Water Water everywhere...

Desalination Powered by Renewable Energy Sources

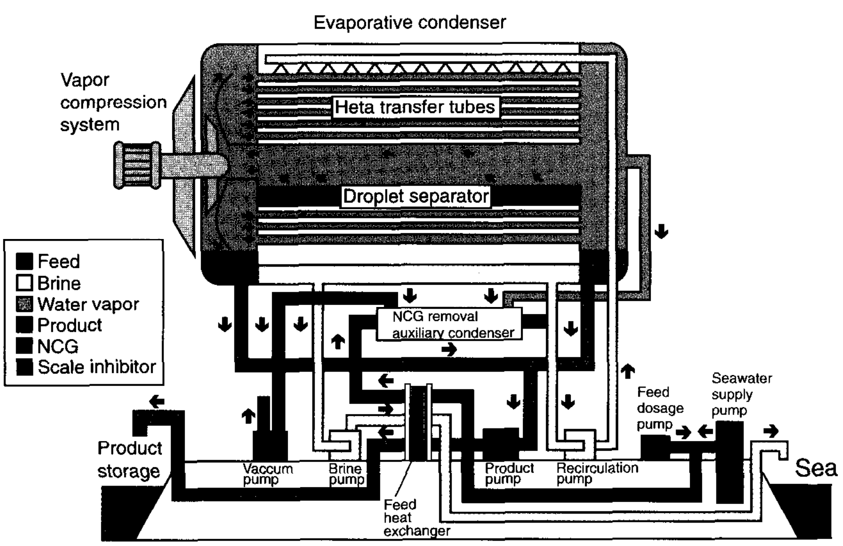

Figure 1. Mechanical Vapour Compression

The reliable and safe provision of fresh water is turning out to be one of the major constraints, which many parts of the world are currently facing. The historical approach of developing new water sources to meet the rapidly increasing demand has reached its limits because inexpensive resources have already been developed and new ones are more expensive.

Desalination, a mature and reliable technology, is becoming a competitive alternative to traditional supply options, although the high equipment and energy costs inhibit its wide market penetration.

The oil rich Middle East, where oil or its associated gas is used to drive desalination plants, relies on desalination to meet over 40% of the domestic and industrial water consumption (Saudi Arabia, Oman, Bahrain, UAE, Kuwait)[1].

Many other arid areas of the world have neither the cash nor the indigenous fossil fuel resources to follow a similar development.

These areas, however, often have a significant Renewable Energy (RE) potential, which can be effectively used to power desalination plants. D. Voivontas, D.Assimacopoulos*, R. Morris, and A. Zervos from the National Technical University of Athens, Greece review the current role that RE is playing in the desalination industry.

Desalination processes

Desalination can be classified into phase-change and single-phase processes. The most commonly used phase-change processes are Multi-Stage Flash (MSF), Multi Effect Distillation (MED), Vapour compression (VC) and Solar Distillation. Highly developed single-phase processes are Reverse Osmosis (RO) and Electrodialysis (ED), which use membranes to separate impurities from water[2].

Multi-stage Flash

In the MSF process seawater is fed through a series of heat exchangers, raising its temperature to the top brine temperature. The water then enters the first recovery stage, which operates below its saturation pressure, producing vapour. The vapour passes through the heat exchanger where it condenses, giving up its energy to heat the upcoming brine flow.

This process of decompression, flashing and condensation is then repeated all the way down the plant by both the brine and distillate streams as they flow through the subsequent stages, which are at successively lower pressures.

In large plants, some of the brine is recirculated and mixed with the seawater in the heat rejection section, improving the process efficiency. For small plants, the process is simplified considerably by removing the heat rejection section at the expense of process efficiency.

Multi-Effect Distillation

In the MED process, the incoming seawater is heated to boiling point into the first effect. Some of the water evaporates and the resultant vapour is used to heat the liquid, which passes from the first effect to the second. The feed to the second effect flashes as it enters the second effect because it is at a slightly lower pressure. This process continues down the successive stages of the plant. In the MED process most of the distillate is produced through evaporation while in the MSF process distillate is produced through flashing.

