Conceptual Investigation of Renewable Energy for Desalination Purposes

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Abstract. Undoubtedly, that freshwater and energy are the two most important factors, which are responsible for the development of socio-economic in any region. According to the many studies, there are many places where the accessibility of potable water are limited, and to meet this demand for freshwater, the use of desalination plants is an important solution. On the other hand, there is a need of energy, either in the form of electricity or heat for operations of desalination plants and we all aware of the availability of conventional energy source, which is limited. Therefore, the Renewable Energy Sources (RES) will be an effective solution in the future to the energy problem and water management for driving the desalination plants. This paper aim has to study and propose appropriate Sustainable energy sources for all kind of desalination system, i.e., thermal or membrane system and the kind of energy used for driving the desalination system.

Keywords: Renewable Energy, RES Driven Desalination, Desalination Technology.

1. Introduction
The whole world is facing the freshwater problem in 21 century, i.e., availability of freshwater, accessibility of freshwater, quality of water. The people also not aware of saving the water for this reason the economy of a country can be decline. [1, 2]. On average, the water available on earth has salinity up to 10,000 ppm whereas seawater normally has salinity in the range of 35,000–45,000 ppm in the form of total dissolved salts. According to the World Health Organization (WHO), the water having salinity, about 500 ppm is drinkable but some special cases it is up to 1000 ppm. The drinking water that has Excess salinity causes many health problems like lungs, stomach, skin, etc. For greater economic development and living standard, the annual water availability should be 1000 m³ per capita [3-5]. There is no doubt that renewable energies have an affluence future and an imperative role in developing countries for seawater and brackish water desalination. Most of the industrial country, including India, are now started to change in their power supply plans to the high share of renewable energy, by supporting business sector presentation and development of those advances [6].

The system of sustainable energy should take into consideration the impact on the environment, social, technical, and economic point of view. Out of renewable energy sources, solar energy for power generation plays an important role. The increase in the supply of the desalinated water will cause many problems, and out of these problems, the demand for energy for desalination of water is the most important problem. It has been studied that the per day demand for drinkable water is about...
13 million m³ requires 130 million tonnes of fuel per year [7]. The use of fossil fuel, mainly hydrocarbon-based fuel causes the CO₂ emission and which is not good for our environments, and we should think and try to find an alternative about this. The better alternative to this is that we should move towards renewable energy sources for power generation [8]. The renewable energy generation is reasonably good as compared to the generation of power through fossil fuels. The main factors, which have affected the cost during the desalination, are water quality that has been supplied as well as the water quality, which has been feed to desalination unit and the cost of energy, which utilizes by desalination plants [9].

In this paper, the RES and desalination technologies integration has been discussed for supply the freshwater demand at the global level, and the aim of this study is focused to increase the supply of potable water through desalination.

2. Renewable power coupling to desalination technologies
The solar thermal, wind, wave, photovoltaic, fuel cell, biomass, and geothermal renewable energies are used in the desalination process[10, 11]. The desalination systems driven by renewable energy can be categories in two ways. In figure 1, different possible combinations of RES and desalination systems are presented. There is a numeralsignificant factors are in consideration while driving the desalination unit by renewable energies system. The renewable energy system must be matching with desalination units [12]. The energy produced by RES can drive the desalination unit, but not all the combination of RES can be used in all practical application of desalination units.

The various parameter like site’s topography, geographical conditions and types of energies, which are available in low cost, availability of electrical grid for power supply, size of the plant and the salinity of feed water, must be studied in combination with various optimum technologies, which are used in desalination process of saline water. While selecting the desalination process, the various factors must be considered, such as [13]:

- The quantity of freshwater production and desalination technologies have been used and the feed water salinity.
- The effectiveness of the desalination process concerning the expense of energy.
- The Convenience of the desalination process from solar energy.
- The requirements of seawater treatment.
- The capital cost of the equipment and used material.
- For the installation of desalination units, the land area required.
- Desalination process simplicity and robustness of the equipment.
- The units must be compact, lesser maintenance and easy transportation to the site.
- Local community support and acceptance.
- The Local-level organization with simple training.
3. Solar energy desalination

The solar energy-driven desalination plants can be of two types; concentrating solar-thermal desalination and Photovoltaic driven desalination.

3.1. Concentrating solar thermal driven desalination

Solar concentrators convert solar energy into heat at high temperature. This thermal energy generates steam in a steam generator or can be used for any other purpose. This steam is used for generation of electricity or other purposes. The solar energy production from concentrating the sun’s rays is the relatively low cost, and it can provide energy during peak demand. This solar power can be a significant contribution to the nation's needs for the future and distributed energy sources.

