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Desalination technologies for developing countries: what solutions?

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Desalination technologies for developing countries: what solutions?

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ABSTRACT

Desalination is a water treatment option known by people at large for its large scale use in rich countries such as in the Middle East. Nevertheless, this is not an option for some developing countries such as Kenya, as, due to the water scarcity existing in such places, saline water is the only source for drinking purposes. Numerous technologies exist for desalinating water, from the very simple process of solar desalination already in use in the antiquity, to the most complicated membrane or electronic technologies. Appropriate solutions adapted to development or emergency situations have to be taken depending on the context in place in developing countries.

Through discussions with private companies and research laboratories, some of the most up to date systems currently usable have been reviewed in order to assess their suitability for an implementation by the charity Oxfam GB in a near future in several locations in West African and South Asian countries. Criteria have been defined according to the needs observed by the charity in targeted places, better targeting possible appropriate technologies. The study focused on technological details as well as long term management issues for optimising ownership of the local communities. After comparison of the reviewed technologies and confrontation with the defined criteria, it resulted that interesting options available for development are membrane-based or distillation. The use of clean energy sources such as brute strength (mechanical systems using animal or human strength) simplify operation and maintenance, and lower operation cost at the same time for a sustainable implementation in remote villages. Automated electronic-based systems are also an opportunity for emergency situations. However, most of those solutions have not been in use in a developing country yet. Consequently, innovative experimentation is needed for the good of all.

Keywords:
Appropriate technology, brackish water, development, emergency, sea water, water treatment.

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In memory to Henri Lacroix, my beloved uncle, who died during the time period of this thesis.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

ACRONYMS

BC	Before Christ
CDI	Capacitive DeIonization
CNT	Carbon Nano Tubes
CSMCRI	Central Salts Marine Chemicals Research Institute
ED	Electrodialysis
ETC	Environment Technology Centre
FO	Forward Osmosis
GB	Great Britain
IDP	Internal Displaced People
IE	Ion Exchange
LLNL	Lawrence Livermore National Laboratories
MD	Membrane Distillation
MED	Multi-Effect Distillation
MEWD	Multi-Effect Water Distillation
MSF	Multi-Stage Flash
NGO	Non- Governmental Organisation
POE	Point-of-Entry
POU	Point-of-Use
PROtector	Pumped Reverse Osmosis system developed by A+ Trading
PV	Photovoltaic
PV-RO	Photovoltaic- Reverse Osmosis
R&D	Research and Development
RADG	Remote Area Development Group
RO	Reverse Osmosis
SDAWES	Seawater Desalination by an Autonomous Wind Energy System
SSS	Small Scale System
TDS	Total Dissolved Solids
TFC	Thin-film composite
USA	United States of America
UTEP	University of Texas at El Paso
WHO	World Health Organisation

1. Introduction

Desalination technologies are an option increasingly used by rich countries, especially in the Middle East, in region lacking safe water. Nevertheless, desalination is not always a high technology option whose use is limited for wealthy countries such as in the Middle East. Whether in West Africa or in South Asia, especially in remote coastal areas, the need to remove salts from water is necessary to supply communities with safe drinking water. Indeed, even if excess salt has no proven negative health impact (WHO, 2004a), salinity as Total Dissolved Solids (see measurement in appendix A1) has to be controlled, as water taste is influenced by the concentration of dissolved salts. As taste limits are strongly dependant on communities and local habits, it is difficult to advise a specific guideline value. Nevertheless, WHO generally considers a TDS of less than 500mg/L as good enough to be drunk, although it is not a standard value.

In numerous areas such as in the Middle East where half of desalination plants are located (figure 1), desalination is considered as a common water treatment process. With over 15 000 desalination plants in 120 countries nowadays (Clayton, 2006), desalination systems constitute an important part of the water market, and are expected to double in the next 10 years.

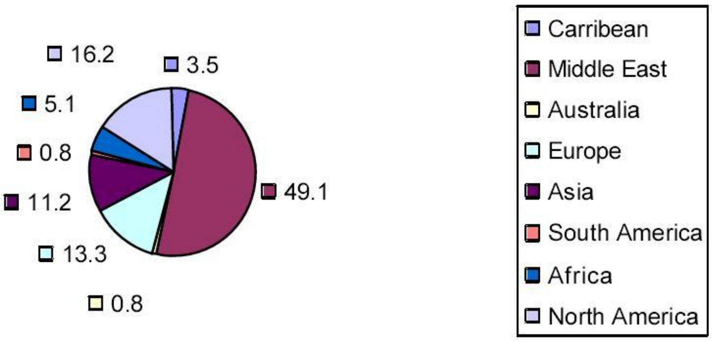

Figure 1. World distribution of desalination plants in 2002 (%) (Clayton, 2006)

Initially defined as the action of "removing salt from seawater" (Cambridge online dictionary, 2009), the definition of desalination is now being extended to the removal of salt from any saline water, including contaminated groundwater. Thus, by extension, it "usually refers to processes which reduce the quantity of dissolved substances in source

water" (Clayton, 2006). Indeed, salts other than sodium chloride naturally occur in water and are part of the TDS, such as calcium bicarbonate and magnesium sulphate.
Although salty water is unpleasant to taste, still for palatability purposes and as source of minerals, these dissolved solids should not be totally eliminated from water as "water that is devoid of these substances tastes 'flat' or insipid" (Clayton, 2006). Classification of waters according to their dissolved solid contents exists (table 1), with taste as discriminating factor (table 2).

Table 1. Classification of waters by dissolved solids contents (categorisation of 'unacceptable' waters) (Clayton, 2006)

Description	Dissolved solids (mg/l)
Mildly brackish	1,000 to 5,000
Moderately brackish	5,000 to 15,000
Heavily brackish	15,000 to 35,000
Average sea water	35,000

Table 2. Palatability as a function of dissolved solids (Clayton, 2006)

Palatability	Dissolved solids (mg/l)
Excellent	less than 300
Good	between 300 and 600
Fair	between 600 and 900
Poor	between 900 and 1,200
Unacceptable	greater than 1,200

Water produced by desalination can be used directly if minerals content is not too low. Indeed, in the case of distilled water, essential dissolved solids such as NaCl have to be re-injected in treated water to make it safe by reducing its acidity and corrosivity (WHO, 2004b). This mildly alkaline water thus obtained can be used for drinking, cooking, or even irrigating.

WHO does not give standard values for desalination as taste limitation depends on communities, nonetheless an average value of 500 mg/L is commonly used as a reference TDS after treatment (WHO, 2004b).

The present study aims to identify what desalination technology is currently available for being used by Oxfam in a short term in several developing countries. The situations targeted are development, e.g. remote villages with contaminated salty water, and chronic emergency, e.g. remote areas chronically suffering from floods. Even if salt removal is the major treatment needed, as fluoride (an element found in groundwater and known to cause significant health impacts following prolonged exposure) is also of great concern in such areas, technologies being able to remove both salts and fluoride are envisaged with equal interest. Firstly, the current literature available on low cost, low energy desalination technologies is reviewed. To supplement this information, companies and research laboratories having worked or still currently developing such technologies are consulted to assess the suitability of all these various technologies for the defined project. A special attention is taken on long-term technology management. All these data are then used to assess which system is relevant and in which context.

2. Objectives

The following study is aiming to identify suitable low cost desalination technologies, where possible integrating fluoride removal with a target value of 1.5mg/L (WHO, 2004b), currently available for an implementation by Oxfam GB in the near future in selected development and emergency contexts. For this goal, after a discussion with Andy Bastable, Public Health Engineering Coordinator for Oxfam GB, several criteria have been defined to better target any possible technology, in correlation with some technology limitations. Brian McSorley, Public Health Coordinator for Oxfam in Kenya, has also been consulted as he already identified a possible test site in Turkana region, Kenya.

Definition of different criteria is needed to better target the design and capacity of the desalination systems highlighted. Those criteria are not only technical (e.g. water demand) but also context-oriented as the success of the technology management over a long time will depend on the cultural context (e.g. time range along the day for collecting water in the village) and the situation surrounding (whether development, emergency, or chronic emergency situations). All these criteria have been defined as follows in agreement with Andy Bastable and also Brian McSorley, Oxfam coordinator in Kenya.

2.1. Water demand

The scale targeted is small scale, whether at the level of one household (e.g. a family of 5 people) or a whole village (1,000-5,000 people). According to Peter-Varbanets et al. (2009), small scale systems refer to several ranges:

- Point-of-use (POU): it only considers drinking water. Generally, its daily amount is about 2l for drinking and 8l for cooking for one person.
- Point-of-entry (POE): this is the household scale. The amounts considered are much higher: about 100-150 l per person per day.

- Small scale systems (SSS): this scale is constituted of several family of a village, but always smaller than centralised systems, which define a flow of about 1000-10000 l/day.

Thus, household systems can be defined as POU or POE, while decentralized systems could be defined as POU, POE or SSS.

For the following study, an average of 5 l per person per day has been considered for drinking purposes. Hence, considering that a family is composed of about 5 persons, a daily demand for drinking water of 25 l/family is obtained. Depending on the system, the technology studied are for a use at the scale of a family (5 people), a cluster of family (about 5) or a whole village (1,000-5,000 people), but always smaller than a town.

2.2. Contexts targeted

Six countries have been identified by Oxfam GB as major demanders of desalination system for remote areas: 4 in West Africa (Ethiopia, Kenya, Somaliland and Uganda), 2 in South Asia (Pakistan, Sri Lanka). Water source is thus brackish water (TDS of the order of 1000mg/L) or seawater (TDS about 35,000mg/L).

Additionally, development or chronic emergency situations are the kind of conditions of use expected. As defined with Andy Bastable, stable situations where the community, through village committees, is willing to enhance their water supply over a long term are considered are development situations. Thus, capacity is considered as low in such situation (no technician or engineer available). Indeed, the community only has to rely on its own capacity for daily operation, with no outside help, even if Oxfam can intervene during the implementation of a technology (building, training, provision of spare parts at the beginning).

On the other hand, in chronic emergency situations, e.g. region regularly flooded (Sri Lanka) or with unstable politic situations (IDP camps in Uganda), external expertise to manage more complicated technologies is usually provided by NGOs as technical support such as engineers and technicians are available/on hand.

Especially, the case of Kenya has been further defined as the Public Health Coordinator for Oxfam in Kenya is willing to implement such a system in some remote villages in the region called Turkana Central where high salinity and especially fluoride are common water quality issues faced by the population. Some testing sites have been identified as described in the paragraph above. For a cultural point of view, if technologies have already been tested in real conditions in similar countries than those defined above, it would be a serious advantage.

2.3. The proposed test site in Kenya

The region in Kenya called Central Turkana is proposed as a test area following advices from Brian McSorley, Public Health Coordinator for Oxfam in Kenya, as “Turkana is the most difficult possible environment to try out”. Indeed, if a suitable solution is able to win this challenge, it will probably be easier to implement a similar system in other areas with higher capacity.

Salinity is moderate in this district, at a level not harmful for consumption (TDS two to four times higher than WHO guidelines), but variation in water quality from sources already provided with support of Oxfam. For instance, one of the wells is not used anymore in dry season. As for fluoride, its concentration is of higher concern with an average of 12.1mg/L in the lake, higher in places surrounding. Indeed, the WHO guideline value for fluoride is about ten times smaller (1.5 mg/L). Water quality analysis is available in different locations (see table 3 below).

Table 3. Some water quality analyses in Turkana Central. (Rop, 2006)

Location	Turkana Lake	Kerio	Longech
Population	-	4,000	1,500
TDS (mg/L)	2,340	1,382	810
Fluoride (mg/L)	12.1	13.8	24
Current water supply	Direct extraction from the Lake, especially in dry season	Borehole, pump equipped with wind turbine (not working)	Shallow well equipped with an Afridev pump

Kerio and Longech villages are two proposed test sites, even if Longech (see figure 2) is the most probable as villagers in surrounding areas always refers to this village as the worst case in terms of water quality. Indeed, numerous skeletal fluorosis cases have been reported in this place and Oxfam’s trials with bone and charcoal filters were unsuccessful due to the very low maintenance capacity. Practically, a supplier for spare parts exists in Nakuru but it is at a distance of 650km from the village, which is not viable.

Figure 2. The current water supply in Longech village: an Afridev pump

(picture kindly supplied by Brian McSorley)

An unsuccessful implementation of low cost water treatment for this kind of issues exists in the Wajir district. It has been reported that the Kenya Red Cross tried to provide a village with a portable unit, rather designed for emergency water supply, which was no more operating after a while. The community was in fact not able to manage the technology in a longer term as “there are too many things that can go wrong and consumables cannot or are difficult to source” (Brian McSorley, 2009).

