# Tackling the water scarcity problem in rural areas: guidelines and best design practices

**Piana F.*, Botti L.*, Casto A.*, Regattieri A.***

**Department of Industrial Engineering (DIN), Alma Mater Studiorum - University of Bologna,*

*Viale del Risorgimento 2, 40136 - Bologna – Italy*

*(francesco.piana2@unibo.it, lucia.botti5@unibo.it, alberto.regattieri@unibo.it)*

**Abstract**:

Pure water is the key resource of the Earth's life. Its availability is as important as critic especially in the developing regions, within areas stricken by natural catastrophes or wars and in humanitarian camps. The lack of drinkable water makes daily life almost impossible, forcing people to make strong efforts to survive. Furthermore, during the last decades, humanitarian organizations invested funds to improve solutions to strike the lack of drinkable water in overpopulated areas. Different improvements made in the last decades on water desalination, the most critical water filtration. These plants should be the answer also in humanitarian sector and in developing regions to tackle the problem of scarcity of drinkable water. Nowadays several desalination technologies and plants are available: however, due to them characteristics, nonporous membranes for the raw-water desalination and purification could be the most feasible solution for this difficult field. Reverse osmosis (RO) or Forward Osmosis (FO) plants allow producing ultra-pure drinkable water from water resources caught in nature, e.g. sea, rivers, lakes and aquifers.

This paper starts from a critical review of the topic and of the most promising technologies for water purification. After that, it proposes a mix of guidelines and best design practices targeted on nonporous membrane technologies to produce ultra-pure drinkable water targeted on rural, i.e. severe, environments. The final long-term goal is to support humanitarian logistics operating in critical contexts.

**Keywords**: drinkable water, reverse osmosis, purification technologies, humanitarian logistics, blue gold

## 1. Introduction

Water for creatures is life. People need water as surely as they need oxygen: without it life could not exist (Conant 2005). Water scarcity, which is the lack of sufficient available water to meet needs, is a problem that affects every continent and around 2.8 billion people (Watkins 2006; UNICEF 2008). Water is not only a scarce resource, but it might be undrinkable because of the presence of man-made and organic pollutants. Since the mid-1990s there has been a proliferation of international conferences dealing with water, along with a proliferation of high-level international partnerships. Meanwhile, there are 23 UN agencies dealing with water and sanitation (Watkins 2006). Clean water and sanitation would save the lives of countless children, support progress in education and liberate people from the illnesses that keep them in poverty (Watkins 2006). This problem become enormous in emergency situations, where water, food and resources are more scarce than usual and people are forced to live for surviving in congested area as humanitarian camps. In the last years problem of refugee and immigrants takes a great importance in worldwide community for the increasing of wars and natural catastrophes (Regattieri et al. 2016).

In poor regions water, should be undrinkable and especially carrier of many disease (Conant 2005): diarrhoea, dysentery cholera and typhoid are caused by many kinds of germs carried by human waste, unsafe water, flies and insects and also by food. Unsafe water should be purified before use, by means of filtration/depuration systems or at least by boiling. Boiling kills viruses and bacteria present in water, and causes of water-related diseases. However, a proper filtration is necessary to ensure the quality of water in terms of taste and turbidity.

Nowadays, water supply is a huge problem in humanitarian camps, as these camps are overpopulated and areas where they are establish do not have natural resources available for all people (Regattieri et al. 2015). A water supply is an essential requirement for people. Providing water is never free: water needs to be collected, stored, treated and distributed. Providing too much water is a waste of money (WHO). Determining how much is needed is one of the first steps in providing that supply (Gorchev and Ozolins 2011). People use water for a wide variety of activities and do not always have predictable needs. In some cultures, the need to wash sanitary towels or to wash hands and feet before prayer may be perceived to be more important than other water uses. Humanitarian agency usually builds camps close to fresh water resources, but often these are not free of pathogens so are usually undrinkable and not safe to use. Some pumps bring fresh water from river or lakes inside the camps, where water is filtered and stored in different purification plants.

A humanitarian camp is organised in modular sector, depending on the number of refugees to host. A unit module consists of a community of 16 families, for a total of about 80-100 persons. Each community has some infrastructures, as tends, latrines, water purification system, health centre, etc. The next paragraph introduces a detailed description of the water purification system adopted in humanitarian camp by United Nation Humanitarian Response Depot (UNHRD) - World Food Programme (WFP).

