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A Review on Recent Trends on Solar Desalination

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Abstract
Water scarcity is a growing global concern, and solar desalination has emerged as a sustainable solution for producing fresh water from saline sources. This review explores recent trends in solar desalination technologies, focusing on advancements in solar stills, membrane-based desalination, and hybrid systems. Key improvements in efficiency, material selection, energy integration, and economic feasibility are discussed. The paper also highlights challenges such as cost, scalability, and environmental impact, along with potential future research directions. The findings emphasize the role of solar desalination in addressing water shortages while promoting renewable energy utilization. With the increasing global demand for freshwater and the depletion of conventional water resources, solar desalination has gained significant attention as a sustainable and energy-efficient solution. This review provides a comprehensive analysis of recent trends in solar desalination technologies, including passive and active desalination methods. Advances in solar stills, membrane distillation, multi-effect and multi-stage distillation, and hybrid desalination systems are discussed, highlighting improvements in thermal efficiency, material innovations, and system integration. Furthermore, the paper examines the role of nanotechnology, phase change materials, and concentrated solar power (CSP) in enhancing desalination performance. Challenges such as high initial costs, system maintenance, scalability, and environmental impacts are also addressed. The review concludes by identifying key research gaps and potential future directions, emphasizing the need for cost-effective, large-scale, and energy-efficient solar desalination systems to tackle the global water crisis.

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I. INTRODUCTION

Water scarcity is a pressing global issue, with increasing demand for freshwater driven by population growth, industrialization, and climate change. Desalination, the process of removing salts and impurities from seawater and brackish water, has emerged as a crucial solution to meet freshwater needs. However, conventional desalination technologies, such as reverse osmosis and multi-stage flash distillation, are highly energy-intensive and often reliant on fossil fuels, contributing to environmental concerns.

Solar desalination offers a sustainable alternative by harnessing solar energy to drive the desalination process, reducing dependency on non-renewable energy sources. Various solar desalination methods, including solar stills, solar-powered reverse osmosis, and hybrid systems, have been developed to enhance efficiency and scalability. Recent advancements in material science, nanotechnology, and energy storage have further improved the performance and economic viability of these systems.

This review explores the latest trends and technological advancements in solar desalination, examining their efficiency, cost- effectiveness, and environmental impact. Additionally, the paper discusses the challenges associated with large-scale implementation and identifies potential research directions to enhance the feasibility of solar desalination for sustainable freshwater production.

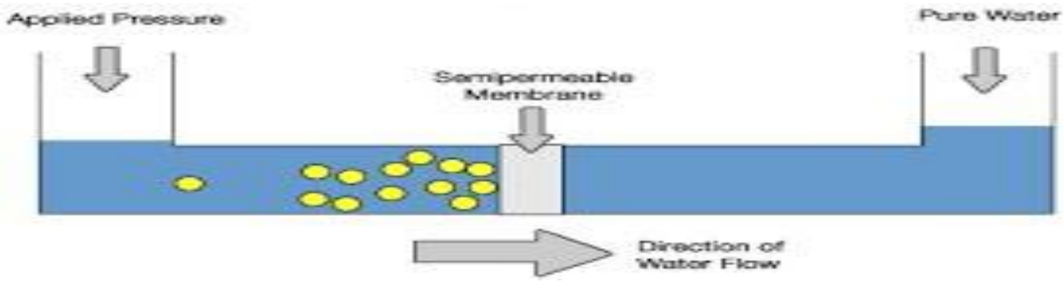

Fig 1:- Reverse Osmosis [14]

Why solar desalination is needed?

Solar desalination is needed because it provides a sustainable and eco-friendly solution to address water scarcity. It uses solar energy to desalinate seawater, making it safe for drinking and irrigation, especially in regions with limited access to freshwater sources. Additionally, it reduces dependency on fossil fuels and helps conserve energy, contributing to the mitigation of climate change.

Types of Desalination Techniques

Desalination techniques can be broadly classified into **conventional** and **solar-based** methods.

1. Conventional Desalination Techniques

1. **Reverse Osmosis (RO)** – A membrane-based process where high pressure is applied to force water through a semi-permeable membrane, separating salts and impurities.
2. **Multi-Stage Flash Distillation (MSF)** – A thermal process where seawater is heated and flashed into steam in multiple stages, leaving behind salt and other impurities.
3. **Multi-Effect Distillation (MED)** – Uses multiple evaporators (effects) to enhance energy efficiency by utilizing waste heat from previous stages.
4. **Electrodialysis (ED) & Electrodialysis Reversal (EDR)** – Utilizes an electric field to move salt ions through ion-exchange membranes, separating freshwater from brine.
5. **Vapor Compression Distillation (VCD)** – Involves mechanical or thermal compression of vapor to improve heat utilization and desalination efficiency.

