Technological Advancement of Solar Thermal System Desalination Process – A Review

B Kalidasan1, Divyabharathi R2, AK Pandey3, Subramaniyan C1, and Mohankumar S4
1 Assistant Professor, Department of Mechanical Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu-638401
2 Assistant Professor, Department of Agriculture Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu-638401
3 Associate Professor, Research Centre for Nano-Materials and Energy Technology (RCNMET), School of Science and Technology, Sunway University, No.5, Jalan Universiti, Bandar Sunway, Petaling Jaya, 47500 Selangor Darul Ehsan, Malaysia
4 Assistant Professor, Department of Automobile Engineering, Kumaraguru College of Technology, Saravanampatti, Tamilnadu-641049
E-mail: kalidasancinna@gmail.com

Abstract. Increase in demand for drinking water due to growth in world population and industrialization has lead route for innovating new technologies for purifying sea water. Desalination by conventional energy source increases the emission of greenhouse gases and leads to global warming. As a solution for pollution and water scarcity, solar desalination techniques are incorporated worldwide for converting brackish water into portable water using solar power. Solar power helps water purification via solar thermal systems and also using solar photovoltaic panels which provide electric supply. This review article consolidate the solar thermal energy based small, medium and large scale solar desalination plants for extracting pure water. The environmental benefits and the futuristic challenges of utilizing solar thermal system for purification of water is also highlighted.

1. Introduction

Water being an essential source for human livelihood, it becomes a must needed factor for human survival. Earth is known as blue planet as it constitutes about 71% of water. But, the percentage of fresh water available on earth surface is only 1%. Advisable salt content for human drinking water is 1000 ppm whereas sea water has salt content of about 35000 ppm [1]. Distributions of saline and fresh water in earth surface are represented in Figure 1. It is also been observed that on an average about 400000 lakhs of human beings from India and China are suffer from lack of water every month. In order to meet the overall water supply worldwide, need for fresh water is at utmost alarm.

To provide a solution for the threatening problem, desalination is the most recommended solution. Desalination is a process in which saline water is converted into fresh water. Desalination technique
requires energy for its operation. During desalination saline or brackish water is heated till it reaches the evaporation point, at which the water gets evaporated to steam, on condensing back the steam we obtain water free from dissolved salts. Conventional fuel like petrol, kerosene and coal used for heating of water causes GHG emission and causes air pollution, energy in the form of electricity generated using thermal power plants also causes air pollution due to combustion of coal. Thus researchers and scientist experimentally work on techniques to convert saline water into drinking water using solar power. Solar power in the form of light is used in PV panels for electricity generation, which can be used in reverse osmosis and other purification techniques. As well solar power in the form of heat energy is used in solar thermal systems like solar stills and solar concentrators for directly evaporating the brackish water.

**Figure 1. Saline and Fresh water Distribution**

Solar energy is an abundant non-polluting energy source available free of cost. Solar thermal system like solar stills, solar chimney and solar concentrator techniques are widely used for purification of saline water [2]. Table 1 consolidated the recent review articles published on solar thermal system based desalination. From literature [3-7] it’s quite evident that no review article has consolidated the advanced technologies opted with small scale, medium scale and large scale solar thermal system based desalination technique for purification of brackish water in order to make it fit for drinking. This review article summarizes advanced solar thermal system based desalination process along with the advanced technologies, environmental benefits and the futuristic challenges.

**Table 1. Recent Review articles**

| Author & Year | Title | Remark |
|---------------|-------|--------|
| Aboelmaaref et al. 2020 [3] | Hybrid solar desalination systems driven by parabolic trough and parabolic dish CSP technologies: Technology categorization, thermodynamic performance and economical assessment. | The performance and economic benefits of desalination units operating using parabolic trough reflector and parabolic concentrators are reviewed in detail along with the challenges in implementation. Critical review on performance and payback period for few selected concentrated solar desalination units analyzed and the benefits were summarized. |
| Omar et al. 2020 [4] | Pathway for integrated concentrated solar power – Desalination: A Critical Review | A detailed review on application of Phase change materials into solar thermal system for water and air heating with enhanced efficiency were consolidated with respect to low, medium and high temperature system. Focus was made on summarizing the numerical simulation of solar desalination plant operating using solar |
| Kalidasan et al. 2020 [5] | Phase change materials integrated solar thermal energy systems: Global trends and current practices in experimental approaches. | |
| Maia et al. 2019 [6] | An overview of the use of solar chimneys for desalination. | |
A review on numerous means of enhancing heat transfer rate in solar-thermal based desalination devices. Heat transfer enhancement methods for improving the efficiency of solar stills for fresh water generation were reviewed in detail.