The purpose of this paper is to provide a critical review on desalination plants, in particular on plants using membrane technology, because the most appropriate to use in humanitarian logistics and developing regions for producing drinkable water from natural fresh spring as lakes, river or also from salty water like aquifer, sea and swamp. Authors decide to choose nonporous membrane technology for desalination because today are the most efficient, and the whole water purification plant could provide humanitarian specific, as dimension (them should ship by aircraft) and the ease to scaling up in relation to humanitarian camps dimension. All of these requirements are mandatory to develop an innovative idea for humanitarian context, because energy usually is expensive, plants should be as small as possible, in relation to water product, to be air shipped and, finally, easier to setting up in relation to people to satisfied during different humanitarian missions.

The integration of these plants in humanitarian sector, moreover, will increases water source available for producing drinkable water, as well as the overall fresh water quality, improving widely life condition of poor refugees in humanitarian camps.

The paper is organized as follow: paragraph 2 discuss the literature review; the water purification problem in Humanitarian Camps and the different technical solutions are discussed in paragraph 3. Paragraph 4 presents further researches and possible challenges.

## 2. Desalination review

Desalination is a natural process for the production of drinkable fresh water from sea salt water. Sea water contains different types of dissolved substances, from mineral salts (sodium, potassium, magnesium, etc) to organic substances like bacteria, viruses, etc. Most common sea water components are shown in the table below (Table 1).

Sea water salinity range is from 18-20‰ (black sea) to most salinity oceans 75‰. Water salinity inlet into the plant is one of the most important parameter to decide plant characteristics (i.e. number of desalination stages, plant sizing, types of membranes, etc).

Process of desalination consists in removing dissolved salt and other macro-substances from the water. There are different processes for make this separation: filter salty water by nonporous membrane holding salt micro molecules, separate liquid from salt by freezing water or by an evaporation/condensation process. These different industrial processes for remove salt from water are inspired by the nature. For example: solar desalination creates humidity that will become rain; water freezing in poles is another method to separate water (in the form of ice) from salt; osmosis in membrane cells is a natural filtration for different salinity liquids with a microporous membrane. Generally, desalination processes can be categorized into two major types: phase-change/ thermal and membrane process separation. Some of the phase-change processes include multi-stage flash, multiple effect boiling, vapour compression, freezing, humidification/dehumidification and solar stills. Membrane based processes include reverse osmosis (RO), membrane distillation (MD) and electrodialysis (ED) (Charcosset 2009).

**Table 1: salt dissolved in sea water** (*http://www.gira-sole.net/acquadimare.htm*)

| | **Teoretical value** | | **Actual value** | |
|---|---|---|---|---|
| **Ion** | **g/kg** | **%** | **g/kg** | **%** |
| Chlorine, Cl | 18,971 | 55,29 | 18,9799 | 55,04 |
| Sulphate, SO4 = | 2,639 | 7,69 | 2,6486 | 7,68 |
| Carbonate, CO3 = | 0,071 | 0,21 | - | - |
| Bicarbonate, HCO3 - | - | - | 0,1397 | 0,41 |
| Bromine, Br - | 0,065 | 0,19 | 0,0646 | 0,19 |
| Fluorine, F - | - | - | 0,0013 | 0 |
| Boric acid, H3BO3 | - | - | 0,0260 | 0,07 |
| Sodium, Na + | 10,497 | 30,59 | 10,5561 | 30,61 |
| Magnesium, Mg + | 1,278 | 3,72 | 1,2720 | 3,69 |
| Calcium, Ca + + | 0,411 | 1,20 | 0,4001 | 1,16 |
| Strontium, Sr + + | 0,411 | 1,20 | 0,0133 | 0,04 |
| Potassium, K + | 0,379 | 1,10 | 0,3800 | 1,10 |
| **Total** | **34,311** | **100,11** | **34,4816** | **99,99** |

People and researchers during years have developed and improved all of these methods to produce fresh water building prototypes and then complex plants to use sea water as fresh water resource. Desalination is not a free-cost process because to remove salt from sea water is a complex activity, which requires a huge quantity of thermal and electrical energy. In the last decade, the increase of desalination capacity is caused primarily not only by increases in water demand but also by the significant reduction in desalination cost as a result of significant technological advances that result in making desalinated water cost-competitive with other water sources (Ghaffour et al. 2013).