Conclusion on objectives

Due to the situation, whether for development or chronic emergency, and depending on the capacity existing in the targeted locations, several limitations appear for technology operation and long-term management. Specifically, Oxfam is searching for a robust and technically appropriate product dealing with very low capacity in region similar to Turkana Central, aiming to replicate successful systems. The table 4 below summarises various criteria and limitations to be considered.

Table 4. Criteria for identifying and assessing suitable technologies.

Initial TDS	1,000-35,000 mg/L
Targeted TDS	Below 500 mg/L
Water demand targeted	From a family (25L/day) to a whole village (up to 25,000L/day)
Building	✓ Development: With local expertise and local materials ✓ Chronic emergency: with help of exterior expertise (civil engineers, computing knowledge…)
Operation	✓ Development: with local expertise, use of renewable energies is an advantage ✓ Chronic emergency: with help of exterior expertise (technicians and engineers)
Maintenance and spare parts	✓ Development: with local expertise, if possible spare parts produced locally ✓ Chronic emergency: with help of exterior expertise (technicians and engineers)

3. Methodology for identifying suitable technologies

3.1. First step: preliminary state-of-the-art through a literature review

The first step to identify technologies that could be used at small scales in remote areas is to do a state-of-the-art of the researches done on this subject. This step will make it possible to identify a range of technologies but also to be aware of existing field experimentations and their issues faced, and as well to identify some possible contacts for the next step.

This literature review has been done starting from information given by Andy Bastable of Oxfam GB consisting of articles, e-mail conversations and a draft report commissioned by OXFAM from the Development Resource Centre Environment-Water-Sanitation (Noble and Grimshaw, 2008). The latter was very useful as numerous sources were provided and as a wide review of new technologies available were described.. Other preliminary sources were books available in the campus library and scientific articles from Science Direct and Springerlink websites. Those sources were not only used as raw information sources but also as a source of other interesting references. Additional sources were the websites of commercial companies and NGOs to provide information on technology commercialization and in particular field experimentations. It has to be noticed that information obtained on commercial websites is not as rigorous and objective as peer review. It consequently has to be taken cautiously and critically. A first draft of the literature review was thus written identifying the main candidate technologies, which was then completed after obtaining additional information by direct contact with organisations and companies concerned.

3.2. Second step: Obtain further practical information with companies and laboratories developing promising technologies

Having identified technologies of potential interest in the literature, knowledge of their functioning in practice over the long term, especially in terms of technology management, were needed to aid the process of evaluating their suitability and comparing their characteristics against the identified criteria. Specifically, feedbacks on existing case studies or field experiences help assess how a technology could be managed in reality.

Advice was sought from Andy Bastable and academic staff to identify possible contacts. This practical part involved contacting private companies, NGOs and research institutions to identify the main issues that might be faced during implementation and long-term use of the technologies found. Additional details on some technologies can thus be found at the same time to complete the literature review.

A list of contacts is given in appendice A5, as well as a written transcription of meetings (A8) and phone interviews (A9).

Developers of potential technologies were contacted to gather information for assessing the suitability of their proposed system for the needs of Oxfam.

3.2.1. Research/Choices of possible contacts

Those contacts are various, from universities and research laboratories to private companies and organisations. They have been identified through literature, thanks to the DEW Point report commissioned by Oxfam GB or after advices from Andy Bastable. Along discussion with the academic staff and additional internet researches, some other potential contacts have been identified. A table gathering the complete contact details is joined in appendice A5.

3.2.2. Method used for contacting

Contact was envisaged in three various forms:

- Face-to-face discussion conducted as semi-structured interviews
- Phone calls interviews
- E-mails, with sending of a questionnaire as a word document, to be filled by the contact

After writing the literature review and after having obtained complete information from Brian McSorley in Kenya, a general questionnaire has been drawn. It is constituted of 5 sections, detailed in appendix A6:

- Description of the technology
- Technical details
- Long-term management
- Socio-cultural acceptance
- Additional information

E-mails were initially sent to the contact identified to present the project and send the questionnaire for obtaining minimum information. Phone calls can thus be planned to obtain further details if necessary. E-mails were used in the first place as this is free and there are no limitations of time due to difference of time zone, contrary to phone calls.

3.3. Step 3: Assessing technologies

Information obtained for each possible system was confronted with the criteria defined in the objectives, as advised by Lockett and Thomas (1978). By comparing the targeted size of the population served and costs per person served among technologies reviewed when possible (cf. corresponding table obtained in part 4.2.1), a match with a possible corresponding context was searched. Systems with existing field experimentation were studied with a specific attention. In order to lower operation and maintenance costs, use of local materials for building and spare parts is considered as a serious advantage, as well as use of renewable energy. Technologies at research level, with a potential for real conditions implementation in short term (1-2 years) were also envisaged. On the contrary, proposed systems not ready for an implementation in the timescale were eliminated, as well as if technical description is out of the range defined (daily flows below 25 l/day or above 50,000 l/day, building cost above US$100/person served).

4-Literature review on existing low cost desalination technologies

Desalination technologies are very numerous. Amongst them, the most developed ones are for large scale applications in industrialized or rich countries, such as in Middle East countries or Australia. Most of those processes, such as multi-stage flash distillation (MSF) and electrodialysis (Clayton, 2006), are not transferable in developing countries according to their operating and maintenance cost (high technologies, high energy cost). Consequently, it is relatively hard to find which technology is suitable for a developing or chronic emergency context. The following literature review aims to gather information (flows, materials, operation and maintenance) on low cost desalination technologies that could be used in remote areas in developing countries at a village scale. Limitations for these technologies are different than for richer countries: they have to be adapted to a small-scale use, with as low operating and maintenance cost as possible, for an easy implementation using local knowledge (Noble and Grimshaw, 2008).

Low-cost desalination processes can be divided in three processes:

- Thermal processes or distillation which simply consist in heating the water to make it change state and be separated to the salts, non-volatile at such relatively low temperatures.
- Membrane technologies (e.g. reverse osmosis) which separate salts from water thanks to a semi-permeable membrane.
- Electronic processes (e.g. ion exchange) where electrodes are used to separate ions diluted inside the water.

However, two systems mixing two of the previous processes exist: membrane distillation, mixing both membrane and distillation processes, and electrodialysis, a process using membranes to separate ions according to their polarity. The figure 3 has been drawn to summarize this classification.

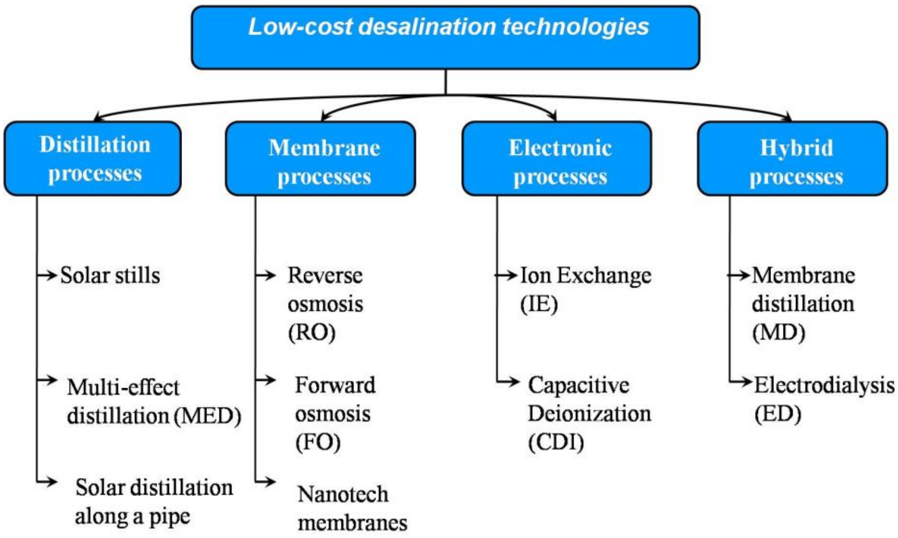

Figure 3. Classification of existing low cost desalination processes.

Although most of the several desalination technologies used in high income countries (MSF, MED…) have a high energy-demand level, for a context of small-scale decentralized system in a developing country, use of renewable energy such as wind and solar instead of fuel are necessary. Brute strength is also readily available and can be used as a low-cost energy source.

4.1. Thermal Processes: distillation

4.1.1. Principle

Distillation is the simplest and oldest way to remove salt from water. It is based on "converting saltwater to steam [by heating] and then condensing and collecting the freshwater distillate" (Spang, 2006). Indeed, salts are not volatile at the temperature corresponding to water vaporization, inducing a separation of water and salts thanks to a simple heating. Figure 4 shows the main steps common for all distillation processes, whether solar stills or multi-effect distillation.

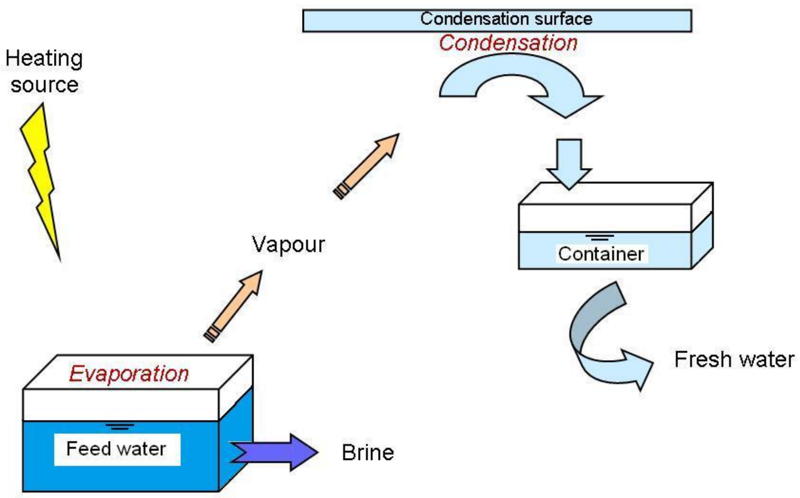

Figure 4. Principles of desalination by distillation.

It can be easily done at home with kitchen utensils such as two pots of different size and a plastic sheet weighted, underneath which the condensation will occur (WEDC, 1999). Solar energy is the first energy source used for this process, which is not surprising as it is broadly available around the world. The idea to use solar energy to distil water is very old, with a first large-scale application as early as 1872 in a small mining community in Chile (Practical action, date unknown).

4.1.2. Solar distillation

The principle of solar distillation is to use solar energy to evaporate water from a shallow basin while salt stay in the basin, and to condense this water on the underneath side of a surface above the basin, such as a slope of glass, and collect it in a container (Figure 6). But use of solar energy as a raw energy source is limited as yield obtained by such a system is only about 2-3 l/m^2/day. At large scale, developed countries usually use more expensive sources of energy such as fuel to distillate as it is often the case in MSF or MED systems. The building of a simple solar still is shown in figure 5.

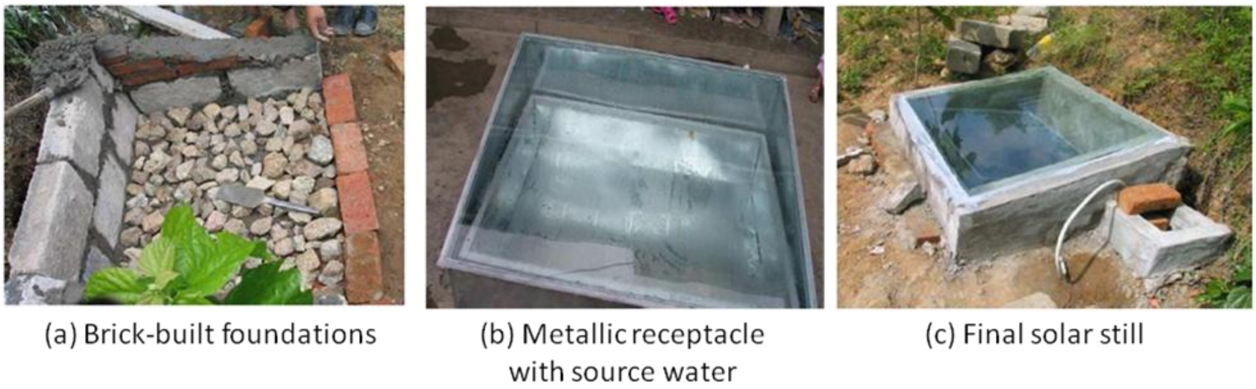

Figure 5. Building of a solar still. (Xin Yang, 2007).

Numerous designs of solar distillation systems exist that could help optimizing it for having the best efficiency according to the local conditions. They can be separated according to the role of sun as a direct (passive stills) or indirect (active stills) source of heating and energy.