The review article has been divided into six section. A brief introduction indicating the need for purification of brackish water, and the novelty of the review article is consolidated in first section. Second section highlight the basic operation of desalination and the drawback of desalination process carried out using conventional methods. Section three elaborated the theme of the review article, all the solar thermal system based on low, medium and high temperature consolidated the recent advancements and performance of solar thermal systems for purification of water. In the fourth section the environmental benefits of using solar power for fresh water extraction are explained. Section five highlights the key challenges faced while using solar thermal system for desalination process. And the last section concludes the review article.

2. Desalination

Solar desalination is a process of extracting salt and dissolved solids from saline or sea water with the support of solar radiation to make the saline water fit for drinking. Evaporation and condensation are the basic principle of solar desalination. During this process solar radiation strike the top surface of the solar still, through which major amount of flux gets transmitted to the inner basin where water is stored. The basin area is made of black sheet in order to help higher absorptivity and reflected only a minor amount of radiation to the environment. Figure 02 represents the working of solar still. The solar radiation rises the temperature of the water thereby evaporation process takes place. The evaporated water precipitates gest condensed in the glass top cover, condensed water droplets are collected which produces fresh water. Based on the quantity of fresh water production, solar desalination system are subdivided into small scale solar thermal desalination system, medium scale solar thermal desalination system and large scale solar desalination system.

Figure 2. Working of Solar Desalination System

3. Advancement in Solar thermal system based Desalination

Solar energy is utilized as direct electric power using photovoltaic and in cooling and heating system as solar thermal system. Solar thermal system like solar water heater, solar parabolic trough and solar Fresnel collectors are used for heating water, similarly solar air heater and solar chimney are opted for air heating. In this section the advancement and technological developments carried out in solar desalination set up based on water production rate are classified and reviewed.

3.1 Small Scale Solar Thermal Desalination Technique

In this review section the advanced techniques tailed with small scale solar desalination systems are consolidated. Size of a solar desalination plant depends on the rate of fresh water produced in a day. Small scale solar still includes single slope solar still, double slope solar still, pyramid type solar still, spherical solar still, wick type solar etc. which tends to produce fresh water in 01-20 L/day. Table 2 shows the recent techniques made with small scale solar desalination plant.
| Authors               | Layout                                      | Modification                                               | Productivity    |
|----------------------|---------------------------------------------|------------------------------------------------------------|-----------------|
| Pal et al. [8]       | Double slope solar still with multi-wick    | 9.02 L/day                                                 |
| Hansen et al. [9]    | Inclined Solar Still with different wick    | 4.28 L/day                                                 |
| Modi et al. [10]     | Single slop double basin area with wick     | 2.7 L/day                                                  |
| Muraleedharan et al. [11] | Solar still with frensel lens concentrator and Al₂O₃ thermic fluid in heat exchanger | 12.190 L/day with Rs. 1.54 |
| Terasaki et al. [12] | Triangular shaped Solar still with performance and economic analysis | 3 L/day with Rs. 2.72/L |
| Kabeel [13]          | Concave solar still with efficiency 45 %    | 4.0 L/day with Rs. 4.85/L                                  |
Kabeel et al. [14] V-corrugated Absorber Plate with PCM 3.5 L/day with Rs. 17.59/L

Arunkumar & Kabeel et al. [15] Compound parabolic concentrator concentric circular tubular solar still with PCM 5.78 L/day

Dashtban & Tabrizi et al. [16] Cascade Solar Still with PCM 6.7 L/day

Rabhi et al. [17] Single slope single basin solar still with pin fins Water production improved by 41.2%

Shanazari & Kalbasi et al. [18] Inverted absorber multi effect solar still Efficiency improvement by 407.3%
3.2 Medium Scale Solar Thermal Desalination Technique

In this review section the advanced techniques tailed with medium scale solar desalination systems are consolidated. Medium scale solar with humidification and dehumidification type of solar desalination system are elaborated. In medium scale solar system the fresh water production rate is about 100-250 L/day. Table 3 shows the recent techniques made with medium scale solar desalination plant.

