UNIVERSITY OF GÄVLE

DEPARTMENT OF TECHNOLOGY AND BUILT ENVIRONMENT

DESIGN OF A DESALINATION PLANT

Aspects to Consider

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2. ABSTRACT

One of the main problems our actual society faces is the shortage of water. Despite the great effort made by authorities and researchers, multiple countries with poor economic resources are experiencing serious difficulties derivative of water scarcity. Desalination provides a feasible solution for inland and coastal areas. Through literature and reviewed articles analysis the reader will meet the actual issues regarding designing a desalination plant, and more over with reverse osmosis (RO) processes, which are the main arguments of this work. One of the big deals is the environmental concern when handling the concentrate disposal. Another important point about desalination processes is the increasingly interest in coupling the units with renewable energy sources (RES). The results point out that regardless of the efforts made until today, additional achievement is required in fields such as membrane's structure materials for RO method, concentrate disposal systems, governmental water policies review and update, and greater distinction researches between brackish water and seawater RO desalination processes. Taking into consideration the previous outcomes it is finally concluded that some particular steps must be accomplished when beginning a desalination plant design.

3. CONTENTS

4. INTRODUCTION

4.1 SHORTAGE OF WATER

With the increase of the world's population and the water consumption per person, the water demand is arising considerably. According to databases from the World Health Organization, less than 1% of the planet's hydric resources are fresh water and accessible for the human, varying on the area we study, the climate and the moment of the year. The access to fresh water is limited and contamination hovers over it. To avoid a superior crisis some countries need to preserve the water supplies, reduce the contamination, regulate the supply and demand, and hold the growth of population.

In one hand the demand of fresh water and in the other one the access to limited and more contaminated water supplies makes that many developing countries have to face difficult situations. The number of inhabitants in the Planet Earth is increasing drastically and we don't have more water than two thousand years ago, when the world's population was 3% of today's. The increasingly water demand for irrigated agriculture, domestic consumption and the industry are imposing a very hard competence in the acquisition of the limited hydric resources in varied areas and kind of uses.

According to databases from the World Health Organization, nowadays thirty-one countries, inhabited by less than 8% of the world's population, face chronicle fresh water deficit. But by 2030 it is foreseen that forty-eight countries will face this deficit, affecting more than 2,800 million inhabitants. In the next twenty-five years countries as Ethiopia, Peru, India or Nigeria will suffer water shortages, whereas countries as China already face water deficit in some areas.

In most of the world, contaminated water, the improper disposal of waste and the poor water management brings serious problems of public health. Diseases caused of water as paludism or cholera kills millions of people every year. It is important to highlight that an excessive use of water and its supply contamination is causing severe damage to the environment and inflicts serious risks to biological species.

4.2 HUMAN NEEDS

Human life depends upon the existence of fresh water. The World Health Organization (WHO) sets in fifty liters per person and day the minimum quantity of water needed to maintain a certain level of hygiene and avoid the transmission of infectious diseases. From those fifty liters just 0.75 are for drinking and the rest would be for self-cleaning, cook, wash, etc.

In Spain, according to the Environmental Ministry, most of the water consumed is used for agriculture (80%), industry (5%) and domestic consume (15%) including the touristic demand in certain seasonal areas and moments.

4.3 WATER RESOURCES

In our planet, water reserves are immense. According to estimates, our hydrosphere has around 1,386 millions km^2, of this area the most is covered by the oceans, near three out of four parts of land surface to be more precise, which have a salinity of 3% in weight, which make it completely useless for any kind of usage. The rest is fresh water, but the 68.9% is present as ice and snow covering polar and mountain areas. The leftover is present as groundwater in a 29.9% and as lakes, rivers and reservoirs in a 0.3%. This last fresh water is the one we can manage without technical and economic limitations.

The terrestrial hydrologic cycle (evaporation, cloud formation, precipitation and runoff) is the responsible for the existence of the renewable hydric resources mentioned before (the renewal period of the polar ice is 10,000 years and seventeen for glaciers and aquifers). The average value of the hydric renewable resources is 42,750 km^3 per year, a very variable quantity in function of the period in the year.

4.4 WATER QUALITY

Water is a solution of various salts, which in whole establish the characteristics of it. Therefore is essential to know its composition in order to be able to submit it to a separation treatment or desalination through membranes. Three reasons obey:

- Not all the membranes have the same rejection level to salts.
- A same membrane also rejects the different ions in a different way.
- There are specific ions that have limitations when trying to separate them.

The optimum pH both for operation and rejection of a membrane's salts is clearly determined. It is hence recommended to review the chemical components that we can locate in the seawater related to the desalination.

As stated before, salts in water are decoupled in form of positive and negative ions. The principal cations we can find in the water are Calcium (Ca^{++}), Magnesium (Mg^{++}), Sodium (Na^{+}) and Potassium (K^{+}) where as the most abundant anions are Chloride (Cl^{-}), Sulfate (SO_4^{-}), Carbonate (CO_3^{-}) and bicarbonate (HCO_3^{-}). In a lesser amount there is also iron, manganese, aluminum or nitrate, phosphate, etc. The predominance or abundance of any of these elements makes it necessary to treat the water or use it directly.