2. Solar Desalination Techniques

1. **Solar Stills (Passive Desalination)** – Mimics natural evaporation-condensation by heating water in an enclosed basin, producing freshwater through condensation.
2. **Solar-Powered Reverse Osmosis (Solar RO)** – Uses photovoltaic (PV) solar panels to generate electricity to power reverse osmosis units.
3. **Solar Humidification-Dehumidification (HDH)** – Involves heating seawater to generate humid air, which is then condensed to yield freshwater.
4. **Solar Multi-Effect Distillation (Solar MED)** – Uses solar thermal energy to power multi-effect distillation, improving efficiency with reduced fuel consumption.
5. **Membrane Distillation (MD)** – A hybrid thermal-membrane process where heated saline water passes through a hydrophobic membrane, separating pure water vapor.
6. **Concentrated Solar Power (CSP) Desalination** – Uses mirrors or lenses to focus sunlight, generating high temperatures for distillation-based desalination processes.
7. **Hybrid Solar Desalination** – Combines multiple technologies, such as solar stills with membrane distillation or PV with RO, to improve efficiency and scalability.

Different types of graph related to solar desalination

1. Efficiency Comparison of Different Desalination Techniques

The **Efficiency Comparison of Different Desalination Techniques** graph highlights the trade-offs between energy consumption, water production rates, and sustainability across various desalination methods. Conventional techniques like **Reverse Osmosis (RO)** and **Multi-Stage Flash (MSF)** demonstrate high water recovery rates (typically around 50%) but require significant energy inputs, ranging from **3 to 15 kWh/m³**, making them energy-intensive and costly in the long run

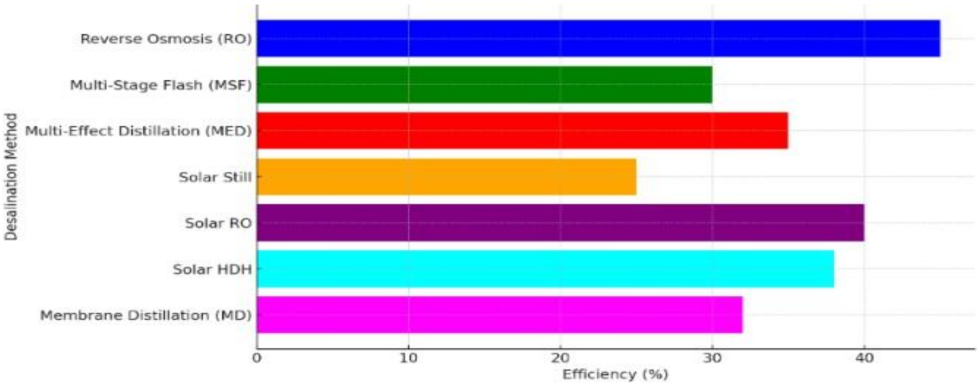

Fig.2:- Efficiency Comparison of Different Desalination Technique [15]

2. Solar Desalination Cost vs. Conventional Desalination Cost.

The graph comparing solar desalination costs with conventional desalination costs from 2010 to 2040. The cost of solar desalination shows a significant decline due to technological advancements, while conventional desalination costs decrease gradually.

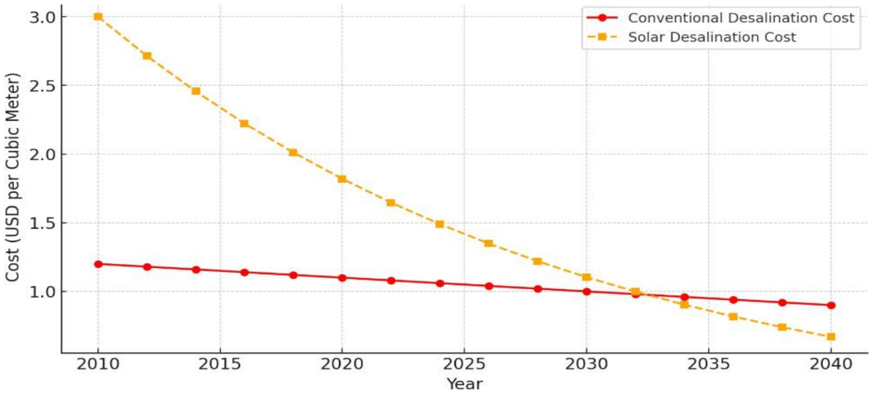

Fig.3:- Solar Desalination vs. Conventional Desalination cost [16]

3. Water Production Rate in Various Solar Desalination Systems

The graph comparing the water production rate of various solar desalination systems. Multi-effect distillation (MED) and solar reverse osmosis (SRO) produce more water than simpler systems like solar stills.

