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Seawater Desalination Processes

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Abstract

All over the world, access to potable water to the people are narrowing down day by day. Most of the human diseases are due to polluted or non-purified water resources. Even today, under developed countries and developing countries face a huge water scarcity. The groundwater quality problems present today are caused by contamination and by overexploitation, or by combination of both. The only nearly inexhaustible sources of water are the oceans, which, however, are of high salinity. It would be feasible to address the water-shortage problem with seawater desalination; however, the separation of salts from seawater requires large amounts of energy. Conventional and non-conventional methods are used to distil the water. Both direct and indirect collection systems are included. The representative example of direct collection systems is the solar still. Indirect collection systems employ two subsystems; one for the collection of renewable energy and one for desalination. For this purpose, standard renewable energy and desalination systems are most often employed. Only industrially-tested desalination systems are included in this paper and they comprise the phase change processes, which include the multistage flash, multiple effect boiling and vapour compression and membrane processes, which include reverse osmosis and electrodialysis. The paper also includes a review of various systems that use renewable energy sources for desalination. The paper also includes a review of various systems, characteristics of the major desalination system and REDS Technology Implementation.

Keywords: Desalination; Renewable energy; solar energy; Wind energy; Geothermal energy

Introduction

Water and energy are two of the most important topics on the international environment and development agenda. These two critical resources are inextricably and reciprocally linked; the production of energy requires large volumes of water while the treatment and distribution of water is equally dependent upon readily available, low-cost energy.

The existing water resources are diminishing due to

- Progressive increase in the demand of water for irrigation, rapid industrialization, population growth and improving life standards.
- due to unequal distribution of rain water and occasional drought
- excessive exploitation of ground water sources and its insufficient recharge
- Deterioration of water quality due to the discharge of domestic and industrial effluents without adequate treatment.

This is resulting into water stress/ scarcity.

The only nearly inexhaustible sources of water are the oceans. Their main drawback, however, is their high salinity. According to World Health Organization (WHO), the permissible limit of salinity in water is 500 parts per million (ppm) and for special cases up to 1000 ppm, while most of the water available on earth has salinity up to 10,000 ppm, and seawater normally has salinity in the range of 35,000– 45,000 ppm in the form of total dissolved salts [1].

The purpose of a desalination system is to clean or purify brackish water or seawater and supply water with total dissolved solids within the permissible limit of 500 ppm or less. . Many countries in the Middle East, because of oil income, have enough money to invest in and run desalination equipment. . It has been estimated by Kalogeria [2] that the production of 1000 m3 per day of freshwater requires 10,000 tons of oil per year.

The dramatic increase of desalinated water supply will create a series of problems, the most significant of which are those related to energy consumption and environmental pollution caused by the use of fossil fuels. Fortunately, there are many parts of the world that are short of water but have exploitable renewable sources of energy that could be used to drive desalination processes. This paper presents a description of the various methods used for seawater desalination. Special attention is given to the use of renewable energy systems in desalination. These include solar thermal collectors, solar ponds, photovoltaic, wind turbines and geothermal energy.

Not all the combinations of RES driven desalination systems are considered to be suitable for practical applications. The different parameters affected like geographical conditions, topography of the site, capacity and type of energy available in low cost, availability of local infrastructures (including grid electricity), plant size and feed water salinity. General selection criteria may include robustness, simplicity of operation, low maintenance, compact size, easy transportation to site, simple pre-treatment and intake system to ensure proper operation and endurance of a plant at the often difficult conditions of the remote areas.

Desalination

Desalination refers to the process by which pure water is recovered from saline water using different forms of energy. Saline water is classified as either brackish water or seawater depending on the salinity and water source. Desalination produces two streams - freshwater and a more concentrated stream (brine).
Desalination systems fall into two main categories:
(i) phase-change or thermal processes
(ii) Membrane or single-phase processes

Table 1. Desalination Process

Driving Power	Process	Phase change process	Membrane Process
Thermal	Evaporation	Direct 1. Solar still Indirect 1.Multi stage flashing(MSF) 2.Multi effect distillation (MED) 3.Multi effect Humidification (MEH) 4. Thermal Vapour Compression (TVC)	
	Crystallization	Freezing	
	Filtration		Membrane Distillation(MD)
Electrical	Evaporation	MVC	1.Electro Dialysis(ED) 2.Reverse Osmosis(RO)
Chemical	Exchange	Ion exchange	

Thermal Processes

In the phase-change or thermal processes, the distillation of seawater is achieved by utilizing a thermal energy source. Water is heated and producing water vapour that in turn condenses to form distilled water. The thermal energy may be obtained from a conventional fossil-fuel source, or from a renewable energy sources such as nuclear energy, geothermal energy, and solar pond.