The chemical properties of saltwater depend upon its total concentration and in a lesser degree of the relative proportion between ions and cations. However, for reverse osmosis processes, this last proportion becomes important due to its incidence in the precipitation or incrustation of salts over the membrane.

The quality of the required product water as well as the quality of the raw water supplied contributed to the process is essential when choosing either process. As an example, the destilation process consumes the same amount of energy independently of the provided salinity, therefore they are only appropriate for seawater desalination. Also especially pure water required for specific industrial applications needs of post-treatment if reverse osmosis process is used. Respecting the salinity of seas and oceans, it is anything but constant.

Sea/ Ocean	Salinity (ppm of TDS)*
Baltic Sea	28,000
North Sea	34,000
Pacific Ocean	33,600
South Atlantic Ocean	35,000
Mediterranean Sea	36,000
Red Sea	44,000
Persian Gulf	43,000-50,000
Dead Sea	50,000-80,000
Worldwide Average	34,800

Table 1. Planet's seas and oceans average salinity. Uche, Valero and Sierra (2001)

One way to classify the water is according to its salinity taking into account the total dissolved salts it contains.

Denomination water	Salinity (ppm of TDS)
Ultrapure	0.03
Pure	0.3
Deionized	3
Fresh water (poor)	<1000
Brackish	1,000-10,000
Saline	10,000-30,000
Marine	30,000-50,000
Brine	>50,000

Table 2. Salinity ranges of different kind of water

* Parts per million of Total dissolved salts

Water Quality required

The water quality required clearly depends on the uses you give to it. Therefore, for certain industrial processes waters up to 5,000 parts per million (ppm) can be used but in others as power plants the limit is negligible. In agriculture, some crops tolerate up to 2,000 ppm, although the land, climate, brackish composition, irrigation method and applied fertilizers can alter this value. Regarding human consumption, the limit is 1,000 ppm, even though in some arid areas an extra intake of salts can be beneficial for the body.

In the Spanish current regulations referred to waters quality, The Royal Decree 1138/1990 14^{th} September adapts to the Spanish legislation the European directive 90/778/CEE 15^{th} July about the same material. In this regulation the characteristics of drinking water are defined, with the maximum concentration values that cannot be exceeded and some guidance levels desired for drinking water. The parameters are divided in:

- Organoleptic
- Physic-chemical
- Undesirable substances
- Toxic substances
- Microbiological
- Radioactivity

Later, the European directive 98/83/CEE 13^{th} November establishes new minimum requirements to obey as from two years after its edition. It includes a series of new parameters divided in three parts:

- Microbiological
- Chemical
- Indicators (guidance values)

Also be added that there is a proposal of the European Federation of national associations of drinking water suppliers and wastewater services (EUREAU) about the technical health regulation to delete the guidance levels and to revise the maximum concentrations admissible for sodium, sulfates and nitrites based in scientific-health researches. Also states to reconsider the inclusion of fixed values for potassium.

The table below compares the most significant parameters of water according to the regulations showed before.

Parameter	**90/778/CEE**	**98/83/CEE**	**WHO guidance**
Chlorides	200	250	250
Sulfates	250	250	400
Nitrates	50	-	-
Alkalinity	30	30	200
Sodium	175	200	-
Magnesium	50	-	200
Total hardness	60	-	-
Total dissolved salts (TDS) ppm	1,500	1,500	1,000
pH	6.5 to 8.5	6.5 to 9.5	6.5 to 8.5
Others	-	Non aggressive water	-

Table 3. Comparative of the most significant parameters of water according to actual standards. Rueda, Zorrilla, Bernaola and Hervas (2000)

4.5 QUALITY OBTAINED BY DESALINATION

The table below shows the average quality of water obtained with single and double step reverse osmosis as well as evaporation processes. Double step RO stands for the same process as in single step but treating the income water through two consecutive membranes.

	R.O. (Single step)	**R.O. (Double step)**	**Evaporation**
Ca^{++} (mg/l)	2	0.1	0.5
Mg^{++} (mg/l)	6	0.3	1.5
Na^{+} (mg/l)	128	15	12
K^{+} (mg/l)	4	0.8	0.5
HCO_3^{-} (mg/l)	8	0.4	0.1
SO_4^{-} (mg/l)	11	0.6	3.0
Cl^{-} (mg/l)	208	23	22
TDS	367	40	40
SiO_2	0.1	0.0	0.0
CO_2	23	12	-
pH	5.8	5.2	7.2

Table 4. Average water quality obtained with different desalination processes. Rueda, Zorrilla, Bernaola and Hervas (2000)

Hence, observing the quality obtained in the processes and the legal requirements, in the post-treatment of the desalinated waters two aspects should be considered. The first one contemplates the chemical equilibrium of the water with the objective of eliminate its high aggressiveness and therefore protect the distribution networks. To do this, its necessary to reduce the high level of CO_2 with the addition of lime, $Ca(OH)_2$, to get slightly fouling water. The second aspect refers to the hardness content of the water supply, with a minimum of 60 mg/l.

4.6 SUPPLY SYSTEMS

The human being has progressively adapted to the environment in order to have water in different locations. History abounds in examples of settlement areas of people at the edge of the water sources, lakes or rivers and after periods flowering are forced to migrate to other sources by resource depletion or what is more frequent, deteriorating water quality available to levels where harvests its use in basic subsistence agriculture or even basic consumption needs.