Nowadays, methods for water desalination are:

- *Physical:* distillation, water freezing (Rahman et al. 2007), osmosis, reverse and forward (Elasaad et al. 2015)(Prante et al. 2014) (Cath et al. 2013);

- *Chemical:* ion-exchange (IX) (Jason et al. 2006), absorbing (Sapre et al. 2013), water precipitation;

- *Electrical:* electrodialysis (ED) (Valero and Arbós 2009).

As cited in the list above, most influence studies on desalination come from US researchers, in particular the most influence academics and researchers in this topic are: from MIT laboratories since 2011, Dubowsky and his team proposed different innovations for smart RO plants. Menachem Elimelech from Yale, for about a decade, is studying FO and other nonporous desalination processes. As cited below, Achilli is studying osmosis processes, in particular PRO such as RO energy recovery systems since 2010. However due to the importance and the vastness of this topic research, in worldwide many scientist, both from academics and industries, study the desalination processes. In fact, this study will be important not only in a humanitarian and social context, but will also crucial in many sectors as aerospace missions, in electronics, in water waste treatments, and so on.

Today, as explained in the paper, is possible to combine more processes together to obtain a more energy efficient plant (Charcosset 2009).

### 2.1 Distillation

Distillation is a low-pressure process based on water evaporation (Wang et al. 2016). This process consists in increasing the temperature of water in a sort of boiler, up to its boiling temperature, to obtain fresh condensed water without salt. This process requires huge amount of thermal energy for boiling water, e.g. solar thermal energy or waste stream energy from industrial processes (Khayet 2013). There are different types of water distillation techniques, as Multi-Stadium Flash (MSF), Multi-effect distillation (MED) and vapor-compression desalination (VCD). MSF (Al-Hengari et al.) is one of the oldest desalination techniques for sea water. Other methods differ for plan complexity, working temperature operation and efficiency.

### 2.2 Electro dialysis

Electro dialysis (ED) (Ho and Li 2014) uses salt ions charges to desalinate solution through the electric potential difference given by two electrodes. An anion exchange membrane and cation exchange membrane are placed within these electrodes. Positive and negative salt ions are attracted by their opposite charge electrode and filtrated by the nonporous membrane. Electrodialysis is the higher recovery process for desalination (M. Reig et al. 2016).

### 2.3 Osmosis

Osmosis is a natural permeation of solvent from two solution with different salt gradient, across a nonporous membrane (Greenlee et al. 2009). Naturally, water with low salt concentration pass through the membrane for dilute salt water until the salty equilibrium is reached. This process is called Forward Osmosis (FO) (Achilli et al. 2009b). The application of a force (pressure) from the salty side produces a contrary flow, and water with high gradient passes through the membrane. Salt molecules cannot pass through nonporous membrane holes, so the desalination filtration takes place. The pressure applied to obtain Reverse Osmosis (RO) is directly proportional to water salt gradient. The following Figure 1 shows all possible situations for nonporous membrane filtration: feed fresh water and draw solution (high salt gradient) are separated by nonporous membrane (Sobana and Panda 2011).

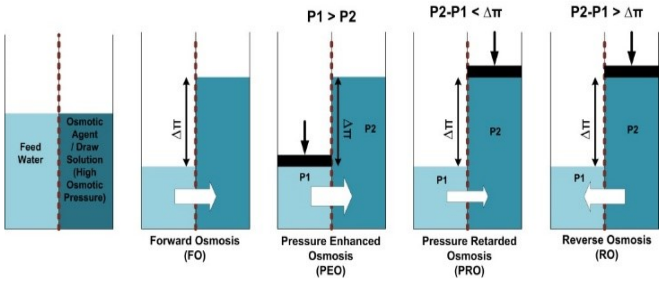


**Figure 1: Possible processes based on osmosis** (*http://ifoa.llobe.com/wp-content/uploads/2014/03/Osmotic_Processes_Diagram-1024x377.jpg*)