Membrane Processes

In the single phase or membrane process, the distillation of seawater is achieved by utilizing electricity. The electricity may be obtained solar or wind energy, which is used to drive the plant.
Solar energy can directly or indirectly be harnessed for desalination.

Direct solar desalination:

Collection systems that use solar energy to produce distillate directly in the solar collector are called direct collection systems. Solar still is direct solar desalination system.

Indirect solar desalination

Indirect solar desalination methods involve two separate systems:

A renewable energy collector (solar collector, PV, wind turbine, etc.) and a plant for transforming the collected energy to fresh water. Energy is used either to generate the heat required for desalination and/or to generate electricity that is used to provide the required electric power for conventional desalination plants such as multi-effect (ME), multi-stage flash (MSF) or reverse osmosis (RO) systems.

Thermal Desalination Processes

Multi-stage flash evaporation/distillation (MSF)

In multi-stage flash evaporation the saline water (sea or brackish) is heated and evaporated; the pure water is then obtained by condensing the vapour. When the water is heated in a vessel both the temperature and pressure increase; the heated water passes to another chamber at a lower pressure which causes vapour to be formed; the vapour is led off and condensed to pure water using the cold sea water which feeds the first heating stage. The concentrated brine is then passed to a second chamber at a still lower pressure and more water evaporates and the vapour is condensed as before. The process is repeated through a series of vessels or chambers until atmospheric pressure is reached. Typically, an MSF plant can contain from 4 to about 40 stages. Multi-stage flash evaporation is considered to be the most reliable, and is probably the most widely used of the three principal distillation processes [3].

Multiple-effect evaporation/distillation (MED)

Multiple-effect distillation (MED) is also known as long-tube vertical distillation (LTV) and is in principle similar to multi-stage flash evaporation, except that steam is used to heat up the seawater in the first stage and the resulting vapour is used in subsequent stages to evaporate the water, and the seawater/brine is used to cool and condense the vapour in each successive stage so that the temperature gradually falls across each stage of the process. As in multi-stage flash evaporation, many stages are used in commercial plants. The MED process is used for what, at the time it began operating, was the largest desalination plant in the world in Jubail, Saudi Arabia, producing over 800,000 m3/day [4]. The plant began operating in April 2009.

Vapour compression distillation (VCD)

Steam is generated from the seawater using a source of heat and the vapour is then compressed using a compressor. As a result of this compression the temperature and pressure of the steam is increased – i.e. the work done in compressing the vapour is changed into heat1 (you notice this effect when pumping up a bicycle tyre and the pump warms up). The incoming seawater is used to cool the compressed steam which then condenses into distilled (fresh) water and at the same time the seawater is heated further producing more steam. Vapour compression distillation is usually used where the requirement for desalinated fresh water is relatively small such as in small communities, ships or in holiday resorts.

Membrane Desalination Process

Electrodialysis (ED/EDR)

The salts in seawater are composed of positive ions (called cations) and negative ions (called anions). For example, common salt (which is sodium chloride, NaCl) dissolves in water to produce positively charged sodium ions and negatively charged chloride ions. Thus:- NaCl = Na+ + Cl-. Electrodialysis uses a stack of ion-exchange membranes which are selective to positive and negative ions. Under the influence of a direct electrical current (DC) the positive sodium ions pass through a cation membrane and the negative chloride ions pass through an anion membrane as The incoming saline water is thus converted into two streams, one of concentrated brine and one of desalinated (fresh) water. Industrial electrodialysis plants consist of stacks of hundreds of membranes. Fouling of the ion exchange membranes can occur and this can be partly overcome by reversing the direction of the DC current; this process is known as electrodialysis reversal or EDR.

Reverse osmosis (RO)

Osmosis is the process in which water passes through a semi-permeable membrane from a low-concentration solution into a high-concentration solution. It is a process which occurs in plant and animal tissue including the human body (e.g. the secretion and absorption of water in the small intestine). If a pressure is applied to the high-concentration side of the membrane the reverse process occurs, namely water diffuses through the semi-permeable membrane from the high-concentration solution into the low-concentration solution, i.e. reverse osmosis. As seawater is pumped under pressure across the surface of the membrane, water molecules diffuse through the membrane leaving a concentrated brine solution on the feed-side of the membrane and fresh water on the low-pressure product side. The brine solution is rejected as wastewater and can be in the region of 10% to 50% of the feed water depending on the salinity and pressure of the feed water. RO membranes are manufactured from modern plastic materials in either sheets or hollow fibres. In a modern RO plant the membranes are grouped together in modules which are linked together according to the size of plant required. RO plants use four alternative configurations of membrane, namely tubular, flat plate, spiral-wound, and hollow fibre. Reverse osmosis is becoming the most widely used method for the desalination of brackish and sea waters.