Little by little the man has been improving its ability to obtain and store drinking water to meet their needs, such as the construction of prisoners to form wetlands or wells. However, the sharp climatic variations have caused great difficulty not only of availability water but storage.

Water shortages also are often linked to the poor quality of it, and although over the centuries there are references of efforts to obtain fresh water from salt water, it can be said that it is in this century when such efforts are reflected in acquiring technologies that ensure the reliability and transformation process.

5. PURPOSE

The purpose of this project is to expose the reader the actual background in the field of design of desalination plants by explaining the processes involved in it, mainly in the Mediterranean regions. Once the main issues are explained it will be possible to understand the actual debate surrounding two main points:

a) Environmental aspects of desalination plants and;
b) Efforts made by engineers and researchers to develop desalination units powered by renewable energy sources.

Some questions will be thrown to be able to follow a path:

- Why reverse osmosis is becoming the most efficient and economic desalination process?
- What factors to take into account when designing a desalination plant?

6. METHODOLOGY

The project has followed a methodology based on literature, consisting mainly in reading and analyzing reviewed articles, which provide a rich documentation in the field of desalination to be able to face the subject in an objective way.

The method was chosen due to the wide range of subjects concerning desalination that are present in reputed scientific e-journals accessed as a member of the university, which constitutes an appropriate way to know the opinions and knowledge of experienced authors in the field.

Also state that unsuccessful contact with companies has been made.

7. THEORETICAL FRAMEWORK

In order to understand the forthcoming overview and discussion points of the project work, the author assesses the importance of explaining the basic notions of desalination and in more detail, due to its actual relevance and strong future perspective, reverse osmosis process.

7.1 DESALINATION PROCESSES

Desalination is achieved through thermal technology processes and membrane technology. Thermal processes cover multi-stage flash distillation (MSF) multieffect distillation (MED) and vapor compression (VC). Membrane processes include electrodialysis (ED) and reverse osmosis (RO). Both methods get as result two flows: A flow of clean water with low salt concentration and a flow with high salt concentration. Both methods require energy for operation. Energy consumption in membrane processes depends on the feed water salinity whereas in non-thermal processes there is no such dependence.

Energy consumption in RO and ED processes for brackish waters and low salt content waters is much lower than in the processes of distillation. In addition, recent advances in RO technology for seawater desalination have reduced energy consumption. The most widespread current technique and the one that holds most of the future projection is reverse osmosis.

Therefore, when choosing either desalination process it is important to know what kind of water will be treated.

Here is a brief description of the various desalination processes for marine waters or continental brackish waters:

a) Distillation processes are divided into:

- Thermal Distillation: the energy for the desalination is obtained from fossil fuels (coal, natural gas, oil, etc.).
- Vapor compression: a compressor to get two adiabatic different sectors of pressure is used to generate a flow of steam from the sector of higher pressure and condensing temperature to the lower, where condensation occurs.

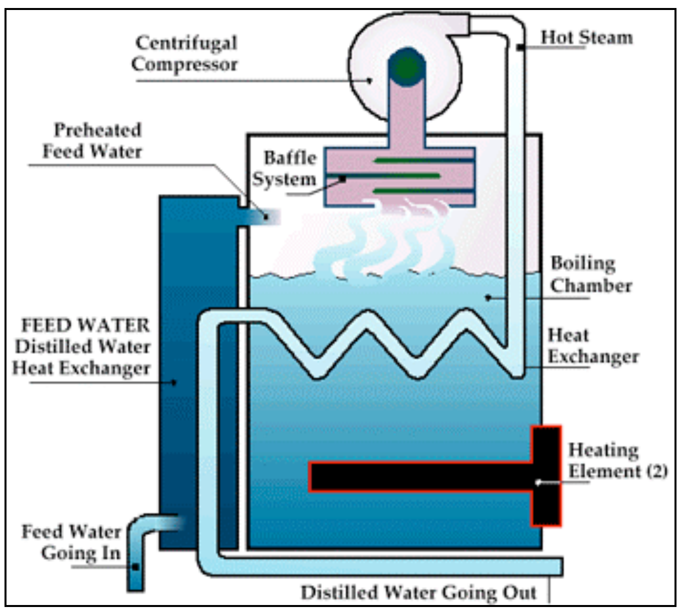

Figure 1.Vapor Compression process diagram. (Norland International)

- Solar distillation: suitable for small communities in arid or semiarid regions. It has two variants depending on whether the sun's energy is used directly or it’s catched by using solar cells.

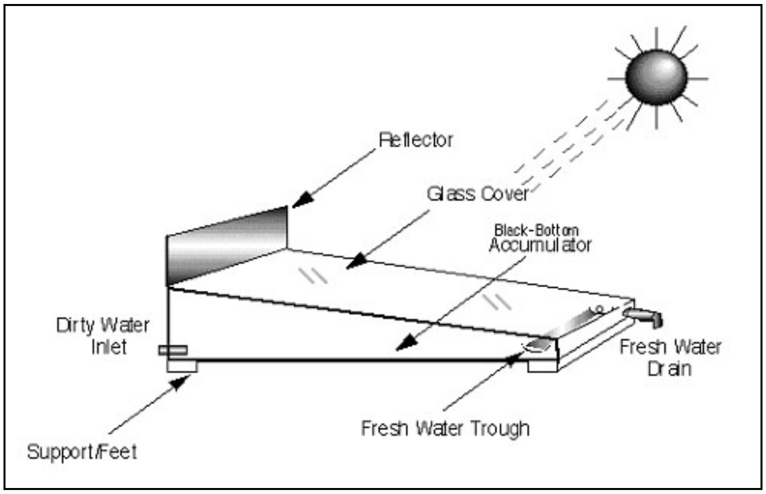

Figure 2. Solar distillation process diagram. (Rueda, J. A., Zorrilla, J., Bernaola, F. y Hervás, J.A. 2000)

b) Freezing processes: salt water is subjected to various cooling systems to subsequently evaporate at low pressure in a vacuum crystallizer. This results in ice crystals mixed with brine crystals that can be separated by mechanical processes.