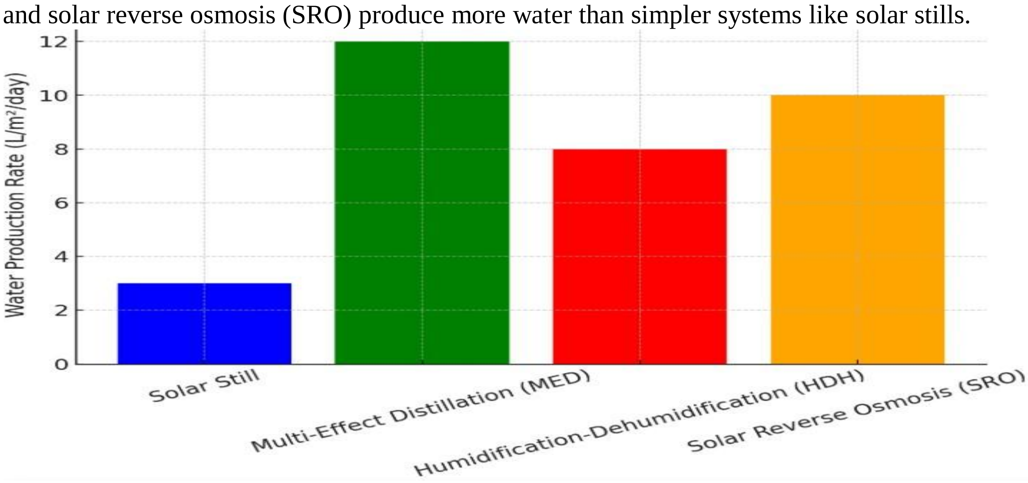

Fig.4:- Water Production Rate in Various Solar Desalination Systems [17]

4. Global Freshwater Demand vs. Desalination Growth

The graph comparing global freshwater demand and desalination growth from 2000 to 2040. Freshwater demand follows a steady linear increase, while desalination capacity grows exponentially

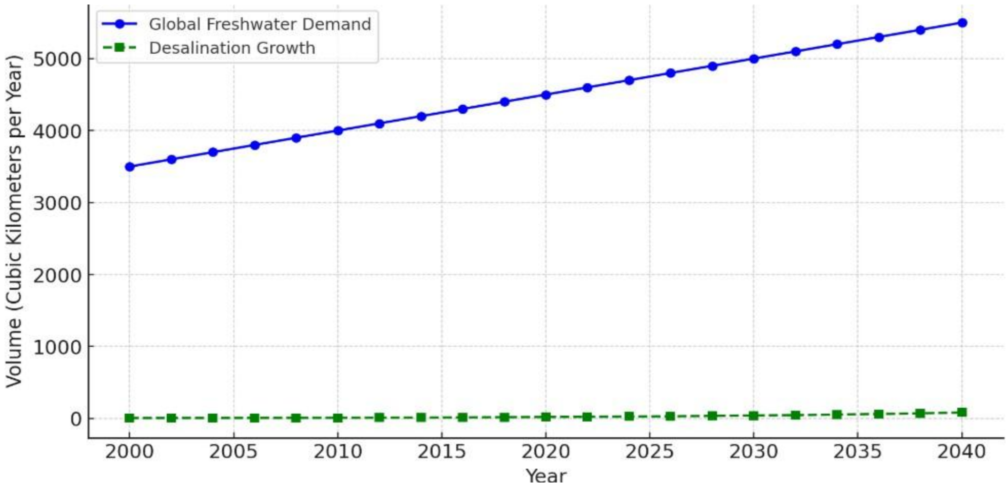

Fig.5:- Global Freshwater Demand vs. Desalination Growth [18]

5. The contribution of each desalination process to the world water production.

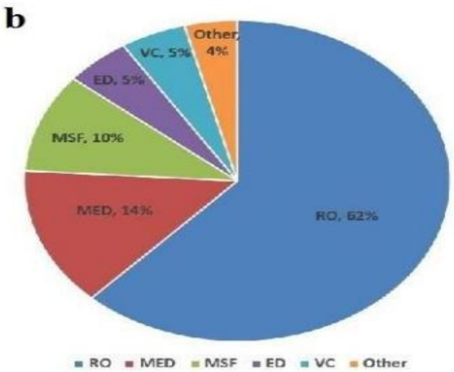

Fig.6:- [1]

Advantages of Solar Desalination

- Renewable and eco-friendly energy source.
- Reduces dependence on fossil fuels.
- Ideal for remote and off-grid regions.
- Low operational costs after installation.