Vapour Compression

In VC the inlet feed is initially pre-heated by the blowdown and product streams and may be further warmed by thermal rejection from the compressor. Then it is evaporated and passed to the compressor where its pressure is raised and condenses. There are two vapour compression processes depending on the type of the compressor: Mechanical Vapour Compression (Figure 1) and Thermal Vapour Compression (Figure 2). Fairly large (5,000 m^3/d) TVC plants are now available but MVC plants have size limitations due to compressor capacities.

Solar Distillation

Solar Distillation is the simplest desalination process and is based on the greenhouse effect. Glass and other transparent materials have the property of transmitting incident short-wave solar radiation but do not transmit infrared radiation. Incident short-wave solar radiation passes though the glass into the still where it is trapped and evaporates the water (Figure 3), which is then condensed on the glass surface and collected as distillate. The equipment is simple to construct and operate but a large amount of space is required.

Reverse Osmosis

In the RO process (Figure 4), the feed is pressurised by a high-pressure pump and is made to flow across a semi-permeable membrane. The feed pressure should exceed the osmotic pressure of the salted water in order for the separation to take place. Typical pressures for seawater range from 50 to 80 atmospheres. Water passes through the membrane, which removes the majority of the dissolved solids, and the rejected salt emerges from the membrane modules as a concentrated reject stream, still at high pressure. In large plants, the reject brine pressure energy is recovered in a turbine or pressure exchanger.

Table 1. Energy consumption of the main desalination processes

Feed Water	Desalination process	Thermal energy(KJ/kg)	Electrical energy kWh/m^3
	MSF	190 – 290	4 – 6
	MED	150 – 290	2,5 – 3
Seawater	VC	–	8 – 12
	RO with energy recovery	– –	4-6 4-6
	RO without energy recovery	–	13-15
Brackish water	RO	–	1 – 3
(1500-3500 ppm TDS)	ED	–	1.5 – 4

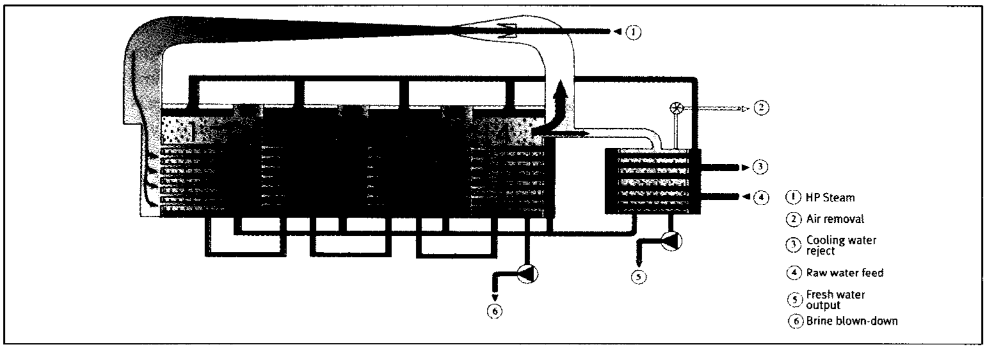

Figure 2 Four-effect thermo-compression

Electrodialysis (ED)

In ED (Figure 5), feed water passes between a pair of membranes (an anion permeable membrane and a cation permeable membrane) in an electrical field applied across the membranes. Impurities are transported across the membranes and low salinity product water remains between the membranes. Between each pair of membranes a spacer sheet is placed in order to permit the water flow along the face of the membrane and to induce a degree of turbulence. An improved ED process, known as electrodialysis reversal (EDR), consists of periodically changing the polarity of the membrane electrodes alleviating the need for continuous chemical addition.

Desalination and renewable energy sources

All RE sources (RES) could be indirectly connected to a desalination plant through the electrical grid. However, direct connection of renewable energy to low or medium capacity desalination plants is more convenient and in most remote arid regions more economically viable. Coupling RE technologies with desalination processes is a technical challenge with most of the problems being associated to the intermittent nature of RES and the total system cost. To solve the matching problem, engineers either follow the power side management or demand side management option. In power side management, hybrid power plants that combine more than one energy source and/or energy storage system balance the power input to the desalination. In demand side management, the desalination unit operates only when adequate power is available from RES provided that the selected desalination technology operates satisfactorily with regular shutdowns. The most common combinations of renewable energy sources and desalination processes are depicted in Figure 6.