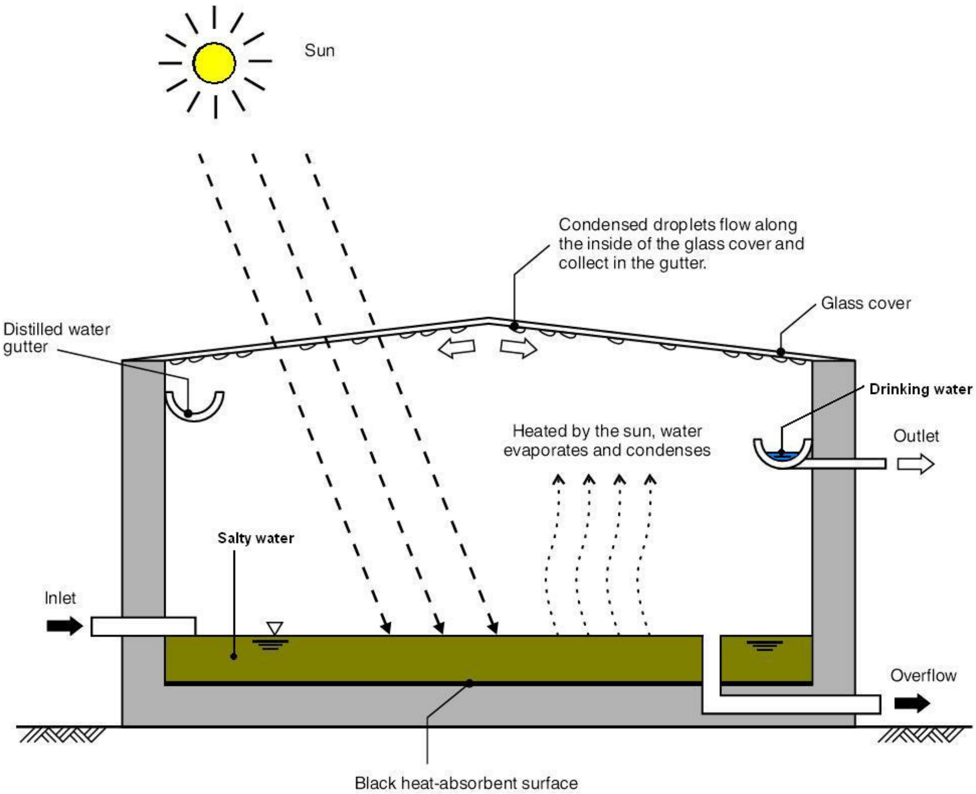

Figure 6. Passive solar still design : a double slope still (after WEDC, 1999).

The daily yield obtained by the simplest design (simple basin passive solar still) of such system is very low: about 2.3 L/m^2 (Practical Action, unknown). Consequently, as the productivity is low with such a system, cost of water is high. Several possibilities exist to slightly increase the yield obtained. For passive stills, the design (e.g. water depth, glass slope) can be adapted to the condition of use, e.g. solar radiation and material available (Arjunan et al., 2009). Additionally, addition of dies can increase absorption of solar radiation by water as shown in table 5. Operation of solar stills is very simple as all is powered by the solar heating. Maintenance is also simple and mainly consists in cleaning the container and the glass cover.

Table 5. Several options to increase the yield of a solar stills (after Arjunan et al., 2009).

Possible improvements	Effects
Dark dyes or absorbing medium	Improvement of radiation absorption of the water
Cover cooling or water flowing inside the basin	Acceleration of condensation process
Use of a double condensing chamber, an internal heat exchanger or a wick	Improvement of overall efficiency by improving heat exchanges

Contrary to passive solar stills, active solar stills do not use sun radiation to directly heat salty water but integrate an indirect heating system (cf. Figure 7). This system can be either a solar heater, or a solar concentrator or other heating devices (Arjunan et al., 2009). Using such an indirect method of heating with solar energy make it possible to increase solar still's yield for instance up to 3.5 times higher than the yield of passive stills with an hybrid photovoltaic/thermal system (Kumar and Tiwari, 2009).

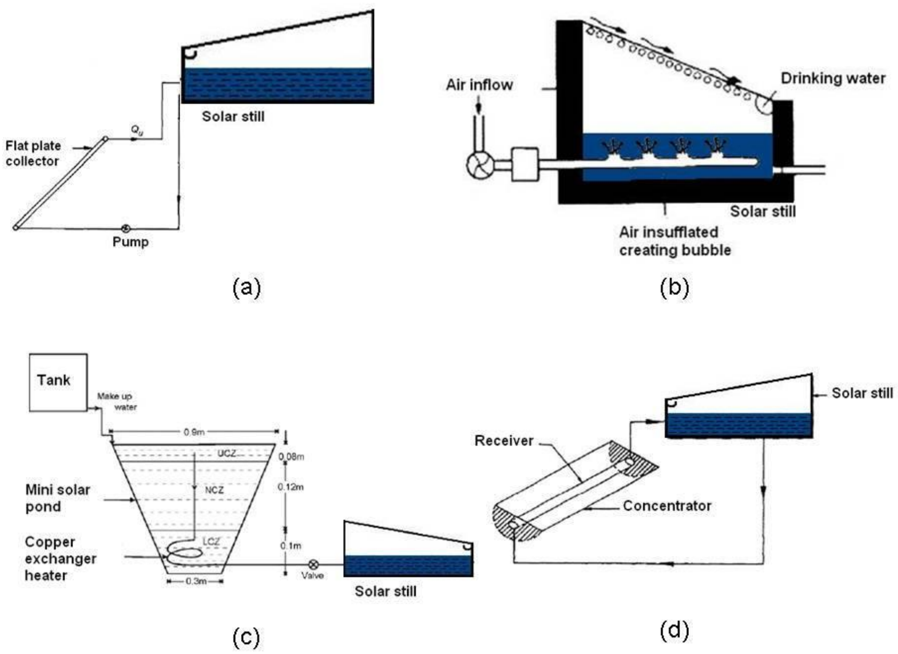

Figure 7. Examples of active solar stills design (after Arjunan, 2009).

Solar still is coloured in blue with black borders.

(a) Using flat-plate collectors, (b) Air-bubbled solar still, (c) Mini solar pond-assisted solar still, (d) Concentrator-assisted solar still

Nevertheless, adding such additional heating system represents an investment which may be more important/higher than the reduction of water price gained by improving the overall yield.

Solar stills are finally an easy to operate and maintain way to desalinate. However, the main disadvantages of this technology is the capital cost and the small yield obtained, which implies a large area of land available for obtaining sufficient quantity of water.

Similar system can provide water for making grow plants in greenhouses at the same time. This technology is called Seawater Greenhouse and is currently studied in real conditions in Sultanate of Oman (in collaboration with Sultan Qaboos University) and Gran Canaria

Table 6. Summary of advantages/disadvantages of solar distillation.

Advantages	Disadvantages
o Possibility to use local material o Low operation and maintenance o Possibility to adapt the design to local specificities to obtain an optimum yield o Possibility to couple a greenhouse to grow vegetables	o Low flow (2-4 L/day) implying the need of large area of land available ($10m^2$ per family) o High capital cost (from 600€ to 1000€ for a family-size still) o Not easy to replicate as parameters have to be adapted to local conditions

4.1.3. Small-scale multi-effect distillation

Principle

This is a distillation technique where the vapour produced by heating at the first "effect" is condensed in the second "effect" while the energy released by this condensation is used to evaporate the water in the second "effect", and so on for each "effect". The difference with multi-stage flash technology used in higher income countries is that the number of stages is generally smaller (Mudgal et al., 2007, Akhatov and Mahkamov, 2008).

Existing projects

In Morocco, pilot plants exist implemented by Solar Energy and Hydrogen Research (ZSW) in Germany in collaboration with the National Centre for Coordination and Scientific and Technical Research in Morocco. This system is a hybrid system using solar energy during daylight and fuel at night designed to be used in remote fishing villages or dedicated supplies to coastal tourist hotels, frequently affected by disruption of piped supplies (MEDRC). Its efficiency is higher than classic solar distillation, reaching yield as big as $0.05\text{-}10m^3$ per day (Noble and Gromshaw, 2008).
Durham University, United Kingdom, is currently studying an experimental multieffect solar thermal water desalination system (an MED unit coupled with solar troughs) which presented so far the advantage of being twice more efficient than conventional solar greenhouse type stills, being only 1.5 times more expensive at the same time

(Akhatov and Mahkamov, 2008). This unit is developed for Central Asia, especially Uzbekistan, but is still a laboratory experiment, not tested in real conditions.

Another successful implementation of a small-scale MED system has been done in India using local materials (Mudgal et al., 2007). This simple system was however using fuel (charcoal, firewood, briquettes, and biomass) as a source of energy. Operation and maintenance can be done by a local mechanic.

Table 7. Summary of advantages/disadvantages of multi-effect distillation.

Advantages	Disadvantages
○ Small scale (0.05 i.e. 2 families-10m^3 of drinking water produced per day) ○ Hybrid system possible ○ Use of local labour and material possible ○ Simple technology	○ Fouling ○ Corrosion due to chloride ions ○ Lack of relevant field testing ○ Low flow of water produced ○ High capital cost ○ Not easy to replicate

4.1.4. The technology GéoNoria™: solar distillation along a pipe

An innovative concept using solar distillation called GéoNoria has been developed by a group of French engineer, who worked on it during their free time (O. Grossat, 2009). Instead of bringing water to a storage tank to then treat it on site, this solution offers to use the following natural process: once transformed into vapour, water moves upward. Thus, no pumping system is needed: solar heating alone, facilitated by several solar convectors placed along the pipe system, makes the water move under vapour form from the water source to the water tank where it is condensed as shown in figure 8.

It is initially designed for desert areas located along sea coasts, lake or river banks. Consequently, distillated water can be obtained by using very simple and cheap equipment available anywhere/in any place around the world.

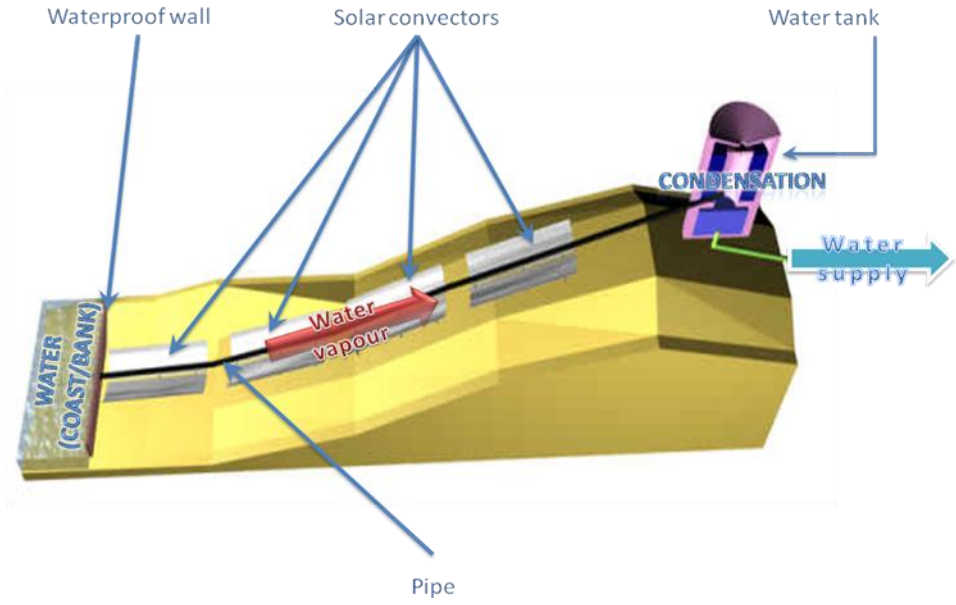

Figure 8. The GéoNoria concept. (after Grossat, 2009)

The proposal of GéoNoria is to make their concept freely available to all, provided that their name is communicated in any document related to an installation based on it.

So far, the system has been successfully tested in real conditions in Greece where the flow obtained was about 6L/hour (T.Vampouille, 2009), but no implementation in a developing country has been done.

Table 8. Summary of advantages/disadvantages of the GéoNoria system.

Advantages	Disadvantages
○ Use of local material ○ No need to supply with additional energy for bringing water from the source (coastal) to the water tank ○ Gravity fed	○ Coastal environment only ○ Not tested in a developing country yet but experimented in Greece

Distillation processes are based on a separation due to a phase change of water and produce distillate water which has to be enriched to become drinkable. Flow obtained by using thermal energy from the sun is relatively slow as large-scale applications are energy intensive and only exist in rich countries. Moreover, in energy terms, this method is relatively expensive: 2.26 MJ are needed to evaporate 1kg of water (Bardi et al., 2007). However, it presents the advantage of being simple technology, easy to operate and maintain, and generally culturally acceptable. Other processes less energy extensive exist developed to lower the scale of use: membrane processes. These technologies are not based on phase change of water but on a physical separation of water and salts, based on the natural phenomenon called osmosis.