Table 3. Advancement of Medium Scale Solar Desalination Systems

| Authors            | Layout | Modification                                      | Productivity          |
|--------------------|--------|---------------------------------------------------|-----------------------|
| Sharshir et al. [19]|        | Solar hybrid desalination system with Humidification and Dehumidification with evacuated solar water heater. | 66.3 L/Day            |
|                    |        |                                                   | With Rs. 36.53 to 2.53 per L |
| Tabrizi et al. [20]|        | Cascade Solar Still Desalination with humidification and dehumidification | Efficiency Improved by 39% |
3.3 Large Scale Solar Thermal Desalination Technique

In this review section the advanced techniques tailed with large scale solar desalination systems are consolidated. Large scale solar with solar chimney type of solar desalination system are elaborated. In large scale solar system the fresh water production rate is about 1000 L/day. Table 4 shows the recent techniques made with large scale solar desalination plant.

| Authors          | Layout                               | Modification                                      | Productivity       |
|------------------|--------------------------------------|---------------------------------------------------|--------------------|
| Zuo et al. [23]  | Solar Chimney with desalination of sea water. | 190410 L/day                                      |                    |

**Table 4. Advancement of Large Scale Solar Desalination Systems**
8

4. Environmental Pros & Cons

Purification of brackish water using solar still is an efficient way to reduce emission of GHG involved in water purification techniques. Numerous research are carried out with idea to resolve the intermittent nature of solar power by using various thermal energy storage system. Integrating phase change material for thermal energy storage are a booming technology with nano additives. Special care has to be carried out to ensure that the PCM does not make any changes to the water, as well the disposal of PCM after its thermal stability is eco-friendly. Solar still with nanoparticles are also opted in large scale, nanoparticle beings a concern for environment, as the passes through membrane, special care has taken for its disposal and integrating with solar thermal desalination techniques.

5. Challenges faced by STS based Desalination

Solar stills, solar concentrators and solar chimney are few solar thermal systems classified based on different temperature level, operating to produce fresh water. Though the process is environmental friendly, certain consequence and challenges faced in real-time applications are mentioned below.

a) Thermal Storage - In order to overcome the intermittent nature of solar power, phase change materials are used as thermal batteries. Phase change material undergo the problem of low thermal conductivity and lack of thermal reliability with number of thermal cycles.

b) Economic – STS such as single slope and dual slope solar still are economically beneficial, with quick payback period. Whereas integrating fins, nano fluids and phase change materials tends to increase the payback period and overall cost. Economic evaluation for high temperature solar thermal system like solar chimney are beneficial only while operating as a dual or tri-generation cycle.

c) Man Power – Need for skilled labor is always required for solar power based desalination unit. Perfect operating conditions such as, glass temperature, solar tracking, free from dust, away from shadow etc. has to be always taken care of for better fresh water production rate.

d) Quality of Water – Technique to ensure the quality of fresh water produced using solar
thermal system has to be monitored regularly has the system involves metals, nano fluids and phase change materials.

6. Conclusion and Future Scope

Growth in population has led to scarcity of drinking water worldwide. Researchers and scientist are working on desalination process to convert sea water into fresh drinking water. Use of solar radiation for evaporating and condensing of sea water is environmental friendly, and does not require electric power generated using conventional fuel. Solar still are low temperature solar desalination system operating with improvement in performance using nano fluids, phase change materials, extruded fins, tracking system and concentrators. Integrating fins for better improvements of PCM fins based solar still increases the charging rate as well also increases the discharging rate which has to be reduced for better performance. Solar concentrators and solar chimney requires huge investment during initial set up and is economically feasible only with a dual or tri-generation system. Quality of fresh water produced using solar thermal system are of higher concern. Researches are focusing to increase the fresh water production rate in the existing techniques. Solar thermal based desalination process is an environment-friendly method, which reduces the emission of greenhouse gas. This research articles also highlights the research gap and drawbacks of STS based desalination process.