c) Membrane Processes are widely distributed today. There are two basic types:

- Reverse osmosis: by applying mechanical pressure to counteract the natural osmotic pressure water flows from the area with higher salt concentration to the lower concentration area until pure water is achieved.

- Electrodialysis: ion separation through a series of membranes located successively millimeters apart. The application of electric fields generates the migration of ions that pass through these membranes that act as sieves.

7.2 REVERSE OSMOSIS DESALINATION

What is natural osmosis?

Osmosis is a natural phenomenon by which two different salt concentration solutions, separated by a semipermeable membrane (i.e. allows the passage of water but not salts) tend to equalize their concentrations from the more dilute solution to the more concentrated, until it reaches equilibrium. The passage of water creates a pressure called osmotic pressure.

What is reverse osmosis?

Osmosis is a natural process that occurs in plants and animals, so by observing figure 3 we can say that when two solutions with different concentrations are united through a semipermeable membrane, there exists a natural circulation for the weaker solution to match the final concentrations, thereby the height difference obtained (assuming the recipients of each solute at the same level) translates into a difference of pressure, called osmotic pressure.

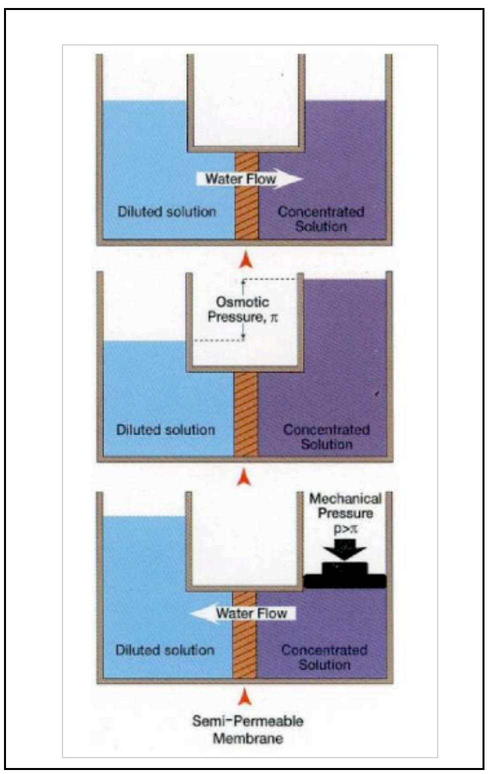

Figure 3. Reverse Osmosis process. (Uche, 2000)

But by applying an external pressure greater than the osmotic one, one solution over another, the process can be reversed by circulating water from the more concentrated solution and purifying the lower concentration area, obtaining finally an acceptable water purity (although not comparable to distillation processes).

The amount of permeate depends on the pressure difference applied to membrane properties and concentration of raw water. The strip is normally brine rejected to sea again, and can be used previously for a process of energy recovery due to the high pressure that comes out of the membranes.

7.3 REVERSE OSMOSIS APPLICATIONS

For food industry:

- Fish industry: wastewater treatment, recovery of protein, processing of biochemicals.
- Concentrated fruit juices: apple juice, tomato, orange, recovery of essential oils from citrus processing.
- Wine industry: increase of alcohol content, avoiding the addition of sugar. Adequacy of drinking water with low sodium content and mineral salts.
- Coffee Industry: wastewater treatment for pollution control.
- Brewing Industry: elimination of alcohol in beers with lower alcohol or without alcohol.
- Chocolate industry: treatment of wastewater from the bottling chocolate syrup.
- Candy Industry: treatment of wastewater from the lubrication of blades for cutting the product.

For industrial water treatment:

- Dairy Industry: Concentration of whey.
- Paper industry: wastewater treatment and recovery of organic and inorganic substances valuable to reduce pollutant concentrations operating costs, and also recovery of process water.
- Metal surface treatment: treatment of oily wastewater, electroplating processes, electrodeposition.
- Textiles: dye concentration and recovery of process water.
- Microelectronics industry: production of ultrapure water.
- Production of nitrogenous fertilizers: ammonium nitrate recovery.

7.4 REVERSE OSMOSIS MEMBRANES

Membrane structure

The structure that forms the basis for the manufacture of membranes is complex and over the years it has been undergoing changes, yet responds to two types that have been quite different from the outset.

These types correspond to spiral membranes and hollow fiber membranes, although in reality these are two structures that might be defined as fibrillar structure and laminar structure, the one that has achieved more acceptances, perhaps because it's easiest construction, in the membrane manufacturing industry.