4.2. Low energy membrane technologies

Membrane technologies are based on the capacity for a given membrane to allow easy passage of some particles through it while blocking some others. That way, salts can be separated from water by using selective membranes (Spang, 2006). They are the most commercially available system for a small scale decentralized system, whether at household level or at a village scale (Peter-Varbanets et al., 2009). Whereas distillation processes only removes salts, membrane can be chosen to additionally remove organic and inorganic contaminants at the same time, fluoride included (Meridian Institute, 2006).

Membrane technologies are inspired from osmosis, a phenomenon naturally occurring in plants to "absorb water from the soil and to transport the water up the stem to all parts of the plant" (WEDC, 1999). Its principle is to use a semi-permeable membrane which prevents the movement of the concentrated molecule concerned to separate two compartments of dilute and concentrated solutions separated. Therefore, water naturally tends to move from the diluted compartment to the concentrated one to equilibrate both sides(Liu, 2000). Hence, level of water in the initially diluted part goes down at a level equal to the application of a pressure called osmotic pressure (see figure 9).

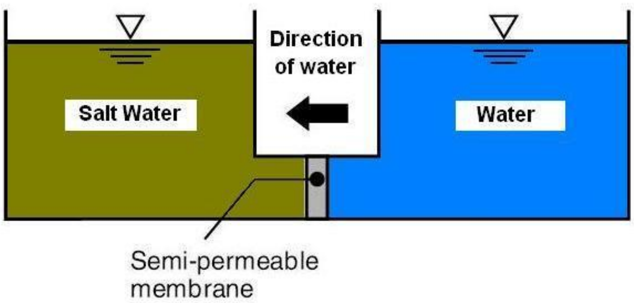

Figure 9. Principle of osmosis. (after WEDC, 1999)

Membrane processes used for desalination are reverse osmosis (or RO, the most well-known) and forward osmosis (FO) also known as direct osmosis, with possibility for both processes to improve their productivity by using nanotechnologies. Another membrane process is membrane distillation which is a combination of membrane and distillation processes but will be developed in a separate part.

4.2.1. Reverse osmosis processes

Developed by high income countries, "reverse osmosis has emerged as the most feasible small-scale desalination technology" and seem transferable for remote areas in developing contexts, provided that membranes are initially afforded or better, its production is possible in local manufactures (Liu, 2000).

Contrary to osmosis phenomenon, in the case of reverse osmosis process water in the concentrated compartment is subjected to a pressure higher than osmotic pressure, which implies a movement in the other direction. Thus, level of water in the diluted compartment is elevated while the other compartment becomes increasingly concentrated (Figure 10).

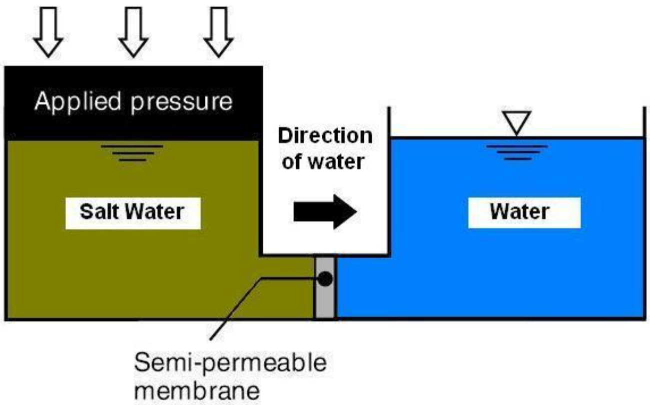

Figure 10. Principle of reverse osmosis. (after WEDC, 1999)

In the table 9 below is shown some characteristics of reverse osmosis technologies that could help comparing it with other technologies. The symbol "++" for "performance" means if the treatment is performed correctly, the water produced reaches WHO microbiological standards. The same symbol for "ease of use" shows that little daily operation is needed. "Social acceptability" depends on the region where RO membranes are used, hence the "-/+" symbol.

Table 9. Requirements of reverse osmosis technologies (after Peter-Varbanets et al., 2009).

In "performance", the symbol "++"means if the treatment is performed correctly, the water produced reaches WHO microbiological standards. For "ease of use", this symbol shows that little daily operation is needed. "Social acceptability" depends on the region where RO membranes are used, hence the "-/+" symbol.

Type of supply	Estimated costs		Evaluation criteria				
	Investment $US	Operational $US (for a family)	Performance	Ease of use	Maintenance	Dependence on utilities	Social acceptability
Single tap	300-600	80-120	++	++	Required annually	Tap pressure of electricity	-/+

Apart from solar desalination, RO technologies demand an external source of energy for producing electricity, not heat. This energy is mainly used to pressurize water, not to change its physical state. For developing countries, several possibilities can be envisaged using renewable energy available or brute strength of humans or animals. This is a way to decrease the weight of energy cost in reverse osmosis process, but investment on technology is therefore higher (table 10).

Table 10. Distribution of costs for conventional and renewable energy-driven reverse osmosis systems (After Al Karaghouli et al., 2009)

Type of process	Capital costs (%)	Operational costs (%)	Energy costs (%)
Conventional RO	22-27	14-15	59-63
RO using renewable energy	30-90	10-30	0-10

The use of renewable energy for reverse osmosis as alternative energy sources is developed further in appendice A3.

Table 11. Summary of advantages/disadvantages for RO systems.

Advantages	Disadvantages
○ Small and medium scale ○ Limited maintenance cost ○ Production of electricity in surplus, lowering operation costs	○ Long-term management has to be supported by authorities ○ RO membrane production is not always possible locally ○ Renewable energy: need of an energy storage system (batteries),high initial capital cost (PV or wind turbine), strongly depending on the weather, land availability for wind turbines

4.2.2. Forward osmosis

When talking about water treatment and desalination in particular, the main osmosis process cited is reverse osmosis. But osmosis processes are wider than that and forward osmosis, also known as direct osmosis, is another process used in various fields including medicine, water treatment and desalination (Cath et al., 2006). Contrary to reverse osmosis, forward osmosis uses the osmotic pressure as the driving force rather than the hydraulic pressure (cf. principle of osmosis, part 2.2). Hence, it is operated at lower pressure, reducing significantly the energy consumption compared with other desalination processes, and demands simpler equipment reducing the capital cost too. The process is simple: use a solution concentrated in a solute to draw water from the saline water (Water online, 2006). Indeed, water will flow from the saline compartment to the concentrated draw solution. Thus, the key problem is to find a draw solution that could easily be extracted after the forward osmosis process to produce fresh water, another problem being to develop robust membranes.

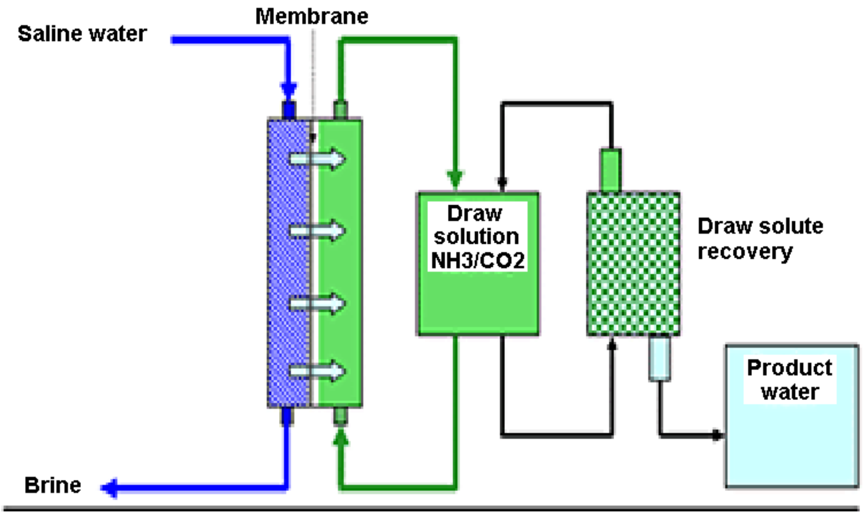

Figure 11. Yale's pilot plant (after Water online, 2006)

Although numerous desalination methods using forward osmosis have been patented, practical applications are scarce. Research has been done in 1976 to develop a forward osmosis batch desalination method to be used in emergency situation on lifeboats. More recently Yale University in the United States has developed a forward osmosis desalination pilot plant producing 1m^3/day (figure 11) through a spinoff company called Oasys (D&WR, 2009). They successfully formulated a draw solution which is now a company secret, solving one of the main obstacles of forward osmosis application to desalination. Whereas forward osmosis processes is still at the research state, it is a potential low-cost desalination option.

Table 12. Summary of advantages/disadvantages for forward osmosis.

Advantages	Disadvantages
○ Operation at low pressure (low energy consumption) ○ Simple equipment (low capital cost) ○ High rejection of a wide range of contaminants ○ Perhaps, lower fouling propensity than reverse osmosis ○ Use of human strength ○ Emergency situation: hydration bags	○ Lack of robust membranes and membranes modules ○ Easily separable draw solutions need to be developed ○ Not tested in the field

4.2.3. Nanotechnologies

Nanotechnology is a recent field of technology with diverse applications, offering new opportunities at the nano scale. Information and data for it is still scarce as only commercialised products are in the range of public information (Meridian Institute, 2006). In the field of desalination, nanotechnologies found applications in all membrane processes as nanofiltration membranes, carbon nanotubes and magnetic nanoparticles.

Nanofiltration membranes

For reverse osmosis desalination, new membranes have been developed, amongst which the most advanced and promising are nanocomposite membranes. By encapsulating nanomaterials into the polymer layer, nanocomposite membranes are not only more productive but also more resistant to fouling. Consequently, energy consumption and capital expenditure of these membranes are lower than for former membranes, reducing its final cost while its production cost only increases by less than 5% for nanocomposite membranes developed by Nanoh2o (NanoH2O,2008). The Korean company Saehan Industries (2009) developed nanofiltration membranes for use in different scales, including household point-of-use. These membranes produce 36% more water at a pressure of 5 bars than their reverse osmosis membranes which operate at 55 bars. For technical reasons, their nanofiltration devices can only be used for flow between 1 and 3.5 L/minute which only allows a use in batch for household scale.

Carbon nanotubes

A membrane made of carbon nanotubes (acting as pores) can be used instead of conventional reverse osmosis membrane to reduce cost of desalination (Stark, 2006). Despite the extremely small size of the pores, water can rapidly flow through the nanotubes due to their very smooth interior and amount of pressure needed to push the water through are thus significantly reduced. Researchers at Lawrence Livermore National Laboratory obtained such a membrane allowing flows of 100 to 100,000 times higher than with conventional membranes. Carbon nanotubes have shown the capacity to remove almost all water contaminants, including salts and as been identified as an alternative for reverse osmosis (Meridian Institute, 2006). Researches are expected to make the production of carbon nanotubes filters cost significantly less than conventional reverse osmosis. Cleaning and reuse could additionally be facilitated, and even become more durable. However, such a technology is expected to reach the market in only 5 to 10 years.

Table 13. Advantages and disadvantages of both nanotechnologies used for desalination.

	Advantages over conventional RO membranes	Disadvantages over conventional membranes
Nanofiltration	Lowest pressure, better productivity, better resistance of fouling	For household application, use in batch
Carbon nanotubes	Higher flow, more resistant, easier cleaning and reuse	Not yet in the market

Membrane technologies i.e. reverse osmosis, forward osmosis and nanotubes in this case, are quite dependant on the technology used (chemicals, maintenance and qualified labour) which increase its operating costs. The highest limitation was initially the demand in energy to drive such a system, but by using renewable energy or mechanical systems, this is no longer the case. Consequently, if membranes are provided at the beginning, these new technologies could be an alternative to thermal systems. Additionally, water produced is potable, not distillate, which is safer for drinking as nothing has to be added. Other processes less energy demanding, called electronic processes, are based on the separation of ions depending on their charges. Water obtained by such technique is deionised and thus may not be suitable for drinking without adding a minimum amount of minerals.

4.3. Electronic processes

4.3.1. Ion Exchange

Ion exchange (IE) is a process "convert[ing] the salt into acid by strong cation exchange" (Hendry, 2003) on an IE resin, following the chemical equation, where R represents the resine, R-H + NaCl → R-Na + HCl. In practice, water is passed through columns filled with cation and anion exchange beads under the form of hydrons (H+) and hydroxides (OH^-) (Tzoneva R., 2003). As the salt is dissolved in the water as the combination of a cation chloride (Cl^-) and sodium (Na^+), during the crossing of the resin, those ions meet agglomerates of cation and anion resin. Thus, an exchange of corresponding polar ion appears on its surface, releasing a cation hydron (H^+) in exchange of a Na^+, and an anion hydroxide (OH^-) for a Cl^-, producing clean water free of salts. A schematic representation of this exchange is shown in the figure 12.