Challenges of Solar Desalination

- Initial setup costs can be high.
- Water production rates are lower than conventional desalination methods.
- Efficiency depends on solar radiation availability.

Future of Solar Desalination

- **Integration with Nanotechnology**: Advanced membranes and coatings to improve efficiency.
- **Hybrid Systems**: Combining solar desalination with wind or geothermal energy.
- **AI & IoT Monitoring**: Smart systems for real-time optimization and maintenance.

Table 1:- Different types of active solar stills and its corresponding values of absorbing area, average daily productivity and daylight hours. [13]

Ref.	Type of still	Still absorbing area m2	Collector's area m2	Average daily productivity l/day	Daylight hours	Country
Maha A. Tony,at el	Single slope single basin	0.5	1	6	9-19	Egypt
Mohammad Al	Innovations in Solar-	0.648	0.354	3.5	9-18	Iran

Addous,at el	Powered Desalination					
Fadi Alnaimat, at el	Solar Desalination	0.1	6 circumferential area	12.2	9_17	Egypt
Domenico Curto, at el	A Review of the Water Desalination Technologies	0.204	_	2.05	9-15	Libya
R.V.S. Madhuri, at el	Solar energy-driven desalination	0.0432	_	6	9–18	Egypt
Zafar Said at el	Sun-powered solutions: Investigating productivity and economics of small-scale solar desalination system	0.0231	0.25	1.2	10-16	Iran

Ref.	**Type of still**	**Still absorbing area m2**	**Collector's area m2**	**Average daily productivity l/day**	**Daylight hours**	**Country**
A. Pacheo, at el	Enhancing efficiency in solar non-intrusive desalination: Solar still prototype optimization in Southwest Europe	0.5 f or stepped still	-	6.12	9–17	Malaysia
Maryam Nooman AlMallahi ,at el	Analysis of solar-powered adsorption desalina tion systems: Current research trends, developments, and future perspectives	1 for finned still	-	5.29	9–17	India
Abrar Inayat, at el	Recent Developments in Solar Thermal Desalination Technologies: A Review	1.16	-	6	9–19	Egypt
Zeinab S. Abdel-Rehima, at el	Improving the performance of solar desalination systems	0.077	0.25	6.35	8–16	Japan & UAE
El-Sebaii , at el	Advanced designs of solar desalination systems: A review	1	5.8 circumferential area	3.78	7–6 next day	Iraq

Table 2 :- Cost analysis of solar desalination system [13]

Ref.	P $	SFF	CRF	FAC $	S $	ASV $	AMC $	AC $	M l	CPL $/l
[1]	94	0.057	0.177	16.64	18.8	1.07	2.50	18.06	681	0.0265
[2]	110	0.057	0.177	19.47	22	1.25	2.92	21.13	559	0.0378
[3]	62.5	0.057	0.177	11.06	12.5	0.71	1.66	12.01	967	0.0124
[4]	122.5	0.057	0.177	21.68	24.5	1.4	3.25	23.54	910	0.0259
[5]	245	0.057	0.177	43.36	49	2.79	6.5	47.07	788	0.0597
[6]	282	0.057	0.177	49.91	56.4	3.21	7.49	54.18	325	0.1667

Ref.	P $	SFF	CRF	FAC $	S $	ASV $	AMC $	AC $	M l	CPL $/l
[7]	165	0.057	0.177	29.20	33	1.88	4.38	31.70	775	0.0409
[8]	99.5	0.057	0.177	17.61	19.9	1.13	2.64	19.12	`1170	0.0163
[9]	38	0.057	0.177	6.73	7.60	0.43	1.01	7.3	130	0.0562
[10]	99	0.057	0.177	17.52	19.8	1.13	2.63	19.02	239	0.0796
[11]	35	0.057	0.177	6.19	7	0.4	0.93	6.72	403	0.0167
[12]	202	0.057	0.177	35.75	40.4	2.3	5.36	38.81	1118	0.0347
[13]	262	0.057	0.177	46.37	52.4	2.99	6.96	50.34	1196	0.0421

Where,

P= The present capital costs SFF= Sinking Fund Factor CRF= Capital Recovery Factor FAC= Fixed Annual Cost
S= Salvage value

ASV= Annual Salvage Value AC= Annual Cost
M= annual yield

CPL= cost of distilled water per liter

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