The manufacturing process of both types of membranes takes place from a viscous solution of long-chain polymers, but the way they are performed are quite different.

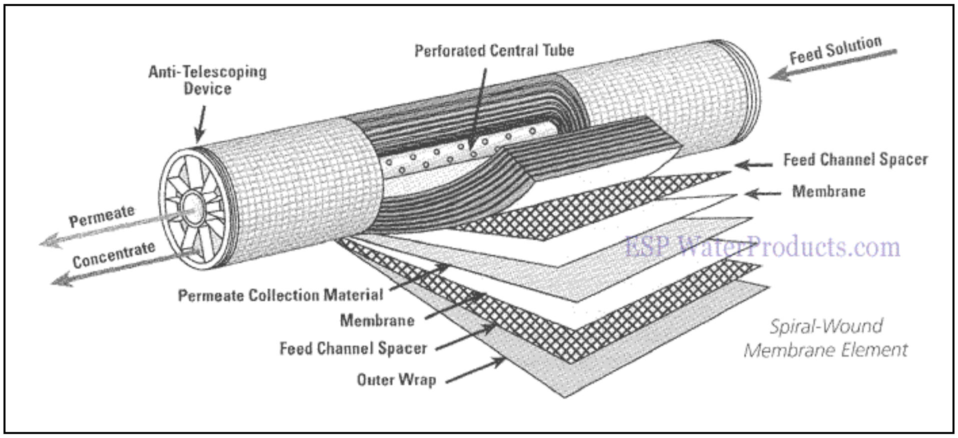

Figure 4. Spiral wound membrane. (ESP Water Products, espwaterproducts.com)

Laminar membranes

The first membranes that were produced were cellulose acetate and both the separating film and the support were produced in one step. This involved difficulties to get both sides of the membrane meeting the appropriate conditions in salt rejection and flow. So it was an important breakthrough discovery the asymmetric membrane, which in reality was only a different manufacturing procedure membrane.

But the final breakthrough in the field of manufacture of the membranes was the thin film composite membrane, TFC. The idea was making the membrane based on two distinct components, one acting as a barrier and another as a support capable of withstanding large operating pressures required. Therefore both components can optimize their respective characteristics independently.

This type of structure remains unchanged until now in the manufacturing process. Successive advances have been more focused in the use of new polymers rather than the research of new structures. The new films are deposited on the old ones and the procedures for its implementation are more sophisticated and accurate.

Fibrillar membranes

Filaments that form the membrane are sewn from a solution of aromatic polyamides and inorganic salts.

Constituent materials

The basis of desalination is constituted by the thickness of the layer that performs the separation of salts. Nowadays only asymmetric type membranes or TFC call attention of manufacturers, and in its constitution we primarily find acetate cellulose in one side and various polyamides in the other.

The first commercial membranes were of cellulose acetate, and are still produced by many manufacturers, although they have been improved. They are pH-sensitive membranes, with moderate flow, and susceptible to biological attacks, but they allow chlorination. Its scope is especially contaminated water or waste due to the smooth membrane surface and it is therefore insensitive to dirt.

Aromatic polyamide membranes represent a new generation of membranes, with numerous advantages over acetate membranes. They have much higher flow rates and rejections than acetate ones and operate at lower pressures, so, with few exceptions, they have almost totally replaced them. On the other hand they are very sensitive to chlorine, which is the weakness of almost all desalination membranes that exist nowadays. The support material of these membranes is a porous polysulfone or polypropylene. There are two types of aromatic polyamide that are the origin of the current membranes: one has carboxylic and the other has sulfonic groups; the first is the base of the spiral membranes and the second one of hollow fiber membranes.

8. OVERVIEW

The forthcoming part reviews the different points of view of authors regarding three main subjects: the environmental aspect of desalination processes (i.e. discharge of brine, use of chemicals, impact on the marine ecosystem, etc.) the design of desalination plants powered with renewable energy sources (RES) and state-of-the-art, and the future development in technology for desalination units.

8.1 ENVIRONMENTAL ASPECTS

An actual aspect that concerns the environment is what to do with the concentrate that results from the membrane absorption. For coastal reverse osmosis plants the focus is on the seawater as a receiving body, where for inland brackish water plants the area to study would be lakes or rivers, as well as for aquifers.

Palomar *et al*. (2010) highlights that due to the high development of desalination plants worldwide, brine discharges have risen significantly in the recent years and therefore additional research needs to be carried out. Also states the real possibility of developing numerical modeling tools with the aid of laboratory tests in order to control in a feasible way the discharge into surface watercourses.

According to Greenlee *et al.* (2009) the most important aspects when removing the concentrate of the desalination plants for seawater reverse osmosis are the pumping system and length of piping that is needed to discharge the brine in a specific underwater point. Also both parts, the intake and discharge of water and brine, respectively, are placed separately. Regarding brackish water reverse osmosis, the author states that the most common process of disposal due to the high costs of different choices is surface water disposal although it is limited to coastal plants. In case of inland plants, the concentrate can be discharged into lakes or rivers. It is important to highlight that brackish water reverse osmosis concentrate can seriously change the salinity of the water that receives it.

According to Mickley (2004) the standard limit for surface water discharge has a variation of less than 10%. Concerning plants in which the intake is from a groundwater deposit, the concentrate needs to be treated before disposal to the groundwater.