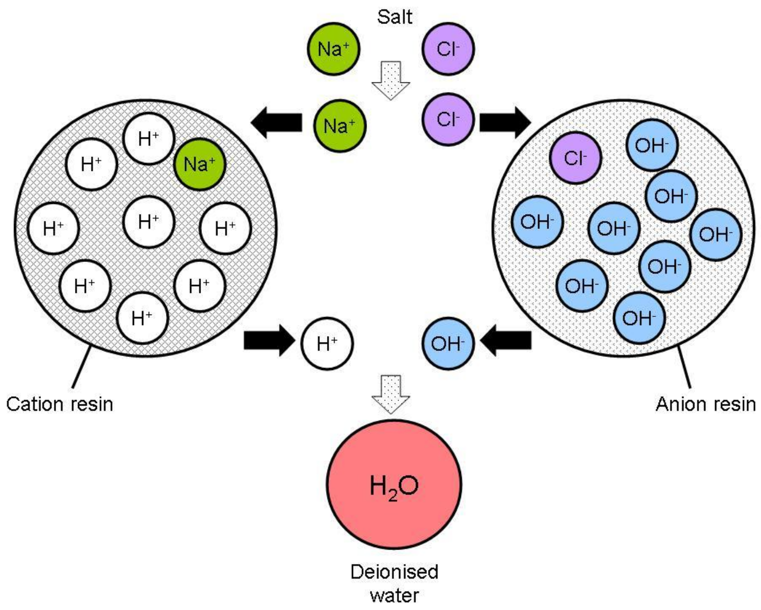

Figure 12. Principle of ion exchange (after Aqua Technology Water Stores, 2005)

Once the resin is full of adsorbed ions, it is regenerated by passing a weak acid (e.g. sulfuric acid, H_2SO_4) through the column. This process of regeneration follows the equation R-Na + H_2SO_4 → R-H + Na_2SO_4.

An automated pilot of ion exchange desalination plant has been developed by the Departments of Electrical Engineering and Chemical Engineering at Peninsula Technikon, South Africa, using ion exchange columns at counter current (B. Hendry, 2003).

As effluents have been reported to possibly contain carcinogenic nitrosamines, a combination of ion exchange column preceded by carbon adsorption beds is obligatory (Aqua Technology Water Stores, 2005).

Table 14. Summary of advantages/disadvantages for ion exchange.

Advantages	Disadvantages
○ Small scale and remote area option ○ Obtaining of pure water	○ Pre-treatment by carbon adsorption needed ○ Maintenance: regeneration of the resin using weak acid ○ Not tested in the field

4.3.2. Capacitive Deionization

Capacitive deionization (CDI) is a process developed since 1950 in the USA, where a desalination pilot has been "tested for 7 years so far, without changes of operation and maintenance" (Tharani, 2009). The principle of CDI is based on the separation of ions dissolved in water by means of electrodes and adsorbed at their surface. The electrodes used are in activated carbon, which has the properties of adsorption and conductivity. This way, if current is on, charged ions are attracted to the electrodes with opposite polarity where they "are adsorbed through a process called electrochemical diffusion" (Atlas, 2007). While ions are retained at the electrodes, clean water is obtained. Once electrodes are jammed by related ions, the current is made off to sweep desorbed ions away in washing water. The figure 13 represents these two phases.

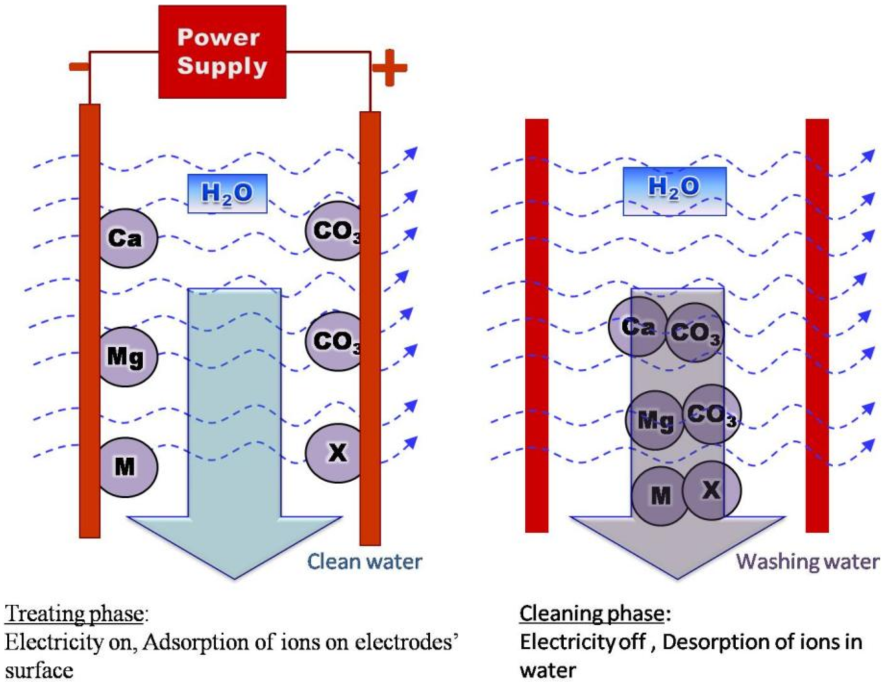

Figure 13. Principle of CDI. (after EWP, 2009)

By this mean, numerous contaminants can be removed (see table 15) using less pretreatment than RO or IE processes.

Table 15. Spectrum removal for CDI system (EWP, 2009)

Heavy Metals	Normal Salts	Other
Chrome, Iron, Copper, Silver, Gold, Zinc, Nickel, Cadmium, Mercury, Lead	Calcium, Carbonate, Magnesium Carbonate, Sulfates, Phosphates, Sodium Chloride, Chlorides/Fluorides, Silica	Organics (that dissolve), Pathogens

Nowadays, several sites in Korea have been equipped with such a system. Current developments of CDI are oriented to small scale use (POU), lowering initial investment and waste rejection (Atlas, 2007). Indeed, CDI systems, such as the Plimmer currently developed for commercialization by EcoAeon (Tharani, 2009), use no chemicals at all for treating.

Table 16. Summary of advantages/disadvantages of CDI.

Advantages	Disadvantages
○ Small scale and remote area option ○ Low investment ○ No chemicals used ○ Large spectrum of contaminants removed ○ Relatively pure water obtained	○ Electricity needed to operate ○ Building cost as it is produced in a developed country ○ Regular cleaning of electrodes (automated) ○ Even though a successful implementation in the USA lasted 7 years, it has not been tested in a developing country yet and need to prove its sustainability, esp. in terms of maintenance.

As a summary of the three previous parts, distillation methods are generally energy demanding and require high building cost, but their technology is relatively simple. On the other side, membrane technologies often present the opportunity to use renewable energy or brute strength to be run, reducing operation costs, but they strongly depend on a complex technology to be produced. Indeed, the main investment to maintain them is membrane replacement. As for electronic processes, with a complexity similar to membrane processes, they demand a smaller amount of electricity. However, they are defined at small scale use only, for a population served by a single unit slightly smaller than a whole village. Nevertheless, this classification of processes is not that inflexible as two processes can be considered as combination of two of the previous processes: membrane distillation and electrodialysis.

4.4. Hybrid systems

Hybrid processes are composed of two processes, combination of the previous processes exposed: membrane distillation, mixing distillation and membrane processes, and electrodialysis, a membrane process using the polarity of ions.

4.4.1. Membrane distillation

Membrane distillation is a process using a micro porous hydrophobic membrane of PTFE having the faculty to be permeable to water vapour but impermeable to liquid water. That way, non-volatile dissolved solids left in the liquid phase are separated from the vapour water. The driving force is therefore the difference of vapour pressure on both sides as a result of a temperature gradient. Indeed, the "hot" side is in contact with the process solution while the "cold" side is in contact with distillate producing a temperature gradient on the membrane. Figure 14 shows how such a membrane works.

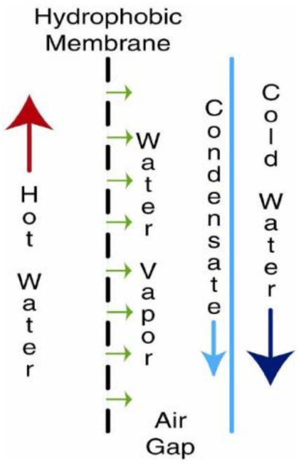

Figure 14. Principles of membrane distillation with air gap (Hein et al., 2004)

Therefore, the diffusion gap produced between the evaporating and the condensing surface is only of the thickness of the membrane (about 30µm, Bier and Plantikow, 1995). In this system, pressure used is low (atmospheric pressure or less) and temperature are less than 80ºC, allowing the use of solar energy to heat the system (see figure 15). Plant capacities are from 0.1 m^3 per day (corresponding to the demand of drinking water for 4 families) to 20 m^3 per day. This is thereby a desalination option adapted to remote areas with poor infrastructures.

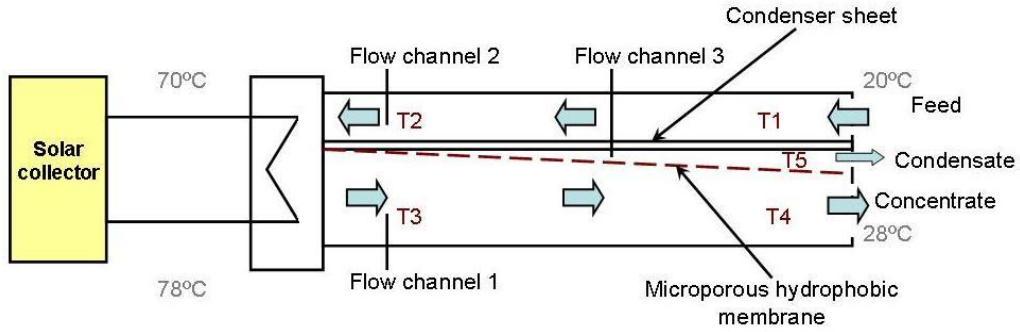

Figure 15. Membrane distillation module with integrated recovery latent heat (after Bier and Plantikow, 1995).

Pilot installations exist in the Canary Islands and in Ibiza. Another research project on membrane distillation is the Mediras project (Mediras, 2009) aiming a stand-alone application on both inland and coastal locations. The University of Texas at El Paso (UTEP) studied membrane distillation system with an air gap using a solar pond (see appendices A2 for solar ponds) to supply energy to provide heat between 13 and 75ºC. Its applications are recommended for “isolated low technologies (village)”, which could correspond to the context targeted.

Table 17. Summary of advantages/disadvantages of membrane distillation.

Advantages	Disadvantages
○ Small scale and remote area option ○ Very small diffusion gap ○ Use of low pressure and low temperature reduces operating costs	○ Need to provide the membrane ○ Large area needed if using a solar pond (cf. appendices A2) ○ Lack of relevant field testing

4.4.2. Electrodialysis

Electrodialysis (ED) is a process invented in 1952 by the company Ionics (presently General Electric). It has been seen first as “a truly practical and less expensive way to desalt brackish water” (Rheal, 2006). Its principle is to separate cations and anions electrochemically and remove them from water using successions of cations transfer membranes and anions transfer membranes, respectively impermeable to anions and to cations. Initially dissolved in water, once current is on, ions are attracted to the electrode of opposite polarity. They then meet membranes stopping their race. Thus, all ions are gathered in common paths, leaving one container over two with deionised water. The diagram shown in figure 16 explains this process. Hardness of water can also be treated with such system at the same time as salt.