Renewable Energy Systems

Renewable energy systems offer alternative solutions to decrease the dependence on fossil fuels. The total worldwide renewable energy desalination installations amount to capacities of less than 1% of that of conventional fossil fuelled desalination plants [5]. This is mainly due to the high capital and maintenance costs required by renewable energy, making these desalination plants non-competitive with conventional fuel desalination plants. This section presents a review of the possible systems that can be used for renewable energy collection and transformation into usable energy, which may be used to power desalination equipment. These cover solar energy which includes thermal collectors, solar ponds and photovoltaic, wind energy and geothermal energy

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Solar energy systems

These include solar collectors, solar ponds and photovoltaic.

Solar collectors

- Flat-plate collectors, which supply hot water up to 95^{0}C.
- Evacuated tube collectors, which reach temperatures up to 200^{0}C and are more suitable for conventional distillation plants, such as multiple effect thermal distillation (MED) and thermal vapour compression (TVC). They have been proven to be very effective in combination with MED.
- Focusing collectors or parabolic trough collector, which produces high-temperature vapour and/or electricity. They are suitable for large-scale dual-desalination plants and for electricity and freshwater production. Thus, small remote regions are excluded.
- Solar ponds, which produce hot water up to 90^{0}C.

Flat-plate collectors and solar ponds require large installation areas (either flat or cascading for flat plate collectors), but if available, capital and operation costs are low. Where land prices are high or electricity or high temperatures are needed, parabolic troughs are generally preferred source of solar thermal energy [6].

Photovoltaic

PV modules convert solar energy into direct current (DC) electricity. The electrical output from a single cell is small, so multiple cells are connected together and encapsulated (usually glass covered) to form a module (also called a 'panel'). PV modules can be connected in series or in parallel to produce larger voltages or currents.

Wind Energy System

Wind turbine converts kinetic energy into electricity (DC). Wind is generated by atmospheric pressure differences, driven by solar power. Wind turbine, which is installed on top of a tall tower, collects kinetic energy from the wind and converts it to electricity.

Geothermal Energy System

Geothermal energy is suitable for different desalination process at reasonable cost wherever a proper geothermal source is available. Low temperature geothermal waters in the upper 100 m may be a reasonable energy source for desalination [7].

The most intuitive way of using geothermal energy for water desalination is by applying geothermal heat to a distillation plant. This source is ideal for the stability of thermal processes.

Comparison of Desalination Technologies

Advantages and limitation of desalination technologies

This section tabulates that advantages and limitation of desalination technologies. Bolded sentences mark significant technology characteristics that note compatibility (in the Advantages column) and non-compatibility (in the limitation column). The water recovery and total dissolved solids (TDS) column is included to evaluate the system's productivity and versatility. High water recovery means a low brine stream and high permeates to brine ratio. Energy efficiency is improved by higher water recovery percentiles. Energy efficiency is a fundamentally important characteristic for matching, as high efficiencies [8].

Table 2 Comparison table of Desalination Process

Process	Recovery and TDS	Advantage	Limitation
RO	•30–60% recovery possible for single pass (higher recoveries Are possible for multiple pass or waters with lower salinity) • <500 mg/L TDS for seawater possible and <less 200 mg/L TDS for brackish water	•**Lower energy consumption** •**Relatively lower investment cost** • No cooling water flow •**Simple operation and fast start-up** • High space/ production capacity •Removal of contaminants other than salts achieved • Modular design •Maintenance does not require entire plant to shutdown	•Higher costs for chemical and membrane replacement •Vulnerable to feed water quality changes •Adequate pre-treatment a necessity membranes susceptible to bio fouling •Mechanical failures due to high pressure operation possible • Appropriately trained