Due to the higher construction of inland desalination plants an alternative option for concentrate disposal has emerged. The brine can be taken to a combine sewer where it is mixed with wastewaters. But some external factors such as regulations, the size of the desalination plant and the location of the nearby wastewater plant apply when studying this alternative.

Another interesting method consists in using evaporation ponds, which are basic, inexpensive to build and very conventional when managing the concentrate (Greenlee *et al.* 2009). To protect local soil and groundwater from chemicals when concentrate leaches into the ground the are regulations that apply (Nicot *et al*. 2007)

The most economical solution for inland plants could be the deep well injection process, consisting in injecting the concentrate several thousand meters above the groundwater deposits, even though due to the short life of the process it is not known whether the salt will eventually leach into the deposits above.

All the processes mentioned before are non-water-recovery processes from the concentrate of the desalination plants.

The last system mentioned by Greenlee *et al.* (2009) consists of a zero liquid discharge (ZLD) where the recovery rate approached 100%. This ultimate achievement manages to completely separate salt from water. The negative aspect is that nowadays the capital cost to build the system is higher than the cost of the desalination plant by itself. Therefore, except for relatively small reverse osmosis systems, it is not a financial possible option.

It is stated that when high waste water discharges coincide with sensitive ecosystems negative effects will emerge considerably (Lattermann *et al*. 2008).

One example one of the author states is the proposal of meshed screens to minimize the impingement and entrainment of larger organisms into the feed water (Lattermann *et al*. 2008).

Palomar *et al*. (2010) proposes to analyze the discharge system location. In this sense, the discharge system should be placed in areas of great hydrodynamic turbulence to help the brine dilute with the receiving water.

García Molina *et al*. (2010) consider that in Spain, water reuse after desalination is practiced just in one part of the country. This is due to the agricultural traditions of the provinces in Spain.

According to Lattermann *et al*. (2008) place selection is a major factor to reduce the impact of the desalination plant to the environment and vice versa. In the proximity of the plant should be water distribution networks and consumers in order to save land-use and over-pumping. One method to mitigate the impact is making use of an environmental impact assessment (EIA) to detect the potential impacts of a proposed project, evaluating alternatives to the effects that can be caused and therefore be able to make modifications.

In Spain, The Ministry of Environmental and Rural and Marine Affairs is the responsible for the correct environmental assessment of desalination plants. This authority has planned a brine discharge system consisting in five steps, i.e. preliminary studies and data collection, location and selection of brine discharge system, modeling of brine discharge and its behavior into the seawater body, optimization of the brine discharge parameters and as a last step, a marine environmental monitoring program and action protocol (Palomar *et al*. 2010)

Another aspect that is especially important would be the chemicals used in the plant for water pre-treatment as for water post-treatment. Some of these chemicals are considered toxic for human health as well as for the environment.

According to Lattermann *et al*. (2008) additives of cleaning solutions have to be taken into consideration, as they cause harm to marine organisms. Substances as alkaline solutions used to dissolve metal oxides are examples of these additives. Also biocides as chlorine, used to reduce biofouling, are catalogued as toxic substances. An alternative substance to chlorine is chlorine dioxide, which added in small quantities can reduce significantly the environmental impact.

8.2 RENEWABLE-ENERGY-SOURCES-POWERED DESALINATION PLANTS

Changing the subject, the coupling of renewable energy sources with reverse osmosis desalination plants has grown in interest and development (Greenlee *et al.*2009) although renewable energy sources are still more expensive than traditional resources (Helal *et al*. 2008). Nowadays there are three main renewable energy sources that are used to operate the plants: solar, wind and geothermal energy; where the first two are common to be matched with reverse osmosis plants. Solar energy embraces the highest percentage of energy share (70%) where reverse osmosis is the process that mostly resort to it (62%) (Mathioulakis et al. 2007) The alternative that has a wider perspective in the field of renewable energy combined with desalination process would be solar energy in the form of photovoltaic cells, where energy is directly converted into electricity, which would be the source for the desalination process. According to Grabber (2006) Spain, which is the European leader in desalination, proved to combine a desalination process with a RES. The result was a wind farm giving energy coverage to a reverse osmosis plant in the Canary Islands. When the RES generates more energy than the needed by the plant, the excess is sold to the power network. On the contrary, if the plant needs additional energy than provided by the RES, then the grid will solve the problem.

PV is seen as a proper solution for small plants in sunny regions, where wind installations are a more proper choice for larger applications that do not require wide open ground (Mathioulakis *et al*. 2007)