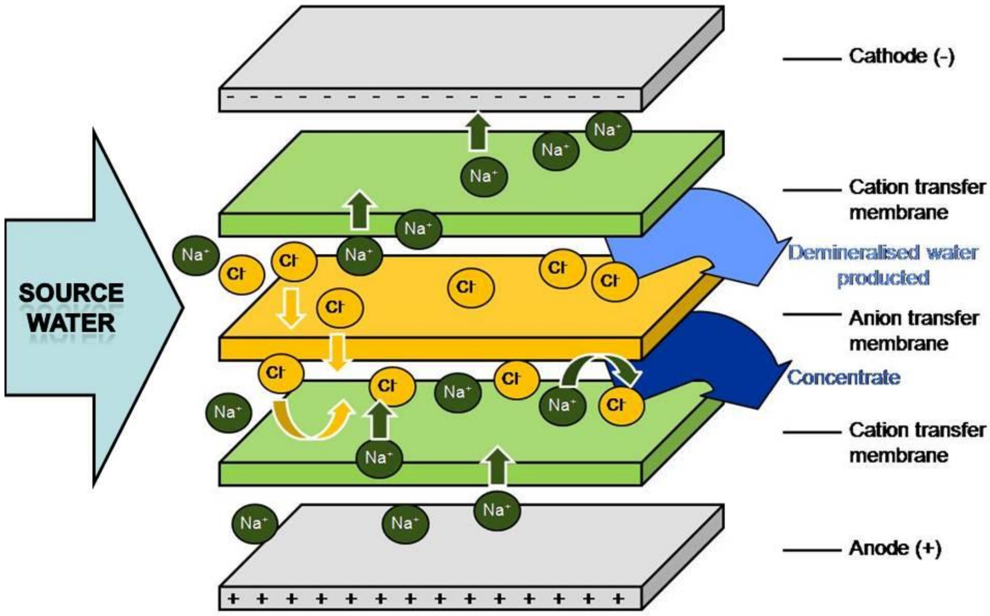

Figure 16. Principle of Electrodialysis (CNGA, 2009)

However, utilisation of ED was commonly known as a system economically viable only for low salinity feedwater (below 1,000 ppm according to Turek, 2007). Important technological improvements happened with the development of ElectroDialysis Reversal (EDR) in 1974, where the electric field is alternately reversed for removing salt scale from membranes, or self-cleaning thin-film composite (TFC) in the eighties (Rheal, 2006). EDR is now more used for desalination than simple ED. It was additionally proven that it is low energy demanding, making ED a competitive opportunity for desalination regarding other processes, especially RO. Initially its competitor in numerous projects, RO is now regularly combined with EDR in projects worldwide. Additionally, contrary to RO, no additional treatment is needed for ED. Nevertheless, EDR is a preferred process regarding RO for plants smaller than 6,000 m^3/day and TDS below 1,500ppm.

Applications of EDR are numerous, with the implementation of the largest EDR plant in the USA in 1995. This plant is still in use, producing 45,000 m^3/day of clean water. A patent has been submitted in the USA by Lichtwardt and Williams in 1998 for a solar-powered direct current electrodialysis reversal system.

Table 18. Summary of advantages/disadvantages of electrodialysis reversal.

Advantages	Disadvantages
o Lower energy demand than RO o EDR and TFC membranes are self-cleaned o Possibility to use solar energy	o Not economically viable for TDS>1,500 ppm

4.5. Discussion of the literature review

This literature review has put forward three main types of technologies, some of them being specifically used and developed for low cost autonomous desalination at small scales: distillation, membrane processes and electronic processes. A fourth type of process can be added (see figure 17 below), mixing two of the previous processes: hybrid processes.

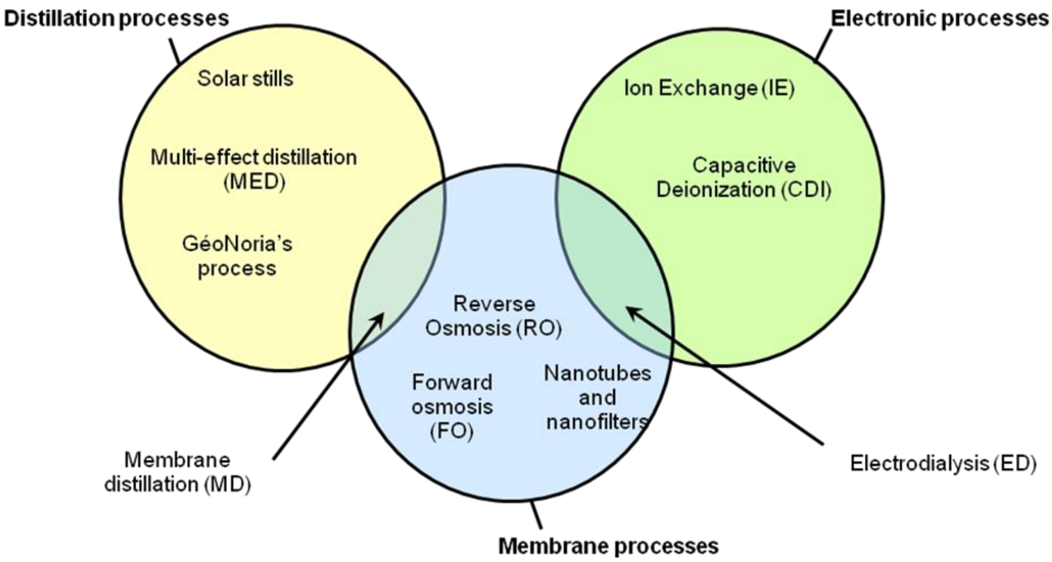

Figure 17. Location of both hybrid processes among desalination processes.

Information sources used were various, from scientific articles to companies' websites through NGOs reports. The general feelings which arises from it is that peer-reviewed journals often give access to the newest technologies developed and sometimes not yet field-tested, but practical aspect is often missing. These aspects can be approached through NGOs. Meanwhile, it is hard to know if companies' information is independent or is motivated by marketing. Consequently, information found is unequal and some technologies are hard to be defined as directly applicable. This is the case for instance for membrane technologies other than reverse osmosis. Consequently, even though the need for desalination is admitted, driving technology development, there is a clear deficit in the credible literature of these technologies being rigorously field tested in the contexts of interest.

Comparison of processes

In general, distillation processes have low operating and maintenance cost but high capital cost. They are also simple techniques, combining evaporation and condensation of water. This makes it a generally acceptable technique in numerous cultures as archaic modules are often already used by the population.

On the contrary, membrane technologies are easy to operate and flexible, following the demand, but they have to be regularly replaced and are not yet producible in local manufactures, apart for ED membranes. Consequently, if provided at the beginning in sufficient quantity for a time period, they have the potential to be run during several years by using a suitable source of energy. Indeed, energy sources are also various: renewable energy such as wind and sun can be used and even combined to produce electricity or mechanical moves. Brute strength (human- or animal-driven) obtained by operating a handle is also an alternative for driving membrane systems.

As for electronic processes, they are simple to operate and maintain as they are usually automated. Electrodialysis systems can even use self-cleaning membranes (TFC membranes). However, they still have to be manufactured in a developed country regarding the complexity for manufacturing and the materials needed. Those processes are adapted for a use at small scale regarding the amount of water produced and the size of the devices. Driven by electricity, they can thus, as membrane processes, use renewable energy for producing the electricity needed.

Whatever the process, fuel can be used for extra needs or in case of breakdown.

Another difference is the quality of water obtained: after distillation, water obtained is a distillate and thus may need to be enriched in some components for being drinkable. Product water for electronic processes also need to be adjusted for reaching drinkable quality standards as it is demineralised (or deionised). As for water from membrane processes, it is almost always drinkable directly.

Table 19. Comparison among low cost desalination technologies.

Technology	Product water	System size (m^3/day)			Manufacturing requirements	Costs	
		Small (1-50)	Medium (50-250)	Large (>250)		Capital	O&M
Solar distillation	Distillate	x			Local materials	High	Low
Solar thermal MED	Distillate		x	x	Local materials	High	Low
Solar distillation along pipes	Distillate	x	x		Local materials	High	Low
Reverse Osmosis	Potable	x			PV cells and membranes need to be provided	Low	High
Forward Osmosis	Potable	x			PV cells and membranes need to be provided	Low	High
Nano - technologies	Potable	x	x		Membranes need to be provided	Low	Medium
Ion Exchange	Deionised	x	x		Resins to be provided	Low	Low
Capacitive Deionisation	Deionised	x	x		Manufactured in developed countries	Low	Low
Membrane Distillation	Distillate	x			Membranes need to be provided	Low	Low
Electro dialysis	Deionised	x	x		Membranes need to be provided or locally produced	Low	Lower than RO for small scale, low salinity

Choosing for one or another technology is thus complex, combining "a range of variables, including: type of feed water, energy source, quality of freshwater output and plant size" (Spang, 2006). The table 19 above is a summary of the main technical and financial aspects obtained for each process. In appendiceA4 can be found more information related to long term management of these technologies. These comparison tables can help choosing between distillation, membrane and even membrane distillation processes according to the limitations specific to a context.

5. Evidence of practical application & long term functioning : Survey results

5.1. General results on contacting organisations

In total, 17 organisations have been contacted whether by direct contact or through online forms or information mailing list. 6 of them gave full details on their technologies, mostly by responding to the questionnaire. Among the respondents, 2 are private research laboratories (Cardinal Resources, Aquaplus Water Purifier which cooperates with the Indian government), 2 are private companies (A+ Trading, EcoAeon) developing a new desalination system not field tested yet, 1 is a research laboratory (CSMCRI) and 1 is an independent "initiative" (GéoNoria) as they call themselves. Table 20 summarises the conditions of contacting for the respondents. Discussions and questionnaires are detailed fully in appendices A7 to A9.

Table 20. List of research laboratories and private companies fully responding.

Organism	Technology	Method of contacting used
Cardinal resources	Seawater greenhouses (solar distillation)	Face-to-face discussion
Aquaplus	Solar distillation	E-mail discussion Questionnaire filled
GéoNoria	Solar distillation	Questionnaire filled Phone interview
CSMCRI	➢ Animal-powered RO ➢ Mobile RO unit ➢ 2-stage seawater RO ➢ RO defluoridation-cum-desalination ➢ Solar-powered RO ➢ Domestic ED	E-mail discussion 6 questionnaires filled
EcoAeon	CDI (called Plimmer)	E-mail discussion Phone interview
A+ Trading	Human-powered RO (called PROtector)	Questionnaire filled

In total, 10 questionnaires were completed. 6 of them are from the same laboratory, CSMCRI, who was contacted through various e-mail addresses. Finally, they made the information circulated among different departments and information on 6 technologies was obtained: animal-powered RO, mobile RO unit, 2-stage seawater RO, RO defluoridation-cum-desalination, solar-powered RO, and domestic ED.

For GéoNoria and EcoAeon, the questionnaire was firstly given before phone interviews were performed, on demand of the correspondents. Hence, more precise information was obtained compared with e-mail questionnaires, whether about technical details (implementation and operation) or about long-term management (maintenance, spare parts production).

In a general manner, respondents were cooperative and interested in the project. They all accepted every piece of information to be communicated, whether in the academic or in the Oxfam report. 5 respondents over 6 are interested in the result of this project. It appears twice that the correspondent asked what other low cost desalination technologies exist nowadays to update their current knowledge on this subject.

4 other correspondents (for the Lawrence Livermore National Laboratories, Murdoch University, Skyjuice and Durham University) answered but were not able to give sufficient details. Reasons given were because the technology developed is not developed enough for an implementation in short term (CNT at the LLNL and Porifera Nano) or because the technology has moved from research to commercialisation (Solarflow, developed at Murdoch University, now manufactured by Solco Ltd in Perth). 8 organisms did not give any answer at all. They are listed in the table 21 below.

Table 21. List the other organisms contacted but who produced no answer during the time period of the thesis.

Organisms contacted	Technology of concern
University of Texas at El Paso	solar ponds and solar desalination including MD
Centre for Rural Development and Technology, IIT, Delhi	small-scale MED in India
Mechanical Engineering Department, CET (IFTM Campus), Moradabad	small-scale MED in India
Yale University	FO
University of Sheffield	Human-powered FO
Solco Ltd	PV-RO
ENERCON	Wind-powered RO
NanoH2O	Nanotech membranes

5.2. Information obtained through questionnaires and interviews

Only 4 types of technology have been detailed through 11 questionnaire and interviews: solar distillation (several kind of design), reverse osmosis (several design and energy source used), electrodialysis, and capacitive deionization. As most of the systems surveyed are based on reverse osmosis, corresponding data are gathered in common tables in order to highlight differences due to specific designs. Three main phases of technology management are studied separately: implementation, operation, and maintenance and spare parts replacement. A last discrimination is about the existence of field testing for each technology.

5.2.1. Implementation

6 systems can be used at a village scale, whether for a small one (about 1,000 people) for animal-powered RO, PROtector and the system using RO and removing fluoride at the same time than salt, or for villages of 5,000 people or more (mobile RO, 2-stage RO plants). For the Plimmer (EcoAeon, using CDI), the scale can be adapted depending on the number of cells used and their configuration (in parallel or in serial). 3 other systems are more adapted for clusters of families: solar-powered RO (about 30 families served), the system of GéoNoria (about 12 families served assuming a production along 10 hours), and domestic ED (10 families). Finally, the distillation system proposed by Aquaplus and entitled “Desalination by evaporation and condensation using solar energy” (referred further as “Aquaplus”) is designed to serve one family. Seawater greenhouses are not designed for producing drinking water by itself but to irrigate plants in a greenhouse. Drinking water produced is an extra and its quantity left depends on the type of plants irrigated.

