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A Review of Renewable Energy Technologies Integrated With Desalination System

*Manish Joshi, #Dr. Neeraj Kumar
*Research Scholar, #Professor, Suresh Gyan Vihar University, Jaipur, India,
*ermanishjoshi@gmail.com, #neeraj.kumar1@mygyanvihar.com

Abstract - Seawater desalination technologies have been designed and developed during the last several decades to insure the supply of fresh drinkable water in infertile and coastal regions of the world. The large cost of desalination is the major reason that these technologies have not been used fully in areas where fresh water resources are not available or available in very less quantity. The higher cost of desalination is also the result of high cost of fossil fuels being used for this purpose or its availability is limited. This is a major constraint in the effective use of these systems. One of the forms of energy that can be used freely or with very less price is the use of solar energy. The idea behind the use of renewable energy sources is fundamentally attractive and many researches are being carried out in this area. This is also to preserve the reserves of fossil fuels so that. It is not only economical but also a viable and environmental friendly option. The use of renewable resources for desalination and water purification is becoming popular. This is justified by the fact that plenty of solar energy is available in the areas of fresh water shortages. This paper reviews the work of various researchers that has been carried during the recent years worldwide in the field of desalination of water. The various forms of renewable energy that are used for desalination purpose are wind energy, solar thermal energy, photovoltaic and geothermal energy etc. Economics of desalination process seems to be very much place specific and the cost per cubic metre ranges from installation to installation at a particular place. The cost of desalination varies place to place as it depends upon many factors, out of which the process of desalination method is of prime importance. The level of feed water salinity, the energy source, the capacity of the desalting plant, and other site related factors are also important.

Keywords — Seawater, desalination, renewable energy, solar energy, wind energy, geothermal energy.

I. INTRODUCTION

Water has been recognized as a basic human need and large quantities of fresh water are required for agricultural, industrial and domestic uses in many parts of the world. Today, nearly one fourth of mankind is suffering from inadequate fresh water supply [1]. Ever increasing growth of population worldwide (especially in the developing countries)is one of the main reasons of this shortage and the above mentioned situation will be even worse in the coming next two decades or so [2].The U.S. Geological Survey [3] found that 96.5% of Earth's water is located in seas and oceans and 1.7% of Earth's water is located in the ice caps. Approximately 0.8% is considered to be fresh water. The remaining percentage is made up of brackish water, slightly salty water found as surface water in estuaries and as groundwater in salty aquifers [4]. The shortage of potable water poses a big problem in remote and arid regions. In many regions of the world, pollution and exploitation of groundwater aquifers and surface water result to a decrease of quantity and/or quality of available natural water resources. Over 1 billion people are without clean drinking water and approximately 2.3 billion people (41% of the world population) live in regions with water shortages [5]. Desalination, a technology that converts saline water into clean water, offers one of the most important solutions to these problems [3]. Fresh water is defined as containing less than 1000 mg/L of salts or total dissolved solids (TDS) [6]. Presently, the total global desalination capacity is around 66.4 million m^3/d and it is expected to reach about 100 million m^3/d by 2015 [7]. The five world leading countries by desalination capacity are Saudi Arabia (17.4%), USA (16.2%), the United Arab Emirates (14.7%), Spain (6.4%), and Kuwait (5.8%) [8] Of the global desalted water, 63.7% of the total capacity is produced by membrane processes and 34.2% by thermal processes **(Fig. 1**).The desalination source water is split with about 58.9% from seawater and 21.2% from brackish groundwater sources, and the remaining percentage from surface water and saline wastewater [7]. The growth of desalination capacity worldwide is shown in **(Fig. 2)**.

The dramatic increase in desalinated water supply will create a series of problems, the most significant of which are those related to energy consumption. It has been estimated that a production of 13 million $m^3$of portable

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water per day requires 130 million tons of oil per year [9].The energy required to run desalination plants remains a drawback. Therefore, the idea of using renewable energy sources is fundamentally attractive. Renewable energy systems offer alternative solutions to decrease the dependence on fossil fuels. Renewable energy resources (e.g. solar, hydroelectric, biomass, wind, ocean and geothermal energy) are inexhaustible and offer many environmental benefits compared to conventional energy sources [10–13].