WT-RO (Wind powered-Reverse Osmosis) is one of the most challenging options in terms of matching the power demand of the reverse osmosis plant with the highly variable power output of the wind

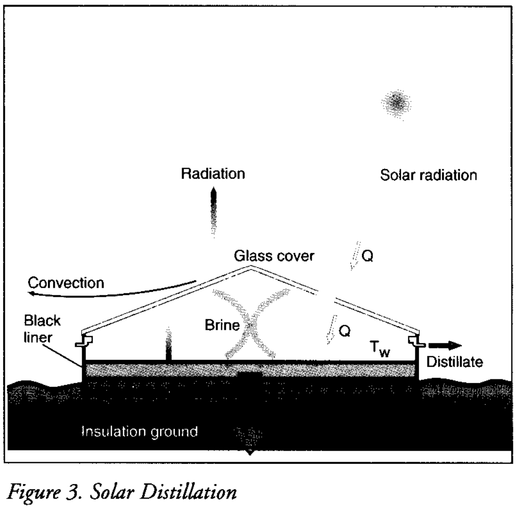

Figure 3. Solar Distillation

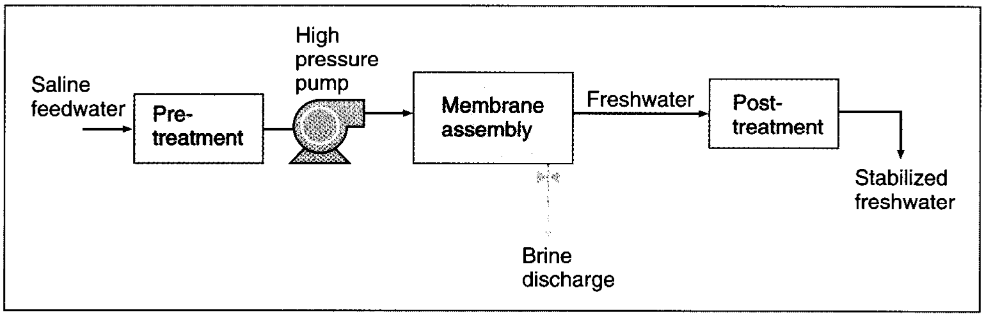

Figure 4. Simple Reverse Osmosis Plant

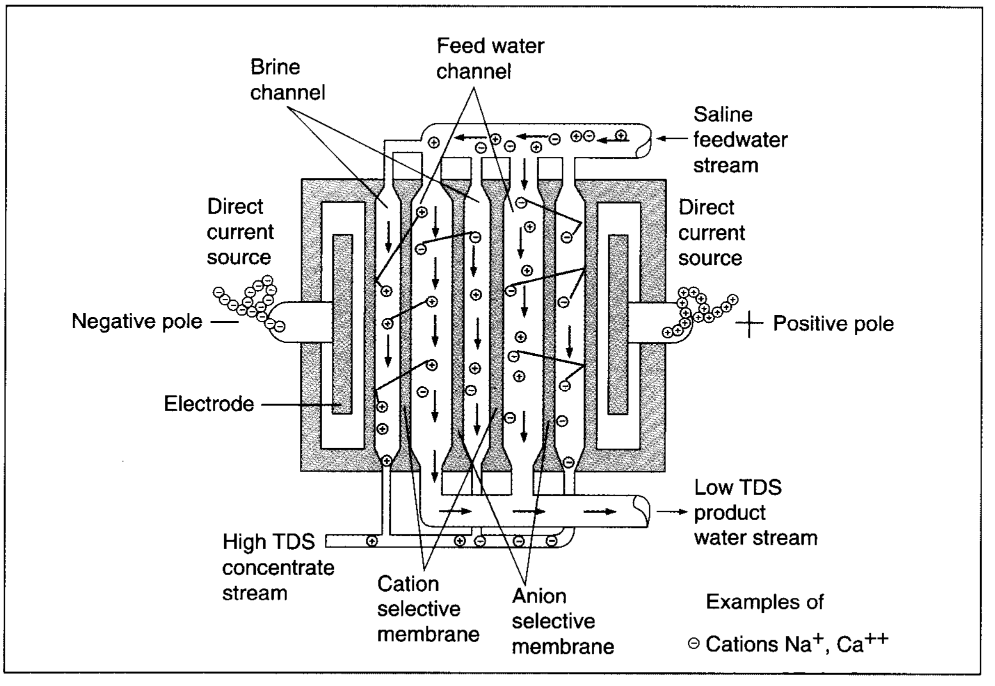

Figure 5. Electrodialysis Process

energy converters. However, the energy production cost of wind power that is becoming competitive to utility grid electricity and the low cost and modularity of reverse osmosis technology make this combination highly preferable for low or medium capacity plants.