The main challenge of engineering and development of solar heat energy is to concentrate the relatively low-density solar energy. Therefore, mirrors with have high reflectivity of up to 95% used, which are continuously track the sun for this purpose. Solar concentration technologies can be channel systems, windscreen/engine systems, and power towers. Design of parabolic solar collectors has in such a way that they can concentrate the rays towards a receiver of the sun for absorbing the heat. The receiver is located at the collector’s focal line. Solar collectors continuously trace the sun. The mirrors, turbines, and receiver are the main components for a power generating unit, which uses parabolic collectors.

The solar radiation captured by the satellite dishes and solar motor system is transfer to the Stirling engine, the motor is required an external source of heat for contracting and expanding the fluid, and the motor is placed at the parabolic plate's center. The above approach is mainly best suitable for non-centralized power generation. The heat from the sun is stored, the phase change material or sometimes ceramic and concreter are used, and this heat is utilized for power generation. During the nighttime, the heat can be extracted from the storing materials for power generation. Figure 2 shows a scheme of combinations of thermal solar desalination.

3.2. Photovoltaic driven desalination

PV driven membrane processes are mainly two type’s first one is reverse osmosis (RO), and the second one is electro-dialysis (ED). PV technology is developed, just as RO, ED technology develops,
and commercially, these are used these days’ time. In the remote sites for desalination, the PV driven RO and ED units can be used, and it has been proven [14]. The main drawback associated with the PV technologies is that of their higher cost and the PV cells availability [15].

![Diagram of solar thermal power plant configuration](https://via.placeholder.com/150)

**Figure 2.** Solar thermal power plant configuration for (a) electricity generation, and for (b) the combined generation of power and water with backup and energy storage [16].

### 4. Wind-driven desalination

#### 4.1. Wind + RO

As mentioned earlier, Reverse osmosis (RO) is a pressure-driven process that separates two solutions with different concentrations through a semi-permeable membrane. The high-pressure pumps, membrane modules, power generation plants, and energy recovery devices are the main component of an RO plant. Out of desalination techniques, RO desalination techniques is one of the most efficient. The freshwater production of 1m³ from the RO system requires 3 to 10 kWh of electricity [17]. As reported by many authors there is the availability of wind energy in the coastal regions, and this energy can be utilized by a desalination plant for producing freshwater, the RO desalination units are the better alternative because of lowest power consumption [18, 19]. The most commonly used in the past were the Wind energy-driven RO system and RO system. Which covers about 19% of total desalination plants driven by RES, after this the RO units driven by PV, which are about 32%.

#### 4.2. Wind + MVC

Though the RO system consumes less power than mechanical vapor compression (MVC) system, still in the MVC has less problem due to energy fluctuations than the RO system. Due to this for remote areas, the MVC system is more suitable than RO system and also due to the simplicity of operation less-skilled workers are required, the unit is robust, and there are fewer chemicals required. Furthermore, also there is no requirement of replacing membrane, and also MVC provides a better quality of freshwater as compared to RO system. In the case of contaminated water, distillation guarantees the absence of micro-organisms in the product.

There are few systems have implemented by using the energy from wind which used to drive the mechanical compression unit of the steam. In 1991 an MVC plant had been installed in Germany which was coupled with a wind turbine of capacity 45 kW and this plant generate 48 m³/day of freshwater. This MVC plant's compressor was required 36 kW of energy for operation [19]. Henderson C R et al. have studied the wind-diesel hybrid system for Star Island. This system can produce and store the potable water during the winter season because of the low demand for electricity and
conclude that the 2 or 3 wind turbines of capacity 7.5 kW can be installed without desalination of water [20]. Further, a larger plant had installed in Germany's Baltic sea island, which capacity was around 360 m³/day, and the wind turbine can generate 300kW which was installed there[21].

4.3. Wind + ED
The ED process of desalination is best suitable for the remote areas as compared to RO desalination process because it can be driven with the available wind energy changing. Veza et al. They presented the experimental results and modeling of the network tests of this system installed in ITC, Gran Canaria, in Spain. The prime objective of this project was to find a suitable desalination system while coupled with a wind turbine without actually coupling. The capacity of the plant was in the range of 72-192 m³/day [22]. Subsequently, they developed an operating envelope for the inversion unit of electrodialysis, outside the network, that is coupled only to the wind farm. The ED desalination system showed its good flexibility; also, this system has adopted wind energy changes [23].

5. Desalination unit is driven by biomass and geothermal energy
The desalination processes which are powered by biomass is not an alternative in the arid regions because there is less availability of organic residues and for producing biomass fresher water required than the production of freshwater from desalination unit. Even though, as compared to solar (solar thermal collectors and PV) and wind energy, the geothermal energy is not used commonly. The energy from the geothermal source can be used for the desalination process at a competitive cost. Since the geothermal energy is continuous and predictable, the main advantage of this energy is that there is no requirement for thermal energy storage, as compared to other RE technologies. [24].