There are many reasons that makes the use of renewable energies suitable for seawater desalination:

1. Plant location- Many arid regions are coastal areas and renewable energy sources are available [14].
2. Seasonal changes- Often freshwater demand increases due to tourism, which is normally concentrated at times when the renewable energy availability is high, especially in the case of solar energy [14].
3. Energy availability- Conventional energy supply is not always possible in remote areas or little islands: on the one hand because of difficulties in fossil fuel supply, and on the other because the grid does not exist or the available power is not enough to drive a desalination plant. In such cases, the use of renewable energies permits sustainable socio- economic development by using local resources [14].

4. Self-sufficiency- Renewable energies allow energetic diversification and avoid external dependence on energy supply. These aspects are important, especially in the least developed countries, which moreover have unstable governments [14].

5. Technology- The development and commercialization of desalination systems driven by renewable energies make possible technology exportation and cooperation among countries with low development [14].

6. Environmental impact- Seawater desalination processes are strongly energy consuming. Therefore, the environmental effects of the fossil fuels consumed are important [14].

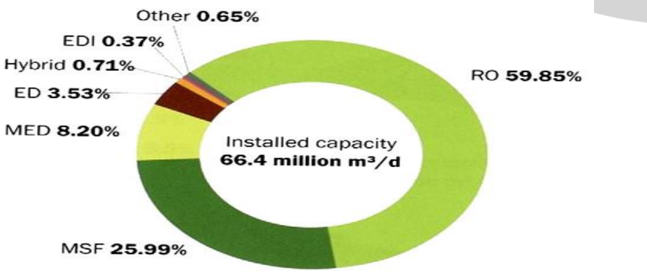

Fig. 1. Installed desalination capacities

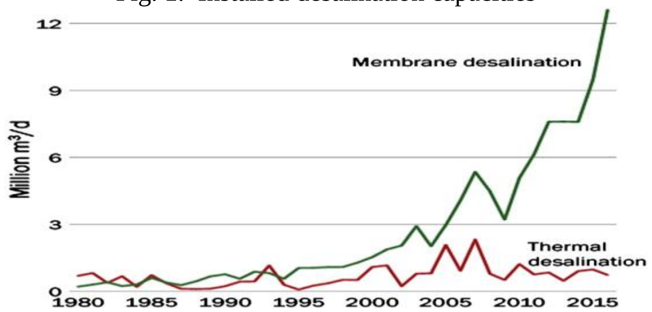

Fig. 2. Forecast desalination capacities

II. RENEWABLE ENERGY COUPLING TO DESALTING TECHNOLOGIES

Renewable energies for use in desalination processes include solar thermal, wind, photovoltaic Biomass and geothermal. There may be two categories of the Desalination system operated by renewable energy. The first category includes distillation processes operated by heat produced by the renewable energy systems, while the second includes membrane and distillation processes operated by electricity or mechanical energy produced by RES. In order to minimize the variations in the level of energy production and consequently water production these systems are connected with a conventional source of energy (e.g. local electricity grid). The most popular combination of technologies is the use of PV with reverse osmosis (see Fig. 3) [15]. PV is specially preferred for small applications in sunny areas. On the other hand for large units, wind energy is preferred due to it does not require large place. Wind energy can be more effective on islands where there is a good wind regime and very limited flat ground. With distillation processes, large sizes are more attractive due to the relatively high heat loses from small units.

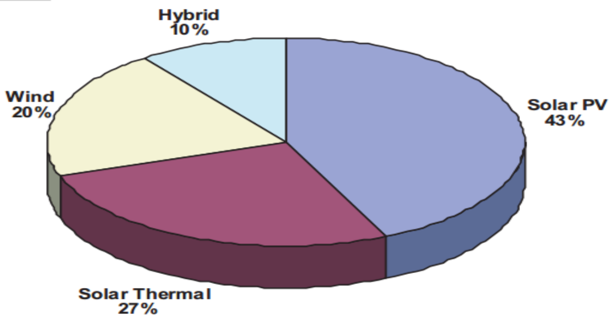

Fig. 3 Energy Sources for Desalination

The boundary between the renewable energy system and the desalination system is met at the place/subsystem where the energy produced by the RE system is promoted to the desalination plant[2]. This energy can be in different forms such as thermal energy, electricity or shaft power.Fig. 4 shows the possible combinations[16,17].