PV-RO (Photovoltaic powered-Reverse Osmosis) is clearly the favoured desalination combination for small stand-alone systems. Since both technologies are highly mature and reliable these systems require minimum maintenance and are especially suited for remote areas.

Distillation methods require large amounts of thermal energy that can be provided from geothermal or solar energy. Table 1 presents typical energy consumptions of the most common desalination processes.

Identification of the most appropriate combination depends on site-specific parameters:

- **Plant capacity.**
  MSF and MED plants are typically used for large-scale plants due to economies of scale, MVC and TVC plants are usually used for low and medium scale plants and membrane processes can be used for all capacities. Solar energy powered plants are typically of low to medium size due to large area requirements. Wind energy powered plants can be of higher capacities. Geothermal heat could be used to power thermal desalination processes in the entire range of capacities.
- **Renewable energy availability.**
  The renewable energy that can be produced at the site of installation affects the energy cost, which in turn determines the viability of the desalination process.
- **Feed water quality.**
  Distillation methods tend to be used for the treatment of seawater since their energy consumption is only loosely related to the feed salinity. RO also can be used for the entire range of salinities from brackish water to seawater due to significant improvements in membrane technology. ED is only used for brackish water because energy consumption is directly related to the salinity of the feed water.
- **Product water quality.**
  In general, distillation processes are used for the production of distillate water (less than 10 ppm TDS for industrial uses) and membrane processes are used for potable water (in the range of 300-500 ppm TDS).
- **Process simplicity.**
  All desalination processes require some operating expertise. PV is the renewable energy technology with the lowest operation and maintenance requirements and is especially suited for remote small-scale applications.
- **Water production cost.**
  The capital, operation and maintenance costs of both the RE and desalination units should be carefully evaluated. In general, distillation methods have higher capital and operating costs than membrane methods while the energy production cost from renewable energy sources depends on the available potential in the installation site.

Success Stories and Policy Priorities

Current research activities in the field of renewable energy powered desalination systems focus on the assessment of market potential, the development of demonstration plants and the improvement of the interface between RE and desalination. Sustainable water resources management policies are, however, the major instrument for boosting the development of systems and markets.

Assessment of the market potential

Project MedCoDesal[2], funded by the DG XII of the European Commission, pointed out that a significant market potential exists for the development of renewable energy powered desalination plants in Eastern Mediterranean Countries (Cyprus, Egypt, Israel, Lebanon and Palestine).

The analysis of seasonal and spatial variations in water supply and demand indicated that water shortage problems on national or regional levels exist or are expected to appear in the near future. A similar analysis[3] in Greece identified the Aegean Islands as the most arid regions of the country.

Niche markets where renewable energy powered desalination plants are currently emerging as viable water supply options, even with purely economic criteria, have the following characteristics:

- Lack of exploitable surface or groundwater resources

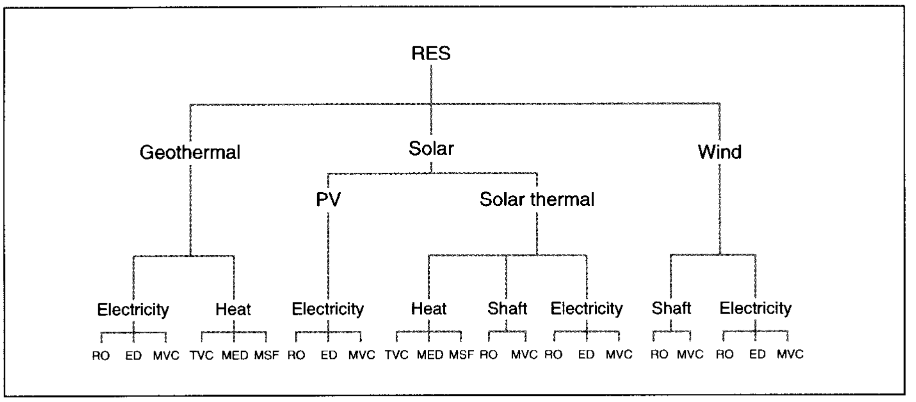

Figure 6. Technological options[5]

