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REVIEW ARTICLE

EFFECTIVE UTILISATION OF WAVE ENERGY FOR DESALINATION PLANTS-A REVIEW

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ABSTRACT

The growing scarcity of freshwater is driving the implementation of desalination on an increasingly large scale. However, the energy required to run desalination plants remains a drawback. The idea of using renewable energy sources is fundamentally attractive and many studies have been done in this area. Membrane processes are also gaining much interest for their scaled-up ability and their economic feasibility. This article presents the effective utilisation of wave energy to run the desalination plants by selecting the most promising wave energy converters, which yields high output.

INTRODUCTION

The excessive growth in population, together with growth in industrial and agricultural activities, has led to the exploitation of available water resources and pollution of fresh water resources [1].Transportation of water between different areas, reusing of waste water in industry and agriculture and improving management of water resource are the possible ways to solve the water shortage problem depending on location. Desalination of seawater or brackish water has become the alternative solution for the water shortage problem across the world [2]. Fossil energy sources are depleted due to pollution and gas emissions that occurred in the environment, obviously we look for the alternative energy sources as a cleaner and safer way for providing fresh water by desalination. The implementation of desalination plants is increasing on a large scale to face the consequences of the growing scarcity of freshwater.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. Compared to conventional energy sources, the renewable energy sources offer many environmental benefits and eco-friendly [3-6]. Based on the applications, renewable energy has its own advantages and almost none of them release any gaseous pollutants during operation. Among renewable energy sources wave power is the most promising one.

Wave power refers to the energy of ocean surface waves and the capture of that energy to do useful work.

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Sea waves are a very promising energy carrier among renewable power sources, since they are able to manifest an enormous amount of energy resources in almost all geographical regions. The global theoretical energy from waves corresponds to 8x106 TWh/year, which is about 100 times the total hydroelectricity generation of the whole planet. To produce this energy using fossil fuels it would result an emission of 2 millions of tons of CO2. This means that wave energy could contribute heavily for the attenuation of pollutant gases in the atmosphere. The global wave resource due to wave energy is roughly 2 TW and Europe represents about 320 GW, which is about 16% of the total resource. However, for various reasons, it is estimated that only 10 to 15% can be converted into electrical energy, which is a vast source of energy, able to feed the present all world. Eventually, wave energy could make a major contribution by yielding as much as 120 TWh/year for Europe and perhaps three times that level worldwide. The ocean is a true store of renewable energy [7].

Desalination technologies

Seawater desalination technologies and processes are mainly classified into two major groups: thermal and membrane desalination. Beside that there is ion exchange and evaporation so on as shown in Fig.1.Thermal desalination includes multi-stage flash (MSF), multi-effect distillation (MED), vapor compression (VC) and membrane distillation (MD), and so on. In the membrane desalination, the reverse osmosis (RO) and electro-dialysis (ED) are technologies used frequently. The dominant processes are MSF and RO, the MSF process represents more than 93% of the thermal process production, while RO process represents more than 88% of membrane processes production [8,9].