The immediate utilization of geothermic fluid adequately of high temperature in association with thermal desalination is the utmost exciting choice [25]. The high-temperature geothermal fluids can be used to power the electrically driven ED and RO plants while the high-pressure geothermal source’s shaft power can be directly used to drive mechanically driven desalination plants.

6. Wave-driven desalination technologies
There are many proposals have been made with insufficient technical details for driving the desalination units with the wave energy, but only two wave-powered desalination plants have been installed. The first wave-powered desalination plants were deployed in 1982. A linear pump was used in the plant that had been driven by the buoy’s up and down motion [26]. The pump feeds the pressurized water that was subsequently past a single-stage reverse osmosis membrane to produce up to 2.0 m³/day. The second wave-powered plant was constructed in 2014 in Kerala, India. A turbine and electrical generator are driven by the plant's oscillating water column [27]. The electrical energy is produced from the wave energy, and this energy used to drive an RO plant of the maximum capacity of about 10 m³/day. The ED and RO desalination plants were driven successful from wave energy for producing freshwater.

7. Fuel cell-driven desalination plants
There are two ways to drive desalination units by using fuel cell technologies. First, by fulfilling the electrical demand of the desalination unit using the electrical energy of the fuel cell. Second, using heat energy released from high-temperature fuel cells such as MCFC and SOFC with 650°C and 1000°C operating temperatures, respectively. Also, there can be a coupling of two desalination technologies with a high-temperature fuel cell, which is driven electrically, and thermally desalination units. In such a case, the fuel cell provides both thermal and electrical demand of two separated desalination units. For an example of such kind of combination, one may think FC/MSF/RO as the cogeneration system. In this system, the MSF unit needs heat energy for the distillation of input water and produce freshwater, and it works on thermal desalination technology while the RO unit is driven by the electrical energy for producing freshwater. The FC/MSF/RO system can be seen as a comprehensive example of desalination units driven by the fuel cell.
7.1. Dual-purpose plants FC/MSF/RO
The fuel cell waste stream of flue gases containing the heat energy in the stream. The amount of heat depends on the type of fuel cell and its temperature. Such type of fuel cell plants can be used as cogeneration plants and coupled with RO plans or MSF plants for producing the distilled water. The cogeneration plant of fuel cell system as depicted in figure 3 where the energy is produced by fuel cell hot stream flue gages for driving the desalination units instead of generating power from a conventional plant for producing the freshwater from RO system and MSF plants. Due to high operating temperatures, the SOFC and MCFC are most appropriate cogeneration technologies. The anode side of the fuel cell is fed with hydrogen gas from any source or natural gas. The cathode side of the fuel cell is fed with fresh air and the recycled carbon dioxide (CO₂) from the fuel cell system's auxiliary boiler. There is no input and output in the fuel cell because of the cooling system within the cycle. During the fuel cell stack, the water generated can be used in reforming of steam; therefore, the flow is represented as recycling. In addition to the generation of water during fuel cell stacks, there are two output of fuel cell system first one is electricity and the second is the stream of hot flue gases. This electricity can be directly used for driving the RO units for the production of pure water. For producing low-pressure steam in Heat Recovery Steam Generator (HRSG) the hot flue gases are used. This low-pressure steam can be fed into MSF units for getting an additional distilled water. The steam from the MSF unit is condensed in a brine heater (BH) and fed to the HRSG unit. Thus, in the cogeneration of fuel cell plant, both the RO and MSF unit fed with seawater and generated distilled water and reject the brine [28].

8. Conclusions and outlook
Nowadays, desalination using renewable energies increasing with an alarming rate because of the scarcity of freshwater and energies shortage. In spite of concentrated research in renewable energy, still very few RES powered desalination systems are installed. Presently, the RES powered desalination plants have installed and developed at a large scale. Practically, there has been a gain in experience and skills. The worldwide there is a scarcity of potable water as well as the electrical power supply, in the low densities population areas. Therefore, from the seawater or brackish water, RES may produce freshwater such as solar, wind, geothermal energy, etc. and we can use other technologies emerging renewable energy. Most of the developing countries are facing scarcity of freshwater also these countries do not have sufficient resources for the production of conventional energy, for those countries the successful development of RES based desalination system will be the most important. In
the remote areas, the membrane desalination process connected with PV cells is an important and interesting option. Nevertheless, wind energy will exhibit lower energy cost as compared to PV cells energy if it’s available. The wind turbines powered desalination units of RO and ED are the best selection for converting brackish or seawater to potable water. Apart from this, there are also other renewable energies like biomass, geothermal, and wave energy, which can be used to drive desalination units. The advantage of geothermal energy is that there is no requirement of energy storage. The PV-driven and wind-driven desalination technologies of renewable energy are the most mature membrane processes of desalination.