References
[1] Ahmed F E, Hashaikeh R, and Hilal N 2019 Solar powered desalination—Technology, energy and future outlook. Desalination (453) 54-76.
[2] Reif J H, and Alhalabi, W 2015 Solar-thermal powered desalination: Its significant challenges and potential. Renewable and Sustainable Energy Reviews (48) 152-165.
[3] Aboelmaaref M M, Zayed M E, Zhao J, Li W, Askalany A A, Ahmed M S, and Ali E S 2020 Hybrid solar desalination systems driven by parabolic trough and parabolic dish CSP technologies: Technology categorization, thermodynamic performance and economical assessment. Energy Conversion and Management (220) 113-103.
[4] Omar A, Nashed A, Li Q, Leslie G, and Taylor R A 2020 Pathways for integrated concentrated solar power-Desalination: A critical review. Renewable and Sustainable Energy Reviews (119) 109-609.
[5] Kalidasan B, Pandey A K, Shahabuddin S, Samykano M, Thirugnanasambandam M, and Saidur R 2020 Phase change materials integrated solar thermal energy systems: Global trends and current practices in experimental approaches. Journal of Energy Storage (27) 101-118.
[6] Maia C B, Silva F V, Oliveira V L, and Kazmerski L L 2019 An overview of the use of solar chimneys for desalination. Solar Energy (183) 83-95.
[7] Jani H K., and Modi K V 2018 A review on numerous means of enhancing heat transfer rate in solar-thermal based desalination devices. Renewable and Sustainable Energy Reviews (93) 302-317.
[8] Pal P, Yadav P, Dev R, and Singh D 2017 Performance analysis of modified basin type double slope multi–wick solar still. Desalination (422) 68-82.
[9] Hansen R S, Narayanan C S, and Murugavel K K 2015 Performance analysis on inclined solar still with different new wick materials and wire mesh. Desalination (358) 1-8.
[10] Modi K V, and Modi J G 2019. Performance of single-slope double-basin solar stills with small pile of wick materials. Applied Thermal Engineering (149) 723-730.
[11] Muraleedharan M, Singh H, Udayakumar M, and Suresh S 2019 Modified active solar distillation system employing directly absorbing Therminol 55–Al2O3 nano heat transfer fluid and Fresnel lens concentrator. Desalination (457) 32-38.
[12] Terasaki H, Umemura T, Akao T, Ito M, Fukuhara T, and Islam K M S 2016 Estimation of Production Cost of a Triangular Solar Still for Remote Area of Bangladesh.
[13] Kabeel A E 2009 Performance of solar still with a concave wick evaporation surface. Energy
34(10) 1504- 1509.

[14] Kabeel A E, Teama M A, Abdelgaied M, and Aziz G B A 2017 Modified pyramid solar still with v-corrugated absorber plate and PCM as a thermal storage medium. Journal of Cleaner Production (161) 881-887.

[15] Arunkumar T, and Kabeel A E 2017 Effect of phase change material on concentric circular tubular solar still-integration meets enhancement. Desalination (414) 46-50.

[16] Dashtban M, and Tabrizi F F 2011 Thermal analysis of a weir-type cascade solar still integrated with PCM storage. Desalination 279 (1-3) 415-422.

[17] Rabhi K., Nciri R, Nasri F, Ali C, and Bacha H B 2017 Experimental performance analysis of a modified single-basin single-slope solar still with pin fins absorber and condenser. Desalination (416) 86-93.

[18] Shanazari E, and Kalbasi R 2018 Improving performance of an inverted absorber multi-effect solar still by applying exergy analysis. Applied Thermal Engineering (143) 1-10.

[19] Sharshir S W, Peng G, Yang N, Eltawil M A, Ali M K A, and Kabeel A E 2016 A hybrid desalination system using humidification-dehumidification and solar stills integrated with evacuated solar water heater. Energy conversion and management (124) 287-296.

[20] Tabrizi F F, Khorasani M, and Sani I S 2016 Experimental study of a cascade solar still coupled with a humidification-dehumidification system. Energy Conversion and management (115) 80-88.

[21] Elminshawy N A, Siddiqui F R, and Addas M F 2016 Development of an active solar humidification-dehumidification (HDH) desalination system integrated with geothermal energy. Energy conversion and management (126) 608-621.

[22] Al-Otoom A, and Al-Khalaileh A T 2020 Water desalination using solar continuous humidification-dehumidification process using hygroscopic solutions and rotating belt. Solar Energy (197) 38-49.

[23] Zuo L, Zheng Y, Li Z, and Sha Y 2011 Solar chimneys integrated with sea water desalination. Desalination 276 (1-3), 207-213.

[24] Asayesh M, Kasaenian A, and Ataei A 2017 Optimization of a combined solar chimney for desalination and power generation. Energy Conversion and Management (150) 72-80.

[25] Rahbar K, and Riasi A 2019 Performance enhancement and optimization of solar chimney power plant integrated with transparent photovoltaic cells and desalination method. Sustainable Cities and Society (46) 101-441.