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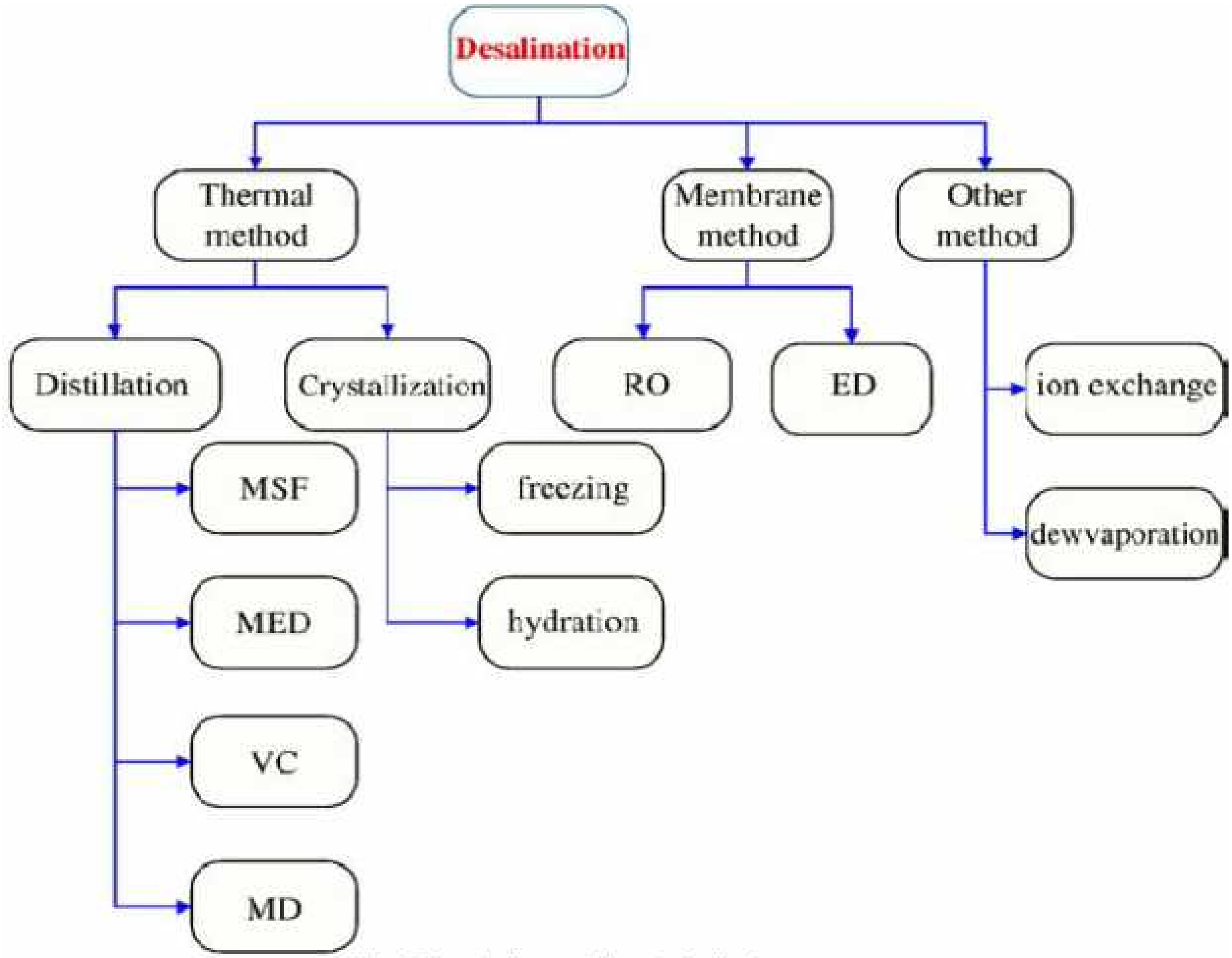

Fig. 1 Schematic diagram of the main desalination processes.

Membrane desalination

The reverse osmosis (RO) and electro-dialysis (ED) are the main technologies in membrane desalination as shown in the Fig.1. The RO process is based on separation rather than distillation although membrane distillation is carried out. A schematic diagram of RO plantis shown in Fig.2. The seawater passing through the modules is not completely desalted, part is rejected as brine. The mechanical energy of brine is used in energy recovery system before entering into the sea again [10], which achieved a significant energy saving. Reverse osmosis has more extensive application in the desalination process of water treatment. Advanced RO facilities recently developed for energy recovery or minimizing RO energy consumption using the pressure exchange and system design of operate condition optimization technology. The new high rejection and high flow membranes made conversions to 55–60% economically feasible. This can be ascribed to the permitted operating at high pressures (up to 80–90bars). Hydraulic efficiency of this type of equipment ranged from 90–94%. All of these technologies have resulted in minimizing RO system capital and operating costs [11,12].

Alternative energies in seawater desalination

Enormous amount of energy is required to desalt the seawater or brackish water in large quantity in which majority amount of energy is obtained from fossil fuels. Environmental studies related to desalination technologies are being conducted but not well known yet [13]. Renewable energy sources such as solar, wind, ocean and nuclear energy is a desirable option to power the desalination processes [14]. For the past few years, several alternative desalination systems are competitive with conventional energy desalination system, providing safe and clean drinking water efficiently in an environment [15, 16, 17].The basic motivation for referring wave energy here is to propose an alternative way of technical options, based on the use of wave energy.

Reverse osmosis

Reverse osmosis process is one of the most efficient desalination technology requires about 3-10kWh of electric energy per m^3 of fresh water produced from seawater [18]. It is a pressure driven process that separates two solutions with different concentrations across a semi-permeable membrane [19].