Naturally feed water passes through the membrane diluting the draw solution (FO). Pressure Enhanced Osmosis (PEO) is obtained by the application of a force on the feed side. On the other hand, the application of a force lower than the osmotic pressure ($\Delta\pi$) on the draw solution produces the Pressure Retarded Osmosis (PRO). Finally, Reverse Osmosis (RO) is the application of a force higher than the osmotic pressure on the draw solution. Moreover, Osmosis processes are appreciated, as different options for the integration of different types of recovery energy systems in the plant are possible (Evenden 2015). For example, Achilli et al. from several years have been studying chemical energy recovery systems using the salt gradient difference (PRO) (Achilli et al. 2009a; Achilli and Childress 2010; Achilli et al. 2013) combined with Pressure-Exchanger (PX) as mechanical recovery. Dubowsky and his research team (Bilton et al. 2011; Elasaad et al. 2015) instead are more focused on an energy recovery systems with pelton-turbine and electordyalisis systems as pre-treatment of the RO plant. These combinations and energy recovery solutions make osmosis the most efficient process among desalination processes.

### 2.4 Nonporous membrane

For water filtration are available many types of nonporous membrane, different by pores size (Geise et al. 2014). The following Table 2 summarizes the most common membrane from gross filtration to most fine osmosis filtration (Table 2).

**Table 2: pore size for each nonporous membrane filtration**

| Technologies | Pores size |
|---|---|
| Filtration | +10 μm |
| Microfiltration (MF) | 0.1 μm |
| Ultrafiltration (UF) | 0.01 μm |
| Nanofiltration (NF) | 0.001 μm |
| Reverse Osmosis (RO<br>Forward Osmosis (FO) | 0.0001 μm |

These polymer thin film membranes are used for different type of physical membrane filtration processes. These membranes differ for pore-size dimension, which are from 0.1 to 0.001 μm. They are more fine than traditional mechanic filter, but rougher than Osmosis filtration. Their use is preferred to separate microorganism, suspended particles, suspended solids, and concentrating macromolecular in chemistry, pharmaceutical, water treatment and electronic industries. These membranes are commonly adopted in osmosis plants as water pre-treatment for reducing particles and to create fooling in osmosis pressure vessel. In particular, this solution increases efficiency and availability of osmosis membranes.

Osmosis is the finest water filtration technique available. The use of a semipermeable membrane allows to filter everything dissolved in water, as sea salt and smaller particles usually contained in water, up to a dimension of 0.0001 μm. Such process requires energy and enough pressure to exceed the osmosis pressure. Actual energy limit for desalinate sea water (35 mg/l of dissolved salt) by reverse osmosis processes is about 1 kWh/m$^3$ for pure water produced. As aforementioned before, there are several benefits in the adoption of osmosis technologies for humanitarian logistics. The next Section 2 deeply explains pros and cons of the use of osmosis plants in remoted area characterised by lack of water.

## 3. AS-IS in Humanitarian Camps

Today in WFP-UNHRD (World Food Programme – UN Human Response Depot) humanitarian camps are used cheap, simple and reliable water filtrations system, to clean fresh water for refugees. Water is used by families for all household needs, from drinking and cooking to personal hygiene. Some pumps take water intake from natural fresh water supply near camps, filtering through some multi-stage filters explain in depth below and then storage in the camp. These systems are very far to be the best solution for producing drinkable water for people usually jet unhealthy and affect by different contagious disease. The quality of the treated water, in fact, in terms of colour, turbidity, and presence of pathogens, depends to the quality of the intake spring water. In addition, with these plants is not possible use sea water or just salty water as a water resource, because they cannot remove salt ions, so is necessary camps be close to some fresh water supply. Anyway, each water filtration system should produce up to 4 m$^3$ of water per day, depending on the spring water presence in the camp site, sufficient to satisfy the community needs.

These water purification systems are composed by some water pumps, pipes, filtration system (the number depends to water purification system dimension), some storage tanks and taps. Tap are used to fill small tanks provided to each family for household water needs. The filtration system, core of these plants, is made by multi-layer filters (Sphere Project 2011) (Figure 2), made with sand, activated carbon and other mechanical filters: the sand layer offers a mechanical filtration, removing part of gross impurities like turbidity and odours. Secondly, the water passes through a charcoal carbon filter, which reduces organics concentration and oxidant by chemical adsorption. Pores in carbon are a natural filter system able to remove particle until 50 μm. After filtration, water is stored in some tank and chlorinate. Chlorine is required to disinfect water and water supply (pipes and tanks), as it kills bacteria and microbes, and makes water ready to use (Ersel 2015).