		• Energy usage proportional to salts removed not volume treated • Higher membrane life of 7–10 years **• Operational at low to moderate pressures**	and qualified personnel recommended •Minimum membrane life expectancy around 5–7 years
ED/ EDR	• 85–94% recovery possible •140–600 mg/L TDS	• Energy usage proportional to salts removed not volume treated • Higher membrane life of 7–10 years •Operational at low to moderate pressures	**•Only suitable for feed water up to 12,000 mg/L TDS** •Periodic cleaning of membranes required Leaks may occur in membrane stacks •Bacterial contaminants not removed by system and post-treatment required for potable water use
MSF	• 25–50% recovery in high temperature recyclable MSF plant • <50 mg/L TDS	•Lends itself to large capacity designs •Proven, reliable technology with long operating life •Flashing rather than boiling reduces incidence of scaling •Minimal pre-treatment of feed water required High quality product water Plant process and cost independent of salinity level •Heat energy can be sourced by combining with power generation	**•Energy intensive process** •Large capital investment required •Larger footprint required (land and material) • Corrosion problems if materials of lesser quality used • Slow start-up rates • Maintenance requires entire plant to shut-down •High level of technical knowledge required • Recovery ratio low
MED	• 0–65% recovery possible • <10 mg/L TDS	• Large economies of scale • Minimal pre-treatment of feed water required • Very reliable process with minimal requirements for operational staff • Tolerates normal levels of suspended and biological matter •Heat energy can be sourced by combining with power generation •Very high quality product water	**•High energy consumption** •High capital and operational cost •High quality materials required as process is susceptible to corrosion •Product water requires cooling and blending prior to being used for potable water needs
VC	•VC(Vapour Compression Desalination) -	• Developed process with low consumption of chemicals economic with	**• Limited to smaller sized plants** •Start-up require

	mechanical and thermal •50% recovery possible • <10 mg/L TDS	high salinity(>50,000 mg/L) • Smaller economies of scale (up to10,000 m3/d) •**Relatively low energy demand** • Lower temperature requirements reduce potential of scale and corrosion Lower capital and operating costs Portable designs allow flexibility • **Ability to rapidly adjust to flux changes**	auxiliary heating source to generate vapour •**Compressor needs higher levels of maintenance**

As a result, an initial review of the desalination technology characteristics table above indicates that RO, from an engineering perspective, is a leader in RES matching due to its lower energy consumption, lower investment cost, simple operation, fast start-up capability, and operational ability at low to moderate pressures, all of which indicate a superior ability to handle low to high electric energy inputs from stochastic renewable energy sources.

The VC technology is also attractive for RES matching due to its relatively low energy demand and ability to rapidly adjust to flux changes. However, VC is limited to smaller plant sizes and its compressor requires higher levels of maintenance (i.e. exhibits a low level of robustness) [8]

Characteristics of the major desalination processes

The following table shows the characteristics of Thermal processes and membrane processes. Table includes most popular and beneficial process like MFD, MED, VC and RO which are used for sea water desalination. ED is also important but it is only used for desalination of brackish water hence it is not included for comparisons.

Table 3: Characteristics of the major desalination processes

Energy used	Thermal		Mechanical	
Process	MSF	MED	VC	RO
Feed water type	SW	SW	SW	SW/BW
Energy source	Steam	Steam	Electricity	Electricity
Product water quality (ppm)	<10	<10	<10	1stage:300 2 stage:10-50
Max Plant Capacity(m^3/day)	5000-60000	5000-20000	2400	100000
Heat consumption (KJ/Kg)	250-330	145-390		
Power consumption (kWh/m3)	10-14.5	6.0-9.0	7.0-15.0	4.0 - 11.0
Maintenance cost (cleaning/year)	0.5-1	01-02	01-02	several times
Plant Cost($/m3/d)	1500-2000	900-1500	1000-1500	900-1200

For Thermal Process, MED is more efficient then MSF due to the parameters like primary energy consumption, electrical consumption and plant cost.
As with MSF plants, skilled labour is required for maintenance of MED pumps and for operation of pre-treatment system, which is required for scale and corrosion control. MED plants are usually operated at lower temperatures than MSF, reducing the incidence of scale, but their heat exchanger configurations make cleaning more complicated. Plant capacity of MSF is also very high compare to MED, so MSF is more popular technology for desalination [9].