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principle, be coupled to electrically-driven desalination plant, either with or without connection to the local electricity grid.

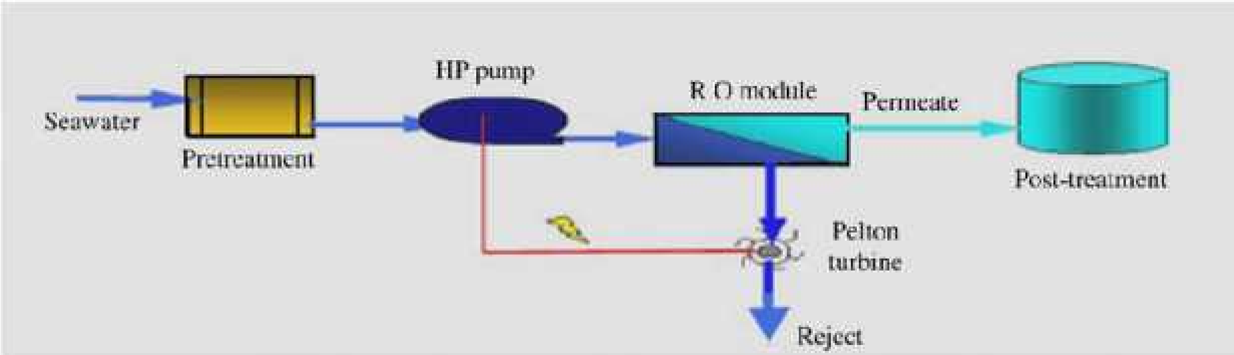

Fig. 2 RO process [11].

The rate at which fresh water crosses the membrane is proportional to the pressure differential that exceeds the natural osmotic pressure differential. The membrane itself represents a major pressure differential to the flow of fresh water. The major energy requirement is for the initial pressurization of the feed water. For brackish water desalination the operating pressures range from 15 to 30 bar, and for seawater desalination from 55 to 70 bar [20]. As fresh water permeates across the membrane, the feed water becomes more and more concentrated. There is a limit to the amount of fresh water that can be recovered from the feed without causing fouling. Seawater RO plants have recoveries from 25 to 45%, while brackish water RO plants have recovery rates as high as 90%. RO system major components include membrane modules, high-pressure pumps, power plant, and energy recovery devices as needed. Two major factors controlling the energy requirements of an RO system are membrane properties and salinity of the feed water. Higher water salinity requires more energy to overcome the osmotic pressure, where the RO system needs only mechanical power to raise the pressure of feed water.

Pre-treatment of seawater feeding RO membranes is an important one in designing RO desalination plants [21]. Depending on several parameters which influence the choice of the pretreatment like dissolved organic carbon, SDI, turbidity, algae content and their evolution during the seasons, and temperature, the pre-treatment can comprise different technologies, such as conventional pre-treatment (i.e. ballasted sedimentation, air flotation, dual-media filtration, monomedia filtration, double stage filtration) or advanced technologies including membranes coupled with a conventional process [22,23]. The use of an adapted pre-treatment minimizes the fouling problems and can provide good protection of the membranes and a longer lifetime.

RO and wave energy

Almost all the works on wave energy conversion have focused on electricity production [24].The conversion principle used in wave energy conversion can be coupled to electrically-driven desalination plant, either connected to the local electricity grid. Most of the works on wave energy conversion have focused on electricity production [24]. Any such converter could, in

Various concepts have associated wave energy converter and RO. The first reported technology (Delbuoy) used oscillating buoys to drive pistons pumps anchored to the seabed [25]. These pumps fed seawater to submerged RO modules. Mathematical modelling, wave tanking testing and sea trials in Puerto Rico were conducted [24]. A second technology consisting of a three section hinged barge was developed in the Shannon Estuary (Ireland) [26]. The two oscillating arms of the floating barge are attached symmetrically to a central section, which is inhibited from pitching by an underslung inertial damping plate. Large forces are therefore developed between the arms and the centre section. These forces are harnessed by means of pistons, pumping either hydraulic oil, for conversion into electrical power, or seawater for feeding RO units. The author concluded that this system may be primarily developed to produce potable water for remote locations. Another technology, the oscillating water column device, was installed at Vizhinjam, India in 1990 [27]. The device was constructed on a concrete caisson connected by a pier to the shore. It works on the principle of a column of air being compressed and decompressed with the rise and fall of the waves. A turbine extracts energy from the air column. The desalination plant can be run using either the supply from wave power or, during low wave conditions, by electricity board supply or a diesel generator to ensure a continuous supply of fresh water. The plant delivers between 4 and 10 m3/d of freshwater, depending on the period of operation. The Vizhinjam system may be envisaged as a solution for small coastal communities.

