensation. The simplest and most widely known device is the solar still, which consists of a water basin, transparent cover, insulation layer, and freshwater collection channel. Solar radiation passes through the transparent cover and heats the saline water. As the water temperature increases, evaporation occurs. The produced vapor reaches the relatively cooler inner surface of the cover, condenses, and flows into the collection channel as freshwater.

The efficiency of a solar desalination device depends on several factors, including solar radiation intensity, water temperature, ambient temperature, water depth, transparent cover characteristics, insulation quality, and condensation rate. Increasing the temperature difference between the saline water and the condensing surface generally improves evaporation and freshwater production. For example, reducing the depth of water in the basin can allow it to heat more rapidly, while good thermal insulation helps reduce heat losses to the environment.

To increase productivity, various improvements can be introduced into solar desalination devices. Solar thermal collectors can be connected to the system to provide additional heat, while external condensers can improve vapor condensation. Heat storage materials can also be used to maintain operation for a longer period when solar radiation decreases. In more advanced systems, photovoltaic panels can supply electricity to pumps and control equipment, creating a combined solar-powered desalination system.

Solar desalination devices have several important advantages. They use renewable solar energy, produce minimal direct emissions, have relatively simple construction, and can be used in remote areas where access to conventional energy and freshwater infrastructure is limited. They are particularly promising for rural and arid regions with abundant solar radiation. However, their main limitations include relatively low freshwater productivity, dependence on weather conditions, and the need for a sufficiently large surface area in some designs.



Further development of solar desalination systems is focused on increasing freshwater productivity, improving thermal efficiency, reducing heat losses, and lowering construction and maintenance costs. The integration of solar stills with advanced heat-transfer materials, solar collectors, energy-storage systems, and membrane technologies can significantly improve system performance. Therefore, solar water desalination devices have considerable potential as an environmentally friendly and sustainable method for freshwater production, particularly in regions facing water scarcity and high solar energy availability.

**CONCLUSION.** Water desalination is an important solution to the growing problem of freshwater scarcity. The analysis of existing technologies shows that thermal, membrane, and electrochemical methods have different operating principles, energy requirements, advantages, and limitations. Among them, reverse osmosis is widely used because of its high efficiency and relatively low energy consumption, while thermal methods such as MSF and MED are suitable for large-scale desalination.

Solar desalination technologies provide an environmentally friendly alternative by using renewable solar energy for freshwater production. Solar stills, solar thermal desalination systems, and photovoltaic-powered reverse osmosis systems can be effectively applied in regions with high solar radiation and limited access to conventional energy resources. Although solar desalination systems have limitations such as relatively low productivity and dependence on weather conditions, their environmental and energy advantages make them promising for sustainable water supply.

Improving the thermal efficiency, freshwater productivity, and reliability of solar desalination devices, as well as integrating them with energy-storage systems and modern desalination technologies, can significantly increase their effectiveness. Therefore, the further development and application of solar water desalination



systems can contribute to reducing freshwater shortages and ensuring a more sustainable and environmentally safe water supply.

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