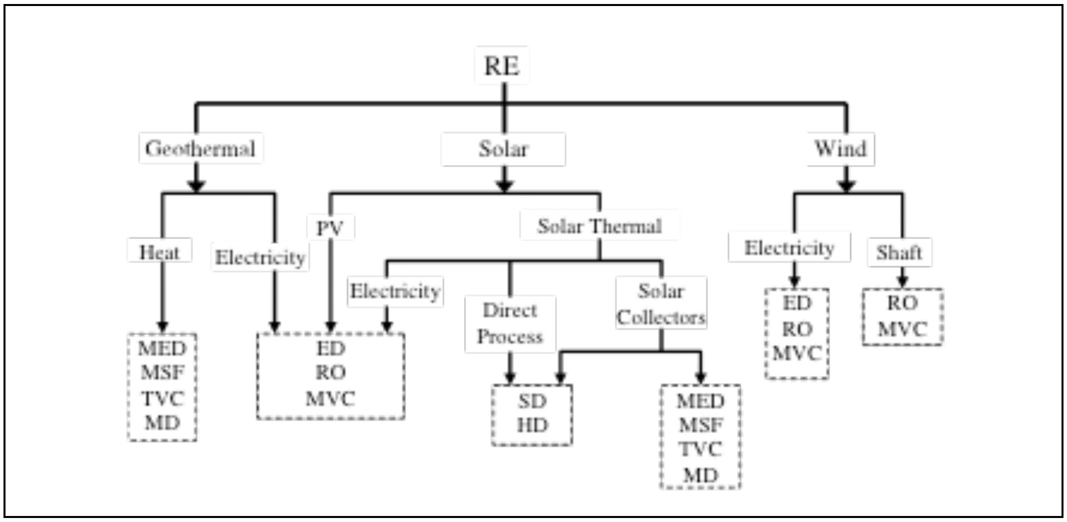

Figure 5. Possible technological combinations of the main renewable energies and desalination methods (Mathioulakis *et al*. 2007)

Some correlated aspects such as technology, cost, availability and sustainability have to be taken into account when designing a RES driven desalination plant (Mathioulakis *et al*. 2007)

For brackish water, small RO plants with simple designs and renewable energy sources can successfully provide water to rural communities (Greenlee *et al.*2009). The author highlights the importance of studying the social aspects that surrounds the use of water for the new circumstances in the rural community.

Mathioulakis *et al*. (2007) argues for the development of integrated solutions, ensuring reliability, robustness, sustainability in terms of local resources and effective performance at acceptable cost with respect to RES desalination programmes. Also, concerning the use of PV and wind power for desalination, the proposal of more efficient and sustainable alternatives by the implementation of system integration, and the development of reliable storage device to manage the fluctuating behaviour of the renewable sources.

Autonomous desalination systems (ADS) provide small volumes of freshwater through distillation or membrane processes. They are usually coupled with a diesel generator or renewable energy system and they are designed to work in arid or semi-arid regions like the Mediterranean. Actual problems arise when trying to develop these ADS in the European Union as numerous barriers in form of administrative impositions affects these small-scale plants. Such barriers are imposed by the Water Framework Directive, the Drinking water directive, EU water initiative, the European Mediterranean Partnership and the European Neighborhood Policy (Gibbons *et al*. 2008)

According to Gibbons *et al*. (2008), when implementing ADS there are some barriers within the European Union policies and legislation for reasons such as that desalination matters were not taken into account when the policies where developed. Therefore the author argues for a careful review of the relevant directives and standards for a widespread of ADS.

8.3 FUTURE DEVELOPMENTS

As Mathioulakis *et al*. (2007) refers, in the field of desalination plants there has been a high effort in R&D in the recent years that has lead into a significant reduction of cost and an increase of the process efficiency. Also the experience gained is a strong factor.

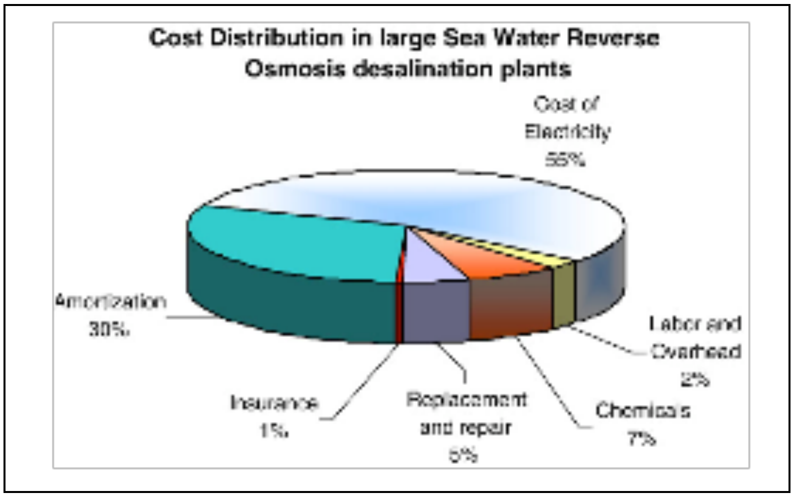

Figure 6. Cost distribution in large seawater RO desalination plants. (García Molina *et al*. 2010)

The future within seawater RO modules points in two different scenes. One of the actual researches is focused in lower the temperature of desalination to achieve in an easy way the required quality of water. The other scenario would be to divide the RO process into two passes in order to reduce the operating expenses by increasing the capital expenses (García Molina *et al*. 2010)

Regarding the challenge against biofouling, considered "the Achilles heel of membrane processes", modifying the membrane through its chemical composition making it smoother, more hydrophilic, stronger negative surface charge and a thicker feed spacer the membrane will be much less propitious to be attacked by bacteria as more turbulence can be created along the feed channel, avoiding attachment of bacteria into the membrane surface (García Molina *et al*. 2010)

One of the main actual problems that face engineers working in designing membranes for RO plants is the concentration of particles that increase significantly the energy consumption. This effect is called fouling. Among all the kinds of fouling, biofouling is considered the main issue to face (García Molina *et al*. 2010)

According to Greenlee *et al.* (2009), actual researches will help future developments in membrane technology, energy use, and concentrate treatment allow a wider application of RO to inland and rural communities.