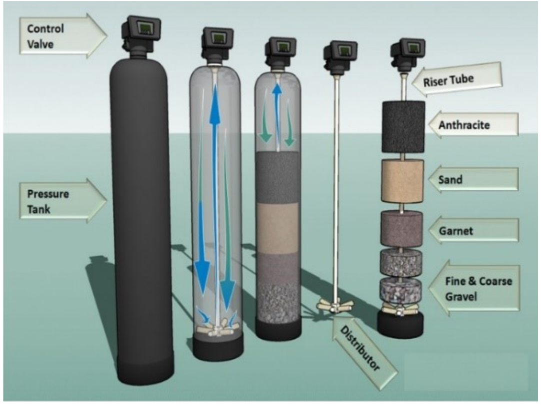


**Figure 2: Example of mechanical multi-layer filter**

### 3.1 Integrate water purification system

To improve current water management in humanitarian field, an interesting solution integrates the use of osmosis plants simultaneously with just illustrated water purification plants. Osmotic plants are more expensive than traditional purification system, and they have a smaller flow rate. However, they use both salty water and spring water, ensuring a production of ultrapure water without pathogens and other substances bigger than the membrane pores. So, this water is suitable to satisfy primary people needs for survive, as drinking and cooking. The use of safe water for cooking and drinking ensures people's health and improves the quality life of refugees. Secondary needs may be satisfied with water purified by traditional sand/carbon purification systems, i.e. drinkable water is not necessary for cleaning activities, as bathing or laundry, or gardening and livestock breeding within the camps.

Like other infrastructure of the camps, water system is usually designed and sized for a community module, which represents a unit module in the humanitarian field. In accordance with humanitarian organization studies on human water needs (Regattieri et al. 2015), the minimum vital allocation for each person is about 7 litres per day. This amount of water is used for drinking and cooking, which are the main human needs. Each community needs an osmotic plant that makes 1m$^3$ of ultrapure water per day.

There are several design alternatives for an integrated community water system:

- Osmosis plants working in parallel with a traditional filtration system. This solution requires a pre-treatment for osmosis plant to reduce fooling in osmosis membrane

- Traditional carbon/sand filter systems using as pre-treatment for osmosis plant. Plants work in series and a tank after traditional filtration system is used both as a buffer for osmosis and for water supply.

The osmosis system consists of a pre-treatment system (mechanical water filtration), high pressure pumps (up to 70 bar), osmosis membranes with pressure vessels (number and design depends to membrane parameters and plan use), nozzle valve, water tank and energy recovery system, as shown in the figure below (Figure 3).

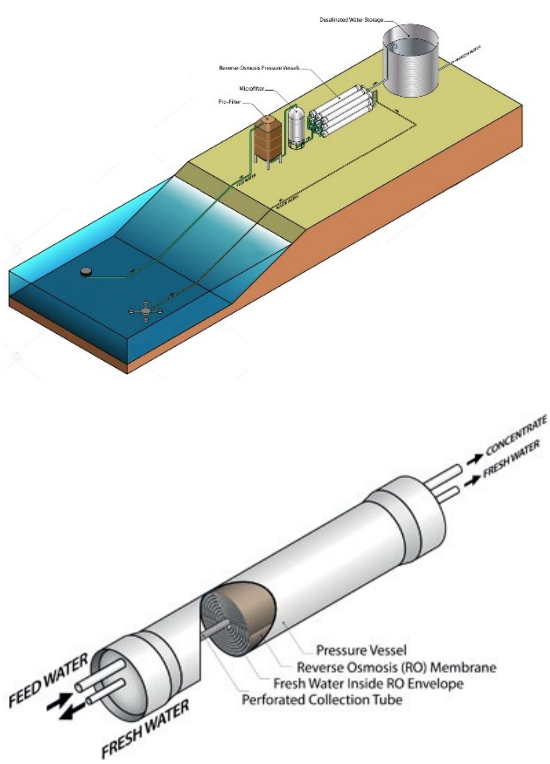


**Figure 3: Osmosis water purification plant and detail of osmosis pressure vessel** (*http://danolyte.com/it/progetti-speciali/desalinizzazione.html*)

After the osmosis treatment, chlorinate water may be adopted to reduce the possibility of bacterial contamination. Chlorine is use also for disinfect tanks and pipes.