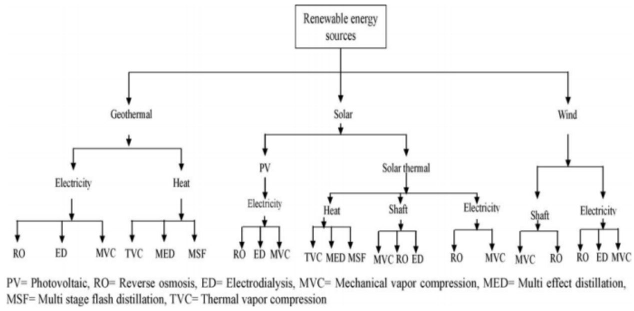

Fig. 4 Combination technologies of RES and Desalination methods

A. *Thermal solar energy:*

Solar energy is one of the most promising applications of renewable energies to seawater desalination. A solar distillation system may consist of two separate devices, the solar collector and the distiller - indirect solar desalination - or of one integrated system - direct solar desalination [14]. Wherever fresh water demand is low

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and land is inexpensive small production systems such as solar stills may be used. High fresh water demands require industrial-capacity systems. Many small systems of direct solar desalination and several pilot plants of indirect solar desalination have been designed and implemented [18-21]. The biggest challenge of solar thermal power and its development is to concentrate solar energy which has a relatively low density. Therefore, mirrors with up to 95% reflectivity that continuously track the sun are required for this purpose [2].

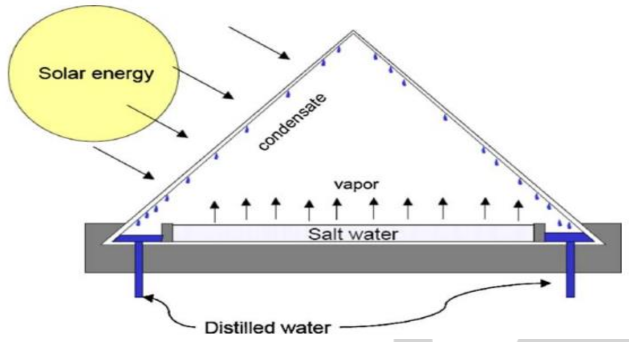

Fig. 5 The basic design of a solar distillation unit [22]

B. *Solar photovoltaic energy:*

Solar energy may be directly converted into electricity by photovoltaic conversion. Photo- voltaic cells usually consist of silicon though other semiconductors may be used. The main points in research of photovoltaic cells are the increase in efficiency, the reduction of manufacturing costs and the search for other materials as GaAs, CdS, CdTe and CuInSe, (CIS)[14]. CIS is sensible to the part of the red and infrared spectrum that the amorphous silicon does not absorb[23].

Photovoltaic technology coupled to a RO system is currently commercial. Several pilot plants using electro dialysis systems connected to photovoltaic cells by means of batteries have been implemented[14]. One of them was installed at the Spencer Valley, near Gallup (New Mexico) and was developed by the US Bureau of Reclamation [21,24].

C. *Wind driven water desalination*

Remote areas with potential wind energy resources such as islands can employ wind energy systems to power seawater desalination for fresh water production [2]. The advantage of such systems is a reduced water production cost compared to the costs of transporting the water to the islands or to using conventional fuels as power source. Wind turbines may be classified depending on their nominal power (Pn) as very low power (Pn < 10 kW), low power (Pn < 100 kW), medium power (100 kW <Pn < 0.5 MW) and high power (Pn> 0.5 MW) [25] turbines. For wind desalination systems variety of approaches are possible. First, desalination system and wind turbines are connected to a grid system. In this case, the optimal sizes of the wind turbine system and the desalination system as well as avoided fuel costs are of interest. The second option is based on a more or less direct coupling of the wind turbine(s) and the desalination system. In this case, the desalination system is affected by power variations and interruptions caused by the power source (wind). These power variations, however, have an adverse effect on the performance and component life of certain desalination equipments. Hence, backup systems, such as batteries, diesel generators, or flywheels might be integrated into the system[2].