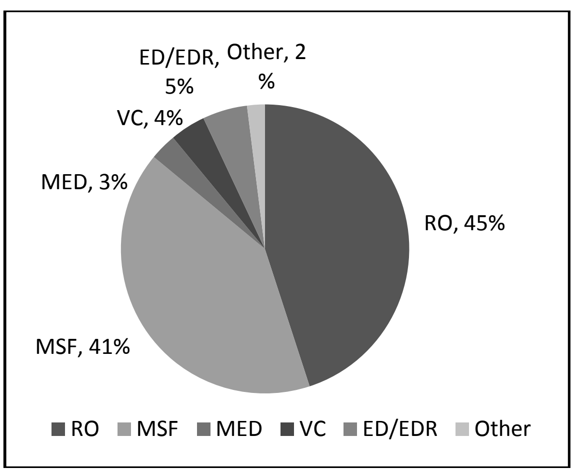
For Membrane Process, the parameters like power consumption, plant cost is higher of VC than RO and maximum plant capacities is 2400m3/d only. So, RO is more suitable than VC.

The much lower primary energy consumption of RO with highly distilled output and the slightly lower cost compared to MSF suggests that RO might be the preferred desalination technology anyway.

REDS Technology Implementation

The most suitable desalination combinations are MED and MSF for solar RES and RO, ED, and MVC for Wind RES.

Figure10 shows the global installed desalination capacity by technology, irrespective of the connected power plant. Clearly RO and MSF are currently the most popular desalination options, with both together taking 86% of the market.



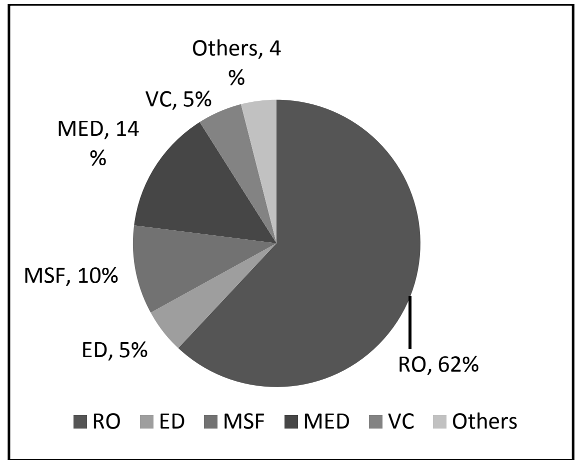


Figure 10(left) Global installed desalination capacity by technology (irrespective of power source)
Figure 11(right) Global RES-powered installed desalination capacity

At 62% market share, clearly RO is the primary user of renewable energy, as depicted in Figure 11 above.

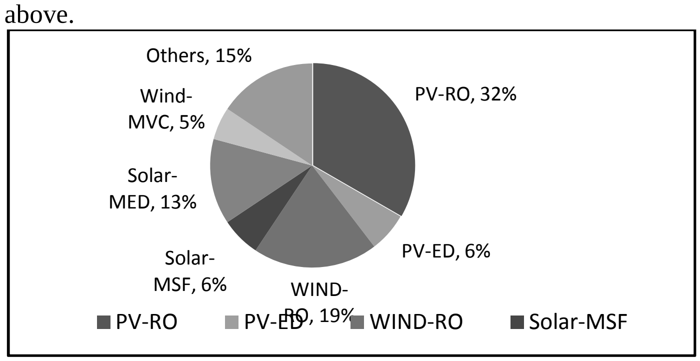


Figure 12 Distribution of renewable energy powered desalination technologies, percent is installed capacity

In 2005, 32% of renewable energy supplied is PV for RO and 19% is wind for RO, as shown in Figure below. This means that 62% of RO (32%/51% by Figure 12) renewable energy was from PV and 37% from wind. Figure 12 shows that the third most popular REDS match is solar and MED, at 13%.

MSF plants (6% of RES with solar-MSF), due to their better efficiencies and reduced costs, pushed out MED systems (13% of RES with solar-MED) in the 1960s, and only small size MED plants were built since then. However, in the late 1990s, interest in MED increased again and currently MED processes are said to compete technically and economically with MSF technologies for solar powered RES matches. Recent advances in MED low temperature processes and increased technology robustness have spurred this comeback, allowing MED plants to perform at 94% to

96% capacity due to decreased corrosion and scaling susceptibility.

Recently newer plants are designed to limit problems with scaling. This allows the plant to be configured for a high temperature (> 90 °C) or low temperature (< 90 °C) operation. The top boiling temperature in low temperature plant can be as low as 55°C The possibility of low temperature operation, low grade heat and waste heat utilization, low cooling water requirement and low energy consumption have made MED an attractive alternative in recent years for sea water desalination [10].