Energy use during osmosis for reach high water pressure is not a waste in the process. After osmosis membrane pressure of retentive, high salinity part of water discard after desalination treatment, and it is used in the energy recovery system. There are different solutions available and relevant, from mechanical turbine or pressure exchanger to chemical energy recovery system as pressure-retarded osmosis. Energy systems are not usually used properly to produce energy, but to increase inlet water pressure and so, decrease high-pressure pump working load. Furthermore, it is possible to integrate the plant with

PV panels and BES system for the production and storage of the solar energy.

## 4. Further research

Further research on this topic will focus on the reverse-osmosis desalination plant design and sizing, in relation to the production of pure water. Sizing these plants on humanitarian camps size standard unit module should offer a modular plant to humanitarian organization. This solution is appreciated in humanitarian context because it offers more flexibility in different missions. Make a desalination plant usable in different environments and with different waters (salinity, turbidity, etc) is not simple as well as these plants work with several variables change with different waters in input. Furthermore, a wide study on an energy recovery system and PV-BES is necessary to offer the best trade-off for energy recovery and guarantee the best plant efficiency as possible. Plant design will follow humanitarian specifics on plant availability, simplicity to use and maintenance. These specifications make this project more complicate as just is: water desalination plants appear simple as principles, however, in spite of the small scale (few cubic meters of water products) requires complicate equipment (probes, sensors, control unit, etc), knowledge to use and daily maintenance. Reach make prototypes as describe above, not only should increase the human standard of living in humanitarian camps, but represents a great research innovation too. This solution should have an important impact also in reverse innovation market, where innovations born for developing regions and only successively for first world.

Desalination should be a trend to produce water in the next decades, in addition membrane solution, today, should be the most efficiency methods. A promising theoretical and research results are coming from graphene as new nonporous membrane desalination materials. Today several studies are on this important topic (Aghigh et al. 2015) (Khaled et al. 2015) (Tiwari et al. 2014).

## 5. Acknowledge

The Authors take this opportunity to express a deep sense of gratitude to the United Nation Humanitarian Response Depot (UNHRD) - World Food Program (WFP) of Brindisi, Italy for their support and valuable information during the development of this research.

## 6. References

Achilli A, Cath TY, Childress AE (2009a) Power generation with pressure retarded osmosis: An experimental and theoretical investigation. J Memb Sci 343:42–52. doi: 10.1016/j.memsci.2009.07.006

Achilli A, Cath TY, Marchand E a., Childress AE (2009b) The forward osmosis membrane bioreactor: A low fouling alternative to MBR processes. Desalination 238:10–21. doi: 10.1016/j.desal.2008.02.022

Achilli A, Childress AE (2010) Pressure retarded osmosis: From the vision of Sidney Loeb to the first prototype installation - Review. Desalination 261:205–211. doi: 10.1016/j.desal.2010.06.017

Achilli A, Williams T, Coutinho C, et al (2013) Pressure Retarded Osmosis Feasibility Study.

Aghigh A, Alizadeh V, Wong HY, et al (2015) Recent advances in utilization of graphene for filtration and desalination of water: A review. DES 365:389–397. doi: 10.1016/j.desal.2015.03.024

Al-Hengari S, El-Bousiffi M, El-Mudir W Performance analysis of a MSF desalination unit. doi: 10.1016/j.desal.2005.03.010

Bilton AM, Wiesman R, Arif a. FM, et al (2011) On the feasibility of community-scale photovoltaic-powered reverse osmosis desalination systems for remote locations. Renew Energy 36:3246–3256. doi: 10.1016/j.renene.2011.03.040

Cath TY, Elimelech M, McCutcheon JR, et al (2013) Standard Methodology for Evaluating Membrane Performance in Osmotically Driven Membrane Processes. Desalination 312:31–38. doi: 10.1016/j.desal.2012.07.005

Charcosset C (2009) A review of membrane processes and renewable energies for desalination. Desalination 245:214–231. doi: 10.1016/j.desal.200

Conant J (2005) Water for Life - Community water security, The Hesper. Berkeley, CA

Elasaad H, Bilton A, Kelley L, et al (2015) Field evaluation of a community scale solar powered water purification technology: A case study of a remote Mexican community application. Desalination 375:71–80. doi: 10.1016/j.desal.2015.08.001