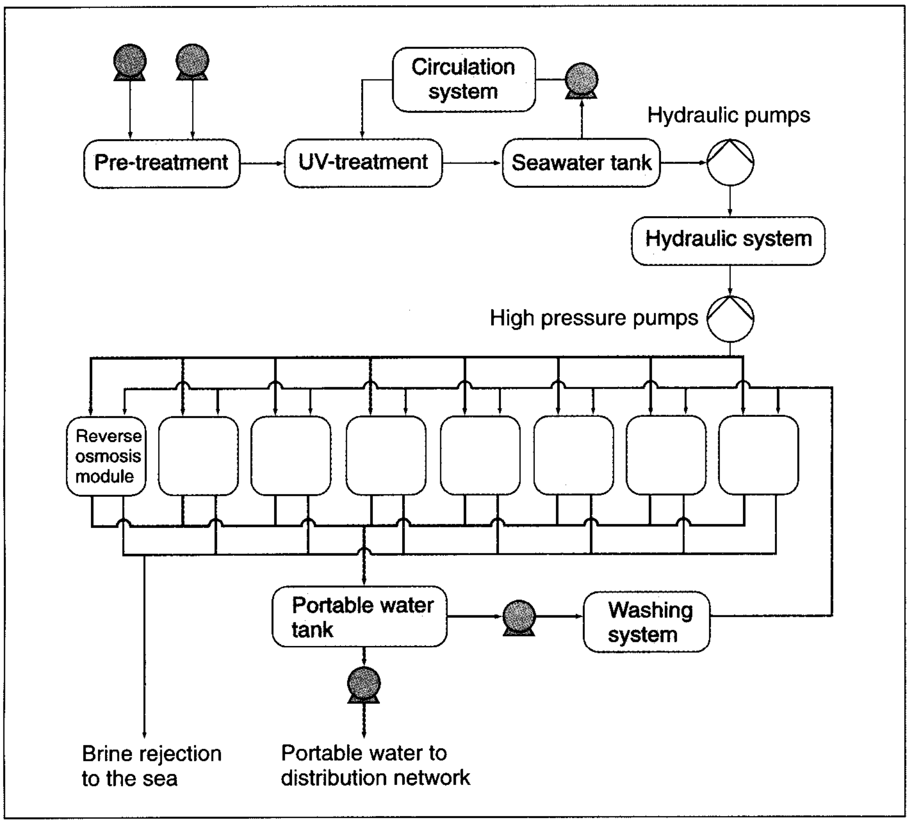

Figure 7. Siros RO plant configuration

- High water prices especially for the domestic and tourism sectors
- High renewable energy potential that leads to competitive energy production costs compared to fossil fuels

Demonstration plant in Syros, Greece

In 1998 a wind driven reverse osmosis plant was built at Syros, an Aegean Island in Greece, partly funded by DG XII of the European Commission[4]. Figure 7 presents the reverse osmosis plant configuration. The wind turbine and the reverse osmosis plant are installed on two different sites some 1.5 km apart.

The wind turbine is erected on a hilltop to get maximum wind power and is connected via a medium voltage transmission line to the reverse osmosis plant, which is situated on the coast. Power from the wind turbine is buffered in the energy storage system that includes a diesel generator, batteries and a flywheel generator. The output is fed into the reverse osmosis unit and electric grid.

The reverse osmosis unit contains 8 parallel reverse osmosis modules, which allows the capacity of the system to vary from 60 – 900 m^3/day according to available wind energy.

The maximum power consumption is 200 kW. The Syros plant is one of the largest RE powered units revealing the potential of such systems to supply entire communities. The plant operation has demonstrated that the novel concepts on energy recovery and energy management are soundly based.

Policy implications

The inherent environmental benefits from RE use as a substitute to fossil fuels is their main advantage and represents the major driving force behind the attractiveness of RE driven desalination plants.

Although existing water policies in arid and semi-arid regions vary substantially, the acute water shortage problems require the adoption of a common direction towards sustainable water management practices. In this framework, desalination is expected to become a flexible and reliable supply side option. RE sources represent the most economical alternative to power desalination plants in arid and isolated regions such as remote villages and islands where neither the electrical grid exists nor indigenous fossil fuels are available. Appropriate investment incentives would expand markets where RE powered desalination provides a competitive option.

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