Sawyer and Maratos [28] propose another concept that uses the water hammer effect to generate large intermittent pressures, by means of a valve that opens and shuts at the end of the pipe. The pressure developed depends on the compressibility of the water and the elasticity of the pipe wall. The authors show that it is theoretically feasible to use the water hammer effect to develop pressures sufficient to drive RO. The technology is very similar to the hydro-ram widely used to lift irrigation water from rivers, although hydro-rams usually generate lower pressures than those required for RO. An economical feasibility study of the concept was presented and costs were shown to be potentially favourable compared

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to conventional RO plant. Very recently, Folley *et al*. [29] proposed a desalination plant consisting of RO membranes together with a pressure exchanger-intensifier for energy recovery.

A numerical model of the combined wave-power and desalination plant shows that it is possible to supply the desalination plant with sea-water directly pressurised by the wave energy converter, eliminating the cost and energy electricity and back to pressurised water. Other projects on water desalination associating RO and wave energy should probably be available in the next future, as wave energy is gaining in popularity. A main challenge will be again the economics of the plants.

Electro dialysis

Electro dialysis (ED) process is a commercial one used for desalinating brackish water for small and medium scale processes [30]. The process utilizes an electric field to remove the salt ions in the brackish water which passes between pairs of cation-exchange and anion-exchange membranes. The cations migrate from the brackish water towards the negative electrode through the cation-exchange membranes which allow only cations to pass. On the other hand, the anions migrate towards the anode through the anion exchange membranes. In a conventional process, a large number of alternating cation-exchange and anion-exchange membranes are stacked together, separated by flow spacers which are plastic sheets that allow the passage of water. The streams in alternating flow spacers are a sequence of diluted and concentrated water which flow in parallel to each other. To prevent scaling, the process utilizes inverters which reverse the polarity of the electric field about every 20 min. This process is called electro dialysis reversal (EDR).

Wave energy converters

SDE Device

The SDE wave power device is an offshore wave energy converter of the floating type, developed by S.D.E. Ltd in Israel. The device has a raft which looks like a segmented boat and takes advantage of both as the kinetic and potential energy of a wave to generate hydraulic pressure (The system creates pressurization of ocean water, which in turn causes pressure on hydraulic oil), the raft has two or three pontoons connected by a hinge. As the hinge bends and flexes, wave energy is translated by hydraulic jacks, which are connected to the hinges, into mechanical or hydraulic energy. The hydraulic device can drive a turbine and generator to produce electricity. The system takes advantage of the wave. s speed, height, depth, rise and fall, and the flow beneath the approaching wave, thus producing energy more efficiently and cheaper than both other sea-wave and conventional technologies which require vast amounts of land space for their ash removal facilities, coal storage space, chimneys, furnaces, and coolers [31]. A number of models have been built and tested and a 40 kW demonstration device has operated successfully (Fig.3).

Fig.3 SDE Device

CETO Float

Carnegie Wave Energy's CETO uses a submerged buoyant float connected via a flexible mooring line to a simple pump (Fig. 4), which is moored to the sea bed using a gravity anchor or steel pile. The float motion with respect to the pump is used to pressurize the seawater. This pressurized water is collected and transmitted to the shore to drive a Pelton turbine for current generation [32].

Fig.4 CETO Float and Pump Unit prior to deployment

Archemedes Wave Swing

Wave Swing that consists of a cylindrical, air-filled chamber in which the oscillating motion of a .floater. (an air-filled chamber which ensures buoyancy).Utilizing a flywheel effect, with respect to the bottom fixed basement, is directly transmitted to a linear electrical generator [33]. The up and down movement of the floater is caused by the change of its buoyancy due to the alternate compression and decompression of the air inside it as waves pass (Fig. 5) [34].

Pelamis Device

Pelamis is a freely floating hinged contour device. The device looks like a snake, floating on the ocean surface. The device consists of 4 tubular sections, connected by 3hinges [33].