Conclusion

In this paper, a comparison of the various desalination systems is presented together. The selection of the appropriate RES desalination technology depends on a number of factors. These include, plant size, feed water salinity, remoteness, availability of grid electricity, technical infrastructure and the type and potential of the local renewable energy resource. Among the several possible combinations of desalination and renewable energy technologies, some seem to be more promising in terms of economic and technological feasibility than others. The "best" desalination system should be more than economically reasonable in the study stage. It should work when it is installed and continue to work and deliver suitable amounts of fresh water at the expected quantity, quality, and cost for the life of a project.

The most popular combination of technologies is MED with thermal collectors and reverses osmosis with PV. 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. Energy cost is one of the most important elements in determining water costs when water is produced from desalination plants.

The worlds water needs are increasing dramatically. Wind, solar and other renewable technologies that can be used for desalination are rapidly emerging with the promise of economic and environmental viability on a large scale. There is a need to accelerate the development of novel water production systems from renewable. Keeping in mind the climate protection targets and strong environmental concerns, future water desalination around the world should be increasingly powered by solar, wind and other clean natural resources. Such environmentally friendly systems should be potentially available at economic costs.

References

[1] *Buros O., The ABCs of Desalting, Second Edition. International Desalination Association, Topsfield, Mass, 2000.*
[2] *Qiblawey H. M., Solar thermal desalination technologies. Desalination 220 (2008) 633–644.*
[3] *Kalogirou S. Survey of solar desalination systems and system selection. Energy— The Int J 1997;22(1):69–81.*
[4] *Ravilious, Kate (2010) Add salt as required: the recipe for fresh water. New Scientist, 207 (2773), 14 August, pages 39-41.*
[5] *Delyannis E. Historic background of desalination and renewable eneries. Solar Energy 2003; 75(5):357–66.*
[6] *Goswami, D. Y., Kreith, F., and Kreider, J. F. (2000). ''Principles of Solar Engineering.'' 2nd ed. Taylor & Francis, Philadelphia.*
[7] *Rodriguez-Gironies, Rodriguez, M., Perez, J., Veza, J., (1996) 'A systematic approach to desalination powered by solar, wind and geothermal energy sources' In: Proceedings of the Mediterranean Conference on Renewable Energy Sources for Water Production. European Commission, EURORED Network, CRES, EDS, Santorini, Greece, 10–12, pp. 20–25.*
[8] *S. Wu, Z Zhang. (2003) Desalination 155: 179-185*
[9] *Awerbuch L,(2009) Future Directions in Integration of Desalination, Energy and the Environment. International Desalination Association Seminar, Boston, Feb 23rd , 2009.*
[10] *Soteris A. Kalogirou, Seawater desalination using renewable energy sources, Progress in Energy and Combustion Science 31 (2005) 242–281*
[11] *Tzen E. and Morris R., Renewable energy sources for desalination, Solar Energy 75, issue 5, (2003) pp.375–379*
[12] *MEDRC R&D Report, Matching Renewable Energy with Desalination Plants, IT Power Ltd, 2001*
[13] *Mehdi N. Bahadori, "Solar Desalination for Domestic Applications", Water Conservation, Reuse, and Recycling: Proceedings of an Iranian-American Workshop "Solar Desalination for Domestic Applications", 2005*
[14] *Van der Bruggen, Bart and Carlo Vandercasteele.. Distillation vs. Membrane Filtration: Overview of Process Evolutions in*

ISSN: 2277-9655
Impact Factor: 1.852

Seawater Desalination."Desalination 143 (2002) 207-218.

[15]Tsoutsos T., Marketing solar thermal technologies: strategies in Europe, experience in Greece, Renewable Energy 26 (2002) 33–46.

[16]Virk G., Ford M., Denness B., Ambient energy for low-cost water desalination, Desalination: 137 (2001) 149-156.

[17]Carta, J.A., Gonzalez J., Subiela V. "Operational analysis o fan innovative wind powered reverse osmosis system installed in the Canary Islands" Solar Energy 75 (2003) 153-168.

[18]Laing, D., Lehmann, D., Bahl, C., Concrete Storage for Solar Thermal Power Plants and Industrial Process Heat, IRES III 2008, 3rd International Renewable Energy Storage Conference, 24.-25.11.2008, Berlin

[19]Harrison, D. G., G. E. Ho, K. Mathew. 1997. Desalination using renewable energy in Australia. WREC, 509-513.

[20]Garcia-Rodriquez, Lourdes. 2002. Seawater Desalination Driven by Renewable Energies: A Review. Desalination 143:103-113.

[21]A review of current knowledge DESALINATION for WATER SUPPLY FR/R0013 First published February 2006 Revised May 2012, Foundation for Water Research