5 systems can treat sea water (Mobile RO van, 2-stage RO plants, seawater greenhouses, Aquaplus, GéoNoria) with high salinity, even if the CDI technology is expected to be able to treat such salty water in 1 or 2 years according to Alykhan Tharani, co-director of EcoAeon.

Corresponding figures are available in tables 22 and 23 below.

Table 22. Building requirements for reviewed systems using reverse osmosis.

	Animal-powered RO	Mobile RO unit	2-stage seawater RO	RO defluoridation-cum-desalination	Solar-powered RO	PROtector
Average daily flow (L/day) assuming a 10-hour-operation/day	10,000 for 20 hour day, 5,000 for 10 hour day	15,000 for SW, 30,000-40,000 for BW	20,000-60,000	10,000-20,000	700-900	7,500 litres per 10 hour day
Quality and salinity of source water (mg/L or ppm)	Clean water, TDS < 3,500 ppm	Clean water,TDS up to 35,000	up to 40,000	TDS up to 3,000, fluoride up to 6	2,000-4,000	as proposed at Longech site
Quality of water produced	TDS~ 500 ppm	TDS < 500 ppm	TDS < 500 ppm	TDS < 500 PPM and 1 ppm fluoride	TDS of about 100-300ppm	optimal rejection rate of 95% (Longech: TDS 41ppm ; Fluoride 1.2ppm)
Space requirements (m2)	~ 450 (24m diameter)	Mobil Van	50-100	40-80	25(room size for RO),100 (terrace/open space size for solar panels)	1.44 (1.2m x 1.2m on plan, with a height of 0.9m)
Cost of a single unit (building, US$)	6 500	100 000	60,000-110,000	20 000	34 000	17 170,00

Table 23. Building requirements for reviewed systems, reverse osmosis excepted.

	Seawater greenhouses	Aquaplus	GéoNoria	Domestic ED	EcoAeon
Average daily flow (L/day)	Enough for 1 to 20 greenhouses	25 (target)	Depending on the needs of the population	200	adjustable, from 7,200 to 28.000
Quality and salinity of source water (mg/L or ppm)	Seawater (35,000)	0-36,000	Indifferent	TDS of < 2500 PPM	pre-filtered water 25-50 microns
Quality of water produced	Distillate	Desalinated Water 1ppm	6.2 l/h distillated water	~ 500 ppm	<500 ppm
Space requirements (m2)	Size of a greenhouse	1	10	50 cm x 50 cm x 60 cm	up to 1x0.48x0.32
Cost of a single unit (building, US$)	Depending on building material used	300 (Target Price)	Depending on the hourly rate and materials costs on site.	250 with out pump	depends on number of cells used

For 9 of the systems surveyed, a building cost comparison (table 24) is possible regarding the whole building cost and the size of the population served, giving a building cost per person served. It results that the solar-powered RO system is the most expensive (about US$200,000 per person served) whereas 2-stage RO plants and mobile

RO van, initially having the biggest overall cost, finally amounts to less than US$40 per person served. The cheapest solutions in terms of building costs are animal-powered RO and domestic ED. However, for animal-powered RO, the purchase of an animal has to be added to capital cost and depends on the situation. EcoAeon produced a cost simulation with a flow of water produced at a target of 8,000 l/day, giving an initial investment of about £15,000 (about US$24,000). As a result, its capital investment amounts to US$15.00 per person served. This cost is higher if solar panels are used to supply electricity, whereas operation cost will thus be negligible.

Table 24. Comparison of building cost for 8 systems reviewed.

	Animal-powered RO	Mobile RO unit	2-stage seawater RO	RO-F removal	Solar-powered RO	PROtector	Aquaplus	Domestic ED	Plimmer
Flow produced (L/day)	5,000 - 10,000	15,000 - 40,000	20,000 - 60,000	10,000 - 20,000	700 900	7,500	25	200	8,000
Population served	1,000 - 2,000	3,000 - 8,000	4,000 - 12,000	2,000 - 4,000	140 180	1,500	5	40	1,600
Building cost (US$)	6,500	100,000	60,000 - 110,000	20,000	34,000	17,170	300	250	24,000
Building cost (US$) per person served	3.25 - 6.50	12.50 - 33.33	5.00 - 15.00	5.00 - 10.00	189.00 - 242.90	11.45	60.00	6.25	15 .00

5.2.2. Operation

For devices using reverse osmosis, a technician has to be trained for being familiar with the machine. Whether by using electricity from the grid or fuel, operation costs are about US$1 to 2 per 1,000 litres produced as shown in table 25 below. If the energy supply is strength (whether powered by animals or humans) or solar radiation, operation cost is significantly lowered. The operation needed for such systems are also simplified. As an example, in the case of the PROtector (using human strength), the system even can be moved by two children.

Table 25. Operation requirements for reviewed systems using reverse osmosis.

	Animal-powered RO	Mobile RO unit	2-stage seawater RO	RO defluoridation-cum-desalination	Solar-powered RO	PROtector
Source of energy	Animal strength	Diesel engine which runs the van	Electricity	Electricity	Solar power/Battery bank	Manually powered by cranking handle up and down
Amount of energy needed	1.25 hp	50 KWH	30 & 60 KWH for 2000 & 6000 LPH	10 KWH	as per RO plant	One child >10 yrs old will be able to operate the unit
Operation costs	Almost negligible	USD 1.5-2 per 1000 liters of water	USD 1.5-2 per 1000 liters of water	USD 1-1.5 per 1000 liters of water	Nominal	$6.57 per day. This equates to 1.75¢ (<USD $0.02) per 20 litre jerry can.

Systems using solar energy for distillation are usually very simple to operate as the sun does the work by itself. However, as the water produced is distillate water, it is advised to add a small quantity of salt in treated water at the end of the process for health reasons. All those operation can be easily done at a community level. Electrodialysis and capacitive deionization system are more complicated as they are electricity-powered. Nevertheless, for the Plimmer (EcoAeon), operation is automated and checked remotely which make operation easier once implemented. For domestic electrodialysis, as for reverse osmosis, prior training is needed. The table 26 below gathers corresponding answers obtained for system not using reverse osmosis on the subject of operation.

Table 26. Operation requirements for reviewed systems, reverse osmosis excepted.

	Seawater greenhouses	Aquaplus	GéoNoria	Domestic ED	EcoAeon
Source of energy	Solar	Solar	Solar	Electricity	Electricity
Amount of energy needed	As available	to be calculated	As available	~ 0.7 kWhr / kg salt removed	~1-1.2 KWh per 1000 liters for a solution of 1000 mg/l of NaCl
Operation costs	Mainly depending on the material used for condensor	None	Regular cleaning of the system/no spare parts necessary. Without filter or chemical products	1.5 k Whr/ m water produced including the power consumption of ozonator	depends on number of cells (250W for 2 cells, 1,000W for 8 cells)

However, additional running cost corresponding to the employment of trained technician is hard to estimate more precisely and has to be considered in the overall operation cost included in a preliminary cost analysis.

5.2.3. Maintenance and spare parts replacement

For RO systems, the main spare parts needed are membranes. They have been widely evaluated to be changed every 2 to 4 years for all respondents working with a system using RO. As a comparison, ED membranes are expected to be changed once in two years, while electrodes used for capacitive deionization are drastically cleaned once a year (even if they are cleaned periodically during treatment) using citric acid crystals (see table 27).

For very simple devices (GéoNoria, Aquaplus), maintenance consist in simple cleaning of all parts. In the case of GéoNoria, it is recommended to do it daily, which is a bit binding. On the contrary, EcoAeon's product called Plimmer (using CDI) has to be maintained only once a year and this operation can be done remotely, for instance from the UK. Nevertheless, if any breakdown is detected, a technician would have to be sent to fix it as the device is too complicated for been totally managed by the community.

Table 27. Maintenance/replacement requirements for reviewed systems except reverse osmosis.

	Seawater greenhouses	Aquaplus	GéoNoria	Domestic ED	EcoAeon
Maintenance and spare parts	Mainly: tubes have to be cleaned due to fouling. This problem is on the way to be solved.	Cleaning of Cooker periodically	Daily	Ion exchange membranes	No chemicals. Push a button once a year after filling the dedicated container. Can be done remotely.
Frequency	If problem of fouling of tubes fixed, 2 years without maintenance.	depends on salinity	Negligible	Once in two years if it is operated as per instructions.	Once a year

5.2.4. Existing experimentation of the reviewed systems

The Plimmer produced by Ecoaeon has not been implemented in a developing country yet, but benefits from several years of field testing in industrialised countries (Korea, up to 7 years in the United States). The three other technologies ditto benefit from various implementation in a developing country, mainly in India, for some type of design. Others are innovative and still need to be tested in real conditions (see table 28 below).

Table 28. State of experimentation for the 10 systems assessed.

Technology	In development	Field tested in developed country	Field tested in developing country
Seawater greenhouses	X	X	
Aquaplus Solar distillation system	X		
GéoNoria		X	
Animal-powered RO			X
Mobile RO unit			X
2-stage seawater RO			X
RO defluoridation-cum-desalination			X
Solar-powered RO			X
Domestic ED			X
Plimmer	X		
PROtector	X		

Nevertheless, only the six solutions from the CSMCRI (from animal-powered RO to domestic ED in the table) have shown their ability in actual real life applications at village scale. The other technologies having been field tested are still at an experimentation stage.

5.3. Completion of the literature review

Additional literature was also obtained thanks to academic and company reports, or even scientific articles provided by contacts. The following literature was obtained this way:

- ✓ Al Ismaili, A. M. (2003), Modification of a Quonset Greenhouse to a Humidification-Dehumidification System: Design, Construction and pilot testing, Sultanate Qaboos University, Sultanate of Oman, MSc thesis
- ✓ Al Ismaili, A. M. (2009), Modelling of a humidification-dehumidification greenhouse in Oman, Cranfield University, United Kingdom, PhD thesis
- ✓ Tharani, A. (2009), Corporate sales presentation of July and August 2009 for the Plimmer, EcoAeon
- ✓ Technical details for EWP sites installed in Korea, SionTech
- ✓ Customer references USA from EcoAeon

- ✓ Water analysis questionnaire and Appendices, EcoAeon
- ✓ K. Mahkamov, Determination of rational design parameters of a multi-stage solar water desalination still using transient mathematical modelling(to be published in 2009), Renewable Energy, United Kingdom

Following answers from CSMCRI (domestic electrodialysis technology) and EcoAeon (contact suggested by Andy Bastable), the decision to include electronic processes (electrodialysis, capacitive deionization and by extension ion exchange) in the literature review was taken.

6. Discussion: choice of suitable technologies

Based on the results exposed in the previous part, the table 29 below has been drawn summarizing information obtained for 10 of the proposed systems. The case of seawater greenhouse being excluded as its initial aim is to grow plant, not to produce drinking water. Indeed, it is hard to define the corresponding characteristics for this system. The aim of this table is to show the recommended conditions of use for each system in order to discuss their appropriateness for the situations targeted, confronted with the defined criteria.

Table 29. Comparison of 10 reviewed technologies regarding the main defined criteria. For each technology, the corresponding element for a category is located by a "X".

		Animal-powered RO	Mobile RO unit	2-stage seawater RO	RO-F removal	Solar-powered RO
Source water	**Brackish water**	X	X	X	X	X
	Sea water		X	X		
Population served	**Village scale**	X	X	X	X	
	Cluster of house					X
	Family scale					
Range of building cost (US$)	**<10**	X			X	
	10-100		X	X		
	> 100					X
Energy cost dependance	**Negligible**	X				X
	Electricity			X	X	
	Fuel		X			
Level of expertise needed for operation	**Local expertise**	X				
	Automated					
	Training needed	X	X	X	X	X
Annual replacement costs (US$)	**Negligible**					
	1-4	X	X	X	X	X
Maintenance complexity	**Negligible**					
	Automated					
	Training needed	X	X	X	X	X

		PROtector	Aquaplus	GéoNoria	Domestic ED	EcoAeon
Source water	**Brackish water**	X	X	X	X	X
	Sea water		X	X		
Population served	**Village scale**	X				X
	Cluster of house			X	X	
	Family scale		X			
Range of building cost (US$)	**<10**				X	
	10-100	X	X	X		X
	> 100					
Energy cost dependance	**Negligible**	X	X	X		
	Electricity				X	X
	Fuel					
Level of expertise needed for operation	**Local expertise**	X	X	X		
	Automated					X
	Training needed				X	X
Annual replacement costs (US$)	**Negligible**		X	X		X
	1-4/spare parts	X			X	
Maintenance complexity	**Negligible**		X	X		
	Automated					X
	Training needed	X			X	

All the reviewed systems are discussed in the following paragraphs, classified according to their driving processes.