9. DISCUSSION

Reverse osmosis has experienced an enormous technological grow in the past two decades thanks to the great investments of governments such as the United States in programs developed by public entities as the Office of Saline Water (OSW). It is a truth that nowadays is the most used system for desalination processes, covering an 80% share in the total number of desalination plants installed worldwide (Greenlee *et al.* 2009).

It is necessary to highlight the importance of the recent improved development of technical components of desalination plants that enables to build efficient inland plants for cities or rural areas. As it was shown before, one possibility to low the costs would be to make a two-steps process for brackish water desalination plants. Even with these improvements the main problem is the concentrate disposal, as the most feasible option is to have receiving water big enough to not experience a high rate of salinity variation, as happens with the seawater.

A feasible solution, studied and researched, is the improvement or the installation of a recovery device in the desalination plant that transforms the mechanical flow of the water into electricity and therefore save big amounts of energy and costs. Inside these improvements are included the design of chlorine-resistant membranes. Many reverse osmosis (RO) desalination plants older than five years are equipped with polyamide membranes, which are degraded in contact with chlorine, which are a very common water disinfectant and also a toxic substance. To prevent fouling many plants in the Middle East have developed nanofiltration (NF), which with a 40% increase of production was successfully achieved.

Another reason that brings hope to the RO desalination process for desalination plants is the facility to couple this process to renewable energy sources (RES), as it is compatible in an energetic point of view with most of the RES. Although the cost of installing RES is decreasing, it is still more expensive than the desalination plant itself. Therefore it is important that companies intending to design desalination plants covered with alternative energy take advantage of the support given by the government, as the European Union provides to all European members the possibility to build autonomous desalination systems (ADS) in rural areas. But it is also a must that decision makers improve policy and institutional framework conditions and will arise general awareness on the ADS benefits (Gibbons *et al*. 2008).

Regarding the design of reverse osmosis desalination plants, it is a good way to start the project by exploring and studying already built desalination plants, to take as a reference the good points of each one in areas such as energy sources, brine disposal, materials used, geographic situation or water income quantity to say some examples. Some of the desalination plants are to be considered as examples of good behavior towards environment, meaning that the economical income is not considered to be the last objective. Examples of these would be small-sized autonomous desalination systems (ADS) for rural or small communities.

Another point to focus in would be the fulfillment of policies concerning environmental affairs such as brine discharge systems, the most important aspect considering the damage it would cause if it runs without any kind of control.

10. CONCLUSIONS

Engineers are facing a difficult challenge regarding the shortage of water in those countries that can't supply water to their inhabitants. The actual social statuses in the world handicaps many attempts to bring interesting programs to be developed, i.e. many countries with economic difficulties that also experience water shortages are the ones that are positioned in a worst side when talking about future perspectives in the field of desalination. It is stated that new technologies using renewable energy sources are becoming more accessible in an economic perspective, although it is still a big deal. If local government authorities are not willing to finance these projects then it will be extremely difficult to achieve any development in desalination. Therefore, as Gibbons states, the first important aspect has to be an economic and social support by local authorities. In accordance with Gibbons *et al*. (2008), the autonomous desalination systems (ADS) community has to make use of the pertinent authorities financing, as the European Union in this case.

Continuing with authorities, many policies and regulations are getting obsolete when implementing a desalination plant. Every year, new researches and studies brings up debates, doubts and questions about the actual environmental policy. The responsible environmental authorities in each country should focus in the researchers demands by facilitating and easy the acceptance or modification of environmental policies. In accordance with Greenlee *et al.* (2009) water quality standards will cause further optimization and development in reverse osmosis technology.

With local authorities support, the big first step to design a desalination plant is achieved. After this, the big deal would be the real matters concerning the desalination plant, i.e. the location, the water capacity, the environmental aspects, the input energy and the technical aspects. In agreement with Gibbons *et al*. (2008) and Greenlee *et al.* (2009) reverse osmosis can still be leading the desalination processes by facing the actual problems that come up regarding technological aspects such as membrane design or chemicals processes that low the efficiency of the membranes such as biofouling.

It is stated that those countries facing a shortage water situation have at the same time wide natural resources from which take advantage of. The sun and wind energy provide an unlimited source and they are completely compatible with reverse osmosis processes, therefore these mechanical energy sources constitute a very important and also a rich energy provider to reverse osmosis desalination plants. But also thermal natural resources can be seized. As Greenlee *et al.* (2009) states, the desalination method that pairs with thermal renewable energy is distillation. Consequently two main desalination processes arise nowadays: distillation and reverse osmosis. Ergo, the second main feature would be the process used for desalination, whether using RES or non-renewable sources.

Once the input energy source is decided then the plant's performance can be studied and calculated so the designers can focus in the environmental impact of the concentrate disposal, either it is brackish water or seawater feed system, taking into account the capacity of the plant, water and environmental policies. The third main direction should be the environmental aspects, leaded by the concentrate disposal.

As discussed before, an advantageous way of starting the design of a desalination unit while saving time and cost at the same time is to study already built plants in order to make a detailed analysis of the strengths and weaknesses of each one.

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