Ersel M (2015) Water and sanitation standards in humanitarian action. Turkiye Acil Tip Derg 15:27–33. doi: 10.5505/1304.7361.2015.48753

Evenden AR (2015) Sea water reverse osmosis - energy efficiency & recovery. Water Pract Technol 10:187. doi: 10.2166/wpt.2015.023

Geise GM, Paul DR, Freeman BD (2014) Fundamental water and salt transport properties of polymeric materials. Prog Polym Sci 39:1–42. doi: 10.1016/j.progpolymsci.2013.07.001

Ghaffour N, Missimer TM, Amy GL (2013) Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability. DES 309:197–207. doi: 10.1016/j.desal.2012.10.015

Gorchev HG, Ozolins G (2011) WHO guidelines for drinking-water quality. WHO Chron 38:104–108. doi: 10.1016/S1462-0758(00)00006-6

Greenlee LF, Lawler DF, Freeman BD, et al (2009) Reverse osmosis desalination: Water sources, technology, and today's challenges. Water Res 43:2317–2348. doi: 10.1016/j.watres.2009.03.010

Ho W, Li K (2014) Process integration of electrodialysis for a cleaner environment. doi:

10.1016/j.coche.2014.01.001

Jason DP, Mark LFP, James A. Voigt, et al (2006) Desalination of Brackish Waters Using Ion-Exchange Media. Ind Eng Chem Res 45:4752–4756.

Khaled AM, Bilal M, Ali M, Marwan K (2015) Functional graphene nanosheets: The next generation membranes for water desalination. desalination 208–225.

Khayet M (2013) Solar desalination by membrane distillation: Dispersion in energy consumption analysis and water production costs (a review). Desalination 308:89–101. doi: 10.1016/j.desal.2012.07.010

M. Reig, S. Casas, O. Gibert, et al (2016) Integration of nanofiltration and bipolar electrodialysis for valorization of seawater desalination brines: Production of drinking and waste water treatment chemicals. desalination 13–20.

Prante JL, Ruskowitz J a., Childress AE, Achilli A (2014) RO-PRO desalination: An integrated low-energy approach to seawater desalination. Appl Energy 120:104–114. doi: 10.1016/j.apenergy.2014.01.013

Rahman MS, Ahmed M, Chen XD (2007) Freezing melting process and desalination: review of present status and future prospects. Int J Nucl Desalin 2:253. doi: 10.1504/IJND.2007.013549

Regattieri A, Piana F, Bortolini M, et al (2016) Innovative portable solar cooker using the packaging waste of humanitarian supplies. Renew Sustain Energy Rev 57:319–326. doi: 10.1016/j.rser.2015.12.199

Regattieri A, Santarelli G, Piana F, Gamberi M (2015) Classification of technical requirements and the means of addressing the problem of waste management in a refugee camp. In: Klumpp M, Sander L, Regattieri A (eds) Humanitarian Logistics and Sustainability, Lecture no. 24/03/2015, p 200

Sapre MS, Auti AB, Singh TP (2013) Design and Manufacturing of Absorber for Solar Desalination System. Appl Mech Mater 446–447:716–720. doi: 10.4028/www.scientific.net/AMM.446-447.716

Sobana S, Panda RC (2011) Identification, Modelling, and Control of Continuous Reverse Osmosis Desalination System: A Review. Sep Sci Technol 46:551–560. doi: 10.1080/01496395.2010.534526

Sphere Project (2011) The Sphere Project: Humanitarian Charter and Minumum Standars in Humanitarian Response_J.

Tiwari I, Singh AK, Yadav A, Jha RK (2014) Sustainable Power Production and Purification of Water. 2258–2263.

UNICEF (2008) Unicef Handbook on Water Quality. United Nations Child Fund (UNICEF), New York, 2008 1–191.

Valero F, Arbós R (2009) Desalination of brackish river water using Electrodialysis Reversal (EDR) Control of the THMs formation in the Barcelona (NE Spain) area. DES 253:170–174. doi: 10.1016/j.desal.2009.11.011

Wang Q, Li N, Bolto B, et al (2016) Desalination by pervaporation: A review. Desalination 387:46–60. doi: 10.1016/j.desal.2016.02.036

Watkins K (2006) Human Development Report 2006 - Beyond scarcity: Power, poverty and the global water crisis.

WHO Minimum water quantity needed for domestic uses. Tech Notes Emerg 9:1–4.