References

[1] Panchal H N and Thakkar H 2016 Theoretical and experimental validation of evacuated tubes directly coupled with solar still Therm. Eng. 63 825–31.
[2] Patel R V P, Kumar A, Kumar S and Mukhopadhyay N K 2017 Effect of Water Depth on the Productivity of Double Slope Solar Still for the Climatic Condition of Sultanpur ICETMIE pp 276–81.
[3] World Health Organization. Guidelines for drinking water quality Recommendations, vol. I. Geneva: World Health Organization; 1984.
[4] Patel R V P and Kumar A 2018 Experimental Investigation of Double Slope Solar Still for the Climatic Condition of Sultanpur Int. J. Eng. Technol. 9 4019–33.
[5] Kalita, P., Dewan, A., & Borah, S. 2016 A review on recent developments in solar distillation units. Sadhana - Academy Proceedings in Engineering Sciences, 41(2), 203–223.
[6] Patel R V and Srivastava A 2019 Present Status and Future Scope of Renewable Energies in India Int. J. Eng. Res. Technol. 8 26–32.
[7] Garcia-Rodriguez L. Renewable energy applications in desalination: state of the art. Solar Energy 2003; 75:381–93.
[8] Alkaisi A, Mossad R and Sharifian-Barforoush A 2017 A Review of the Water Desalination Systems Integrated with Renewable Energy Energy Procedia 110 268–74.
[9] Dore MHI. Forecasting the economic costs of desalination technology. Desalination 2005; 172:207–14.
[10] Kabeel A E, El-Said E M S and Dafea S A 2019 Design considerations and their effects on the operation and maintenance cost in solar-powered desalination plants Heat Transf. Res. 48 1722–36.
[11] Gude V G 2018 Use of exergy tools in renewable energy driven desalination systems Therm. Sci. Eng. Prog. 8 154–70.
[12] Eltawil M A, Zhengming Z and Yuan L 2009 A review of renewable energy technologies integrated with desalination systems Renew. Sustain. Energy Rev. 13 2245–62.
[13] Kalogirou and Soteris 1998 Use of parabolic trough solar energy collectors for sea-water desalination Appl. Energy 60 65–88.
[14] MEDRC R&D Report, VARI-RO Solar Powered Desalting Study. SAIC, USA; 2000.
[15] Alkhaitib A 2014 Reverse-Osmosis Desalination of Water Powered by Photo-Voltaic Modules Comput. Water, Energy, Environ. Eng. 03 22–9.
[16] Trieb F, Nitsch J, Kronshage S, Schillings C, Brischke L-A, Knies G and Czisch G 2003 Combined solar power and desalination plants for the Mediterranean region — sustainable energy supply using large-scale solar thermal power plants Desalination 153 39–46.
[17] Fritzmann C, Löwenberg J, Wintgens T and Melin T 2007 State-of-the-art of reverse osmosis desalination Desalination 216 1–76.
[18] García-Rodríguez L, Romero-Ternero V and Gómez-Camacho C 2001 Economic analysis of wind-powered desalination Desalination 137 259–65.
[19] Forstmeier M, Mannerheim F, D’Amato F, Shah M, Liu Y, Baldea M and Stella A 2007 Feasibility study on wind-powered desalination Desalination 203 463–70.
[20] Henderson C R, Manwell J F and McGowan J G 2009 A wind/diesel hybrid system with desalination for Star Island, NH: feasibility study results Desalination237 318–29.

[21] Plantikow U 1999 Wind-powered MVC seawater desalination — operational results Desalination122 291–9.

[22] Veza J M, Peñate B and Castellano F 2001 Electrodialysis desalination designed for wind energy (on-grid tests) Desalination141 53–61.

[23] Veza J, Peñate B and Castellano F 2004 Electrodialysis desalination designed for off-grid wind energy Desalination160 211–21.

[24] Barbier E 2002 Geothermal energy technology and current status: an overview Renew. Sustain. Energy Rev.6 3–65.

[25] Cost Estimating Procedures. In: Desalting handbook for planners (Chapter 9)2003. United States Department of Interior, Bureau of Reclamation, Technical Service Center, Desalination and Water Purification Research and Development Program Report No. 72 (3rd ed.): p. 187–231.

[26] Hicks D C, Mitcheson G R, Pleass C M and Salevan J F 1989 Delbouy: Ocean wave-powered seawater reverse osmosis desalination systems Desalination73 81–94.

[27] Sharmila N, Jalihal P, Swamy A K, Ravindran M, Sharmila N, Jalihal P, Swamy A K and Ravindran M 2004 Energy. vol29 (Pergamon).

[28] Lisbona P, Uche J and Serra L 2005 High-temperature fuel cells for fresh water production Desalination182 471–82.