In 1984 a wind turbine was installed at Los Moriscos (Gran Canaria, Spain) for driving a brackish water desalination plant. It is a 200 m^3/d RO system [26]. In 1993 a wind driven seawater desalination system began operation at Pajara (Fuerteventura Island, Spain). It is a RO plant with a capacity of 56 m3/d driven by a hybrid diesel-wind system[27].

D. *Biomass*

Biomass is any type of organic matter whose origin is a biologic process. It may be used by direct combustion or by transformation on bio- fuels (e.g., methanol, ethanol, hydrogen, oils)[9].The use of biomass in desalination is not in general a promising alternative since organic residues are not normally available in arid regions and growing of biomass requires more fresh water than it could generate in a desalination plant [2].

E. *Geothermal Energy:*

The geothermal energy is not very common in use in comparison to others such as solar (PV or solar thermal collectors) or wind energy, it presents a mature technology which can be used to provide energy for desalination at a competitive cost [2]. Furthermore, and comparatively to other RE technologies, the main advantage of geothermal energy is that the thermal storage is unnecessary, since it is both continuous and predictable [28]. The direct use of geothermal fluid of sufficiently high temperature in connection to thermal desalination technologies is the most interesting option [29]. There are different geothermal energy sources. They may be classified in terms of the measured temperature as low, medium and high. The corresponding thresholds are lower than 1OO”C, between 100°C and 15O”C, and up to 150°C, respectively.

The availability and/or suitability of geothermal energy, and other RE resources, for desalination, are given by[30].

III. ECONOMICS OF DESALINATION

Kaldellis et al. [31] studied the desalinated water production cost for remote islands, by using RES (wind, solar) and RO desalination techniques and according to the results obtained, the maximum water production cost was less than 2.5€/$m^3$for medium-size capacity installations and no more than 3.5€/m^3in very small systems. For wind energy driven desalination units, the cost of fresh water produced can be as low as 1€/m^3[32] but it may reach 5€/m^3[33]. However for a Wind-RO unit with a capacity of 52,500 m^3/day the cost can be lower than 1€/m^3[34]. Fiorenza et al. [35] claim that the water production cost for a PV-RO plant with capacity of 5000 m^3/day is at the range of 1.6€/m^3 (2$/$m^3$), similar to that of Solar Thermal/MEE and approximately 2.5 times higher than that of a conventional system. In Kimolos island, Greece, the use of geothermal energy for a system desalinating 80 $m^3$of brackish water per day costs 2.00€/m^3 of fresh water produced [33]. When solar

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collectors are used for the desalination of seawater, mainly for small units and experimental installations, the cost can be as high as 3.5 to 8€/m^3 [33, 36]. Table 1 summarizes the cost of fresh water when the desalination unit is powered by different energy sources.

Table 1: Type of Energy supply system and cost of water produced [37, 38]

Type of feedwater	Type of energy used	Cost (per m^3)
Brackish	Conventional	0.21€–1.06€ (0.26$–1.33$)
	Photovoltaics	4.50€–10.32€
	Geothermal	2.00€
Seawater	Conventional	0.35€–2.70€
	Wind	1.00€–5.00€
	Photovoltaics	3.14€–9.00€
	Solar collectors	3.50€–8.00€

IV. CONCLUSION

The worlds water needs are day by day increasing due to ever increasing population. The cost of Desalination cost has been decreasing in the last few years over due to technical up gradation. This is also due to the fact that the cost of fossil fuel is also increasing. The Solar, Wind and other renewable technologies that can be used for desalination are rapidly seeing the improved systems day by day. Renewable energy systems offer alternative solutions to decrease the dependency on rapidly decreasing fossil fuels. Renewable energy resources (e.g. solar, hydroelectric, biomass, wind, ocean and geothermal energy) are inexhaustible and offer many environmental benefits compared to conventional energy sources. This paper also reveals about the economics of desalination which shows that when renewable energy sources are used the cost is much higher due to most expensive energy supply systems. This higher cost of desalination can be counterbalanced by the environmental benefits that it offers.

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