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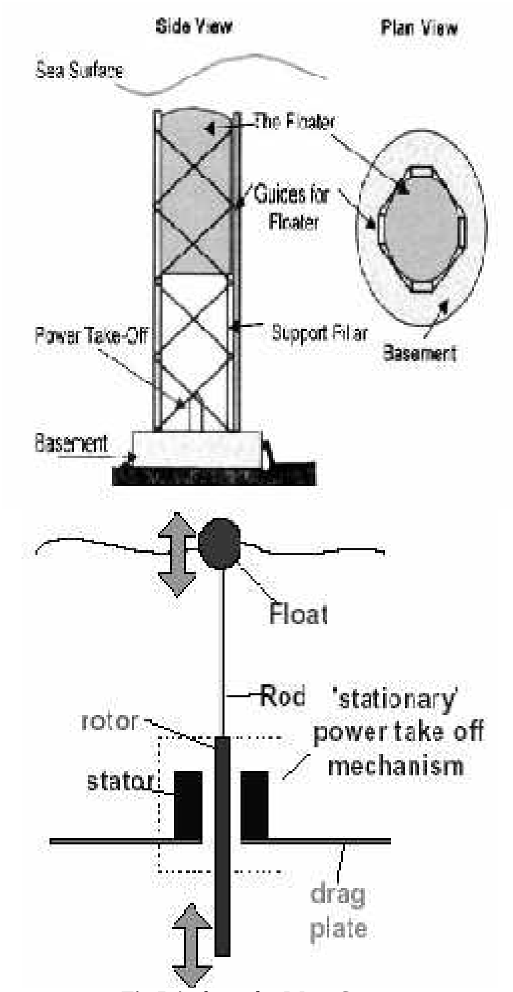

Fig.5 Archemedes Wave Swing

The 4 sections move relative to each other and the hinges convert this motion by means of a digitally controlled hydraulic power conversion system (Fig.6).Each hinge of the device contains its own hydraulic power take off. Each power take off contains a total of 3 hydraulic rams, which convert the motions into hydraulic pressure. Using accumulators' generator sets, the hydraulic power is generating electricity [34].

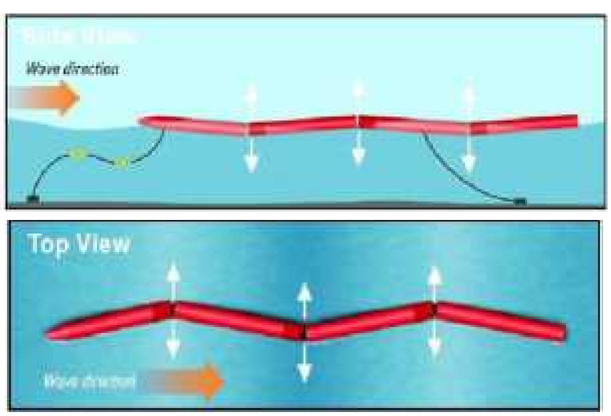

Fig.6 Pelamis device.

The Wave Dragon

The Wave Dragon is an offshore wave energy converter. Both the kinetic and the potential energy of the waves are used to generate electric power. Two arms (wave reflectors) bundle the waves towards a double curved ramp, the energy stored in the waves lets the water flow over this ramp into a basin. As the basin water level lies above sea level, the water caught in the reservoir can be used to operate propeller turbines [33].

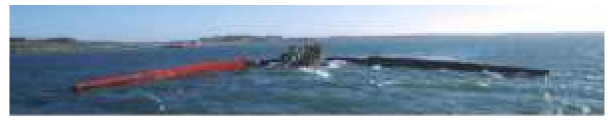

Fig.7 Wave Dragon prototype

One Wave Dragon unit produces electricity corresponding to:

- In a 24kW/m wave climate = 12 GWh/year
- In a 36kW/m wave climate = 20 GWh/year
- In a 48kW/m wave climate = 35 GWh/year
- In a 60kW/m wave climate = 43 GWh/year
- In a 72kW/m wave climate = 52 GWh/year
- In a 24kW/m wave climate = 12 GWh/year

CONCLUSION

Many wave energy converters are developed till now to produce electricity and also to fulfill the requirements of people and industrial applications. Desalination plants face problems due to lack of power supply, to overcome the above problem renewable energy sources is used. Wave power is the most promising one at present scenario, in this paper various wave converters are discussed which gives high output compared to other converters. These wave energy converters can be employed with desalination plants to provide fresh water to the society.

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