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A Review of Renewable Energy Technologies Integrated With Desalination System

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ABSTRACT

Seawater desalination technologies have been developed in large numbers during the last decades to supplement the supply of water in many arid regions of the world. Due to the limitations of high desalination costs, many countries are unable to afford these technologies as a resource for fresh water. However, the energy required to run desalination plants put a constraint for its effective use. The idea behind the use of renewable energy sources is fundamentally attractive and many researches have been done in this area. When the global reserves of fossil fuels are decreasing which results in threatening the long-term sustainability of global economy the only option is the use of Renewable energy which provides a variable and environmental friendly option and national energy security. The integration of renewable resources in desalination and water purification is becoming increasingly attractive. This is justified by the fact that plenty of solar energy is available in the areas of fresh water shortages. In this paper an attempt has been made to present a review, in brief, work of the highlights that have been achieved during the recent years worldwide and the state-of-the-art for most important efforts in the field of desalination by renewable energies, with emphasis on technologies and economics. Renewable energies for use in desalination processes include wind, solar thermal, photovoltaic and geothermal. Many studies of water desalination costs appear regularly in water desalination and renewable energy related publications. Economics of desalination seem to be very much site specific and the cost per cubic meter ranges from installation to installation. The variability in economics exists because the water cost depends upon many factors, most important of which are the desalination method, the level of feed water salinity, the energy source, the capacity of the desalting plant, and other site related factors.

Keywords: desalination technologies, energy, geothermal, renewable, solar

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INTRODUCTION

Water is a basic human right and it is used in the field of agriculture, industries and domestic purpose. Approximately one fourth of mankind is suffering from inadequate supply of fresh water [1]. Owing to the foreseen growth of population worldwide (especially in the developing countries), the above mentioned situation will be more and more critical over the 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 results 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 (Figure 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 (Figure 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 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 make 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].

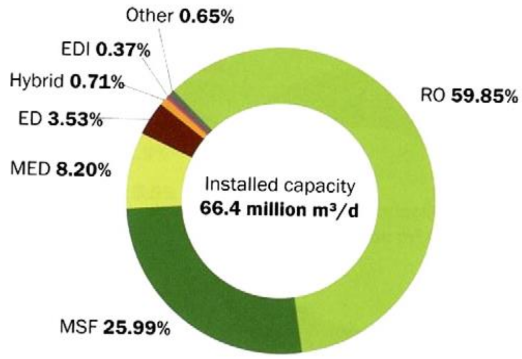

Fig. 1. *Installed desalination capacities.*

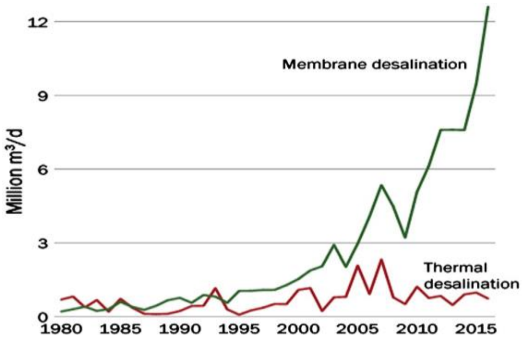

Fig. 2. *Forecast desalination capacities.*

RENEWABLE ENERGY COUPLING TO DESALTING TECHNOLOGIES

Renewable energies for use in desalination processes include solar thermal, wind, photovoltaic, Biomass and geothermal. Desalination systems driven by renewable energy fall into two categories. The first category includes distillation processes driven by heat produced by the renewable energy systems, while the second includes membrane and distillation processes driven 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 Figure 3) [15]. PV is particularly good for small applications in sunny areas. For large units, wind energy may be more attractive as it does not require anything like as much ground. This is often the case on islands where there is a good wind regime and often very limited flat ground. With distillation processes, large sizes are more attractive due to the relatively high heat loses from small units.

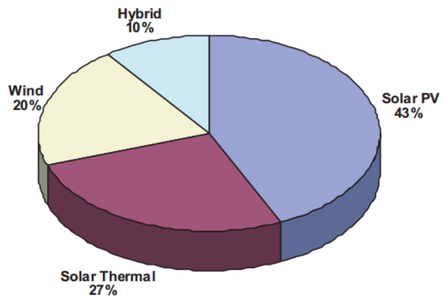

Fig. 3. *Energy sources for desalination.*

The interface between the renewable energy system and the desalination system is met at the place/subsystem where the energy generated 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. Figure 4 shows the possible combinations [16, 17].

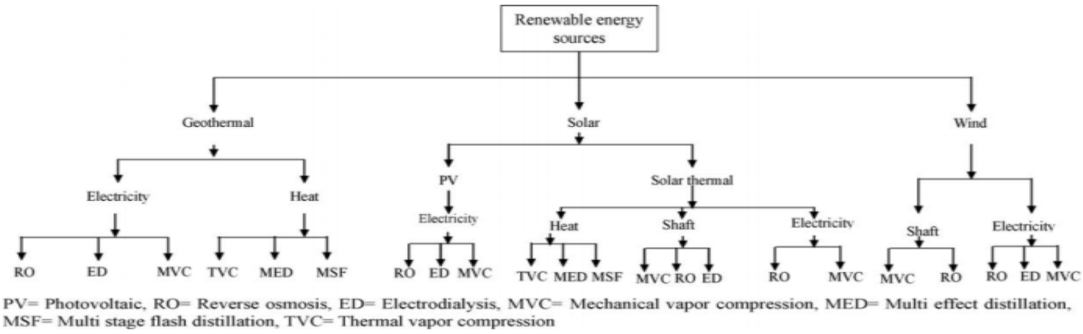

Fig. 4. *Combination technologies of RES and desalination methods.*

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 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 main challenge of solar thermal power engineering and 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 (Figure 5) [2].

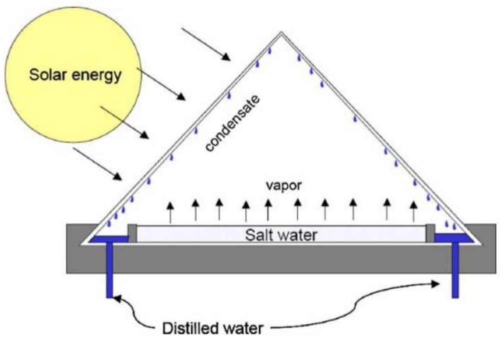

Fig. 5. *The basic design of a solar distillation unit [22].*

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].

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 equipment. 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].

Energy From 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].

Geothermal Energy

Also, even though geothermal energy is not as common in use 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].

ECONOMIES 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 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 feed water	Type of energy used	Cost (per m^3)
Brackish	Conventional	0.21€-1.06€
		0.26USD-1.33USD
	Photovoltaics	4.50€ -10.32€
	Geothermal	2.00€
Seawater	Conventional	0.35€-2.70€
	Wind	1.0€-5.00€
	Photovoltaics	3.14€-9.00€
	Solar Collectors	3.50€-8.00€

CONCLUSION

The worlds water needs are increasing intensely. Desalination cost has decreased over the last years due to technical improvements and learning in a world of increasing fossil fuel prices. The Solar, Wind and other renewable technologies that can be used for desalination are rapidly. 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. 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. However, this cost is counterbalanced by the environmental benefits.

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