6.1. Reverse osmosis

Among the 6 options using reverse osmosis reviewed, the mobile RO unit is specifically designed for emergency situation. It has proven its capacity in the past for treating contaminated water at village scale during drought and natural calamities in India. Despite its relatively high overall cost (mainly due to the use of fuel as energy source and to spare parts needed), this option is valuable as the purchase of one single unit will worth the investment. Indeed, it is easily replicable and it can be moved from a village to another depending on the needs with the help of a trained technician from an external organisation, available in emergency contexts.

Strength-powered systems (animal-powered RO and PROtector, a human-powered RO unit) are suitable for village scale in development. Indeed, their overall cost is viable as energy needed is only strength. The unit will have to be designed by abroad but, once implemented, local expertise is sufficient for operating the system. However, maintenance and membrane has to be done by an external observer. As it is only needed at a relatively low frequency (about every 3 years for membrane replacement, between 3 months and 1 year for checking mechanics), this is not such a constraint. A modelisation of the PROtector is shown in figure 18.

Figure 18. The PROtector, designed by A+Trading (2009).

For removing both fluoride and salts at the same time, RO-F removal units are a possibility, regarding its low building cost sufficient for serving a whole village with a single unit. It also presents the advantage of having shown its adaptability and its social acceptance in India.

2-stage RO plants can also be envisaged at village scale but this is not the most economically costly as its scale is relatively high (plant scale) compared to the scale of villages envisaged, and as training is needed for operation and maintenance, which may not be accepted depending on the community, although it was well accepted in India according to the CMSCRI.

Finally, solar-powered RO can serve several houses for an operating cost close to zero as it is simply driven by solar radiation. However, regarding its high building costs and the spare parts replacement needed, this option is not suitable for the targeted use. Its overall cost remains too high compared with the scale expected.

6.2. Solar distillation

As expected in the literature, all the three solar distillation systems studied have a negligible operation cost as no pumping system is needed when solar heating is sufficient for moving water through the system. Local expertise is thus sufficient for daily operation. Cleaning of the device is also possible by a nominee by the community.
Two of the three solar distillations options studied are still at research stage and need to be optimized before envisaging any replication. The desalination by evaporation and condensation system designed by Aquaplus Water Purifier, planned to be used for a single house, is certainly adapted for a use at family scale in development situations, regarding its operation costs, local expertise sufficient for operating and maintaining the system, low replacement cost. Nevertheless, it is not ready for being implemented at the time being. Whatever, it could worth try it in a near future.

Similarly, seawater greenhouses are not ready to be replicated somewhere else that in research field experimentations. Moreover, the feedback of the discussion with a PhD student working on seawater greenhouses is that this technology is too expensive for being implemented in low income countries regarding the investment needed in rich countries such as Sultanate of Oman. Additionally, at the present state, this system is not effective enough and is not dedicated to the production of drinking water itself. Consequently, regarding the actual state of the research for this technology, this system is not recommended for any of the possible situations envisaged.

Meanwhile, the case of GéoNoria is more encouraging. Indeed, this system could supply several houses for slightly no operation costs. Local material is also sufficient for building and spare parts production and maintenance, regarding its simplicity, can be done by a community nominee, once made aware of the main issues (protection of glass covers, the need to left convectors free from any obstruction, daily cleaning).All this make GéoNoria an economically valuable option that worth to be tested in development situation, according to local material and expertise available.

6.3. Electronic processes

Domestic electrodialysis is an interesting example to follow for the case of an implementation for about 10 families per unit in development context. As a matter of fact, whereas it is designed for a relatively small scale (a cluster of about 10 families), its building cost is low compared with the other options. Additionally, membranes have been successfully produced locally in India, which make this option economically valuable regarding the overall expenses. However, the operation cost could be lowered if energy source used is renewable (e.g. wind turbine producing electricity) for becoming relatively as cheap as animal or human-powered RO for instance, but no such experimentation has been found. If renewable energies are envisaged, a cost analysis taking into account the potential additional capital and operating costs, corresponding to implementation of a wind turbine for instance, should be carried out for estimating the viability of this solution.

In another register, the main specificities the Plimmer (figure 19), designed by EcoAeon and using capacitive deionization are its automation of operation and maintenance, and its remote control. This makes such a system an adapted solution for chronic emergency. Indeed, if the technical aspects are managed by an NGO, with checking of the operation remotely, the community will be free of responsibility. Technical operations at the expense of an external organism include remote O&M, sending of a trained technician on site if repairing needed, programming and any other adjustment on site, depending on fluctuation of water quality. Although field-tested for 7 years in the USA, this technology still has to show its ability for developing countries as an innovative alternative for emergency.

Figure 19. The plimmer, developed by EcoAeon(Tharani, 2009).

6.4. Carbon nanotubes

As a result to the e-mail discussion with Olgica Bakajin, former employee at the Lawrence Livermore National Laboratories, Canada and currently employed by Porifera Nano, it seems that carbon nanotubes (CNT) technology is not relevant for this study for the time being. Indeed, this correspondent thinks that "the CNT membranes are still in an early stage of development, so [she] doubt the technology would be available in the time frame". This promising technology is not ready for being implemented at this stage but it seems to be an interesting opportunity in a near future for developing countries. As no other developers of nanotechnologies answered during the time of the thesis, this solution has been eliminated for a use in the near future. This could be even so an interesting opportunity once this technology is finalised.

As a summary, the following table (table 30) classifies the reserved solutions according to their recommended context of use, and the options eliminated for an implementation in short term.

Table 30. Technologies with potential.

Development	Emergency	Not relevant
➢ GeoNoria. ➢ Hand-powered RO (A+Trading). ➢ Animal-powered RO (CSMCRI). ➢ 2-stage sea water RO (CSMCRI). ➢ RO-fluoride removal (CMSCRI). ➢ Domestic ED (CSMCRI).	➢ Mobile RO van (CSMCRI). ➢ Plimmer (EcoAeon), esp. for chronic emergency.	➢ Seawater Greenhouse (Cardinal Resources). ➢ Desalination by evaporation and condensation using solar energy (Aquaplus Water Purifier). ➢ Solar powered RO (CSMCRI). ➢ Carbon nanotubes. (LLNL, Porifero).

One of the six systems reserved for development is certainly relevant, but not of first interest due to its higher overall cost and expertise needed (2-stage sea water RO). Domestic ED has also to be taken as a secondary option as, when membranes are not produced locally, its cost mainly depends on grid electricity which may not be reliable.

7. Recomendations and conclusion

7.1. Recommendations

7.1.1. Appropriate solutions

Use of local materials for building and spare parts production, together with renewable energies for driving the systems is recommended whenever possible in development. O&M will consequently be lowered in terms of complexity and costs. This is thus logical that solar power pipe system and strength driven RO, whether animal- or human-powered, are recommended for such situations. In emergency contexts, however, the technology can be more complex to operate and maintain as trained staff are supposed available. Table 31 summarizes the recommended solutions for each of the two contexts aimed.

Table 31. Recommended solutions depending on their contexts aimed.

Development	Emergency
➢ GeoNoria.	➢ Mobile RO van (CSMCRI).
➢ Hand-powered RO (PROtector, A+Trading).	➢ Automated CDI (Plimmer, EcoAeon), esp. for chronic emergency.
➢ Animal-powered RO (CSMCRI).	
➢ RO-fluoride removal (CMSCRI).	

Among these recommended solutions, three (Animal-powered RO, RO-fluoride removal, Mobile RO unit) are proven technologies and enjoy a reasonable level of confidence for further implementation. The other three need to be tested at pilot scale before being replicated widely.

For the test site of Longech, where salts and fluoride removal are needed, the PROtector or an animal-powered RO system is recommended. Nevertheless, if Oxfam is interested in testing GéoNoria or the Plimmer with the goal to replicate it in other places, the district of Central Turkana can be considered as similar to the situations expected.

7.1.2. Possibilities to improve the thesis

The contacting phase gave some interesting results but more time would have been better for improving its efficiency. To achieve it, being related with Brian McSorley for knowing the context in Turkana Lake right from the beginning would have been helpful. Thus, more companies could be contacted and advices to NGOs already working in targeted countries would have been taken to better define the context in other targeted countries.

7.2. Conclusion

Choosing appropriate technology for a development or chronic emergency context demands precise criteria to be defined from the beginning.

Even more than basic technical criteria, such as water demand and source water salinity, long-term management specificities are essential. Actually, comparison of operation and maintenance, whether in terms of complexity or costs, is a necessary process for assessing its suitability in long term. It results that use of local materials for building and spare parts is a serious advantage for successful experimentations, as well as use of renewable energies. As a consequence, operation and maintenance costs are lowered.

After having sorted the possible solutions, four systems have been reserved for development situations, while two other systems are recommended for chronic emergency regarding their higher complexity. Hence, two RO solutions driven by gross strength are envisaged for the test site of Longech in Kenya. Additionally, the Plimmer and the system of the initiative GéoNoria need to be tested for further approval. As a matter of fact, numerous solutions existing have not been in use in a developing country yet and need consequently innovative experimentation for the good of all.

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Xin Yang (2007), Solar still brick, China, pictures kindly supplied by Andy Bastable, Oxfam GB.

APPENDICES

Table of content

A1. Measure of salinity

Measure of salinity can be done:

- by measuring the electric conductivity (EC) obtained between two electrodes of a conductivity probe,
- by using of a refractometer,
- thanks to a hydrometer estimating specific gravity.

The two latter solutions are commonly used by aquarists.

Electric Conductivity (EC)

This measurement is used for soil and water salinity estimation. Indeed the EC of a sample is influenced by the concentration in total dissolved solids such as salts, which can increase the conductivity of water or soil (Madden, 2005). It is measured in mS/cm (and its corresponding subdivisions such as µS/cm). It can be thus converted into Total Dissolved Solids (TDS), expressed in parts per million (ppm) or mg/L, using a convertion factor depending on the manufacturer (Waterwatch SA, 2005). For instance, the conversion factor used in South Australia is 0.56, giving the conversion table 32.

Table 32. Conversion factors EC-ppm (after Greentrees hydroponics, 2009)

Electrical Conductivity (EC)		Parts Per Million (PPM)	
miliSiemens (mS)	microSiemens (mS)	NaCl Conversion	442 Conversion
1.0	1000	500 ppm	700 ppm
1.5	1500	750 ppm	1050 ppm
2.0	2000	1000 ppm	1400 ppm
2.5	2500	1250 ppm	1750 ppm
3.0	3000	1500 ppm	2100 ppm

Two conversion systems are used in the industry, depending on the composition of TDS considered: the NaCl conversion and the 442 conversion (corresponding to a 40% sodium sulfate, 40% sodium bicarbonate, 20% chloride ratio). Related factors are 1TDS=500EC (mS/cm) and 1TDS=700EC (mS/cm) for the 442 conversion.

Refractive index

Instead of conductivity of water, its index of refraction (also known as refractive index) can be measured by a refractometer. Indeed, refractive index (dimensionless) is the ratio of the speed of light in a phase over the phase velocity and can be related to a linear combination of the electrical conductivity and the electrical permittivity for a specific wavelength (Weisstein, 2007). The amount of salt dissolved in water can thus increase its wavelength from 1.3330 to 1.3394 for seawater (salinity of about 35,000 ppm) (Reefkeeping, 2008). Salinity and index of refraction are hence proportionate, making possible the measure of salinity by refractometer. Nevertheless, refractometer measures are not as accurate as EC but it can be a simple way to estimate salinity, although this method is only suitable for estimating high salinity such as in source water and can not be used for measuring salinity as trace levels after treatment.

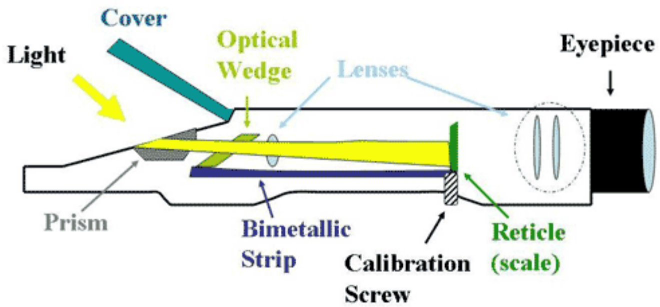

Figure xxx. Schematic of a hand held refractometer (Reefkeeping, 2008)

Specific Gravity

In the case of saline water, specific gravity is the ratio of the density of saline water over the one of pure water (1,000kg/m^3 at 4°C) for a fixed temperature (The engineering toolbox, 2005). As a matter of fact, density of pure water is for instance 998.2kg/m3 at 20°C (Walker, 2008). This value is dimensionless, as refractive index. Not as accurate as conductivity probes or even refractometers, hydrometer measures specific gravity working on Archimedes principle (Holmes-Farley, 2002).

A2. Solar ponds

This simple process is inspired of a natural phenomenon occurring in the Solar Lake, Sinai, Israel where, due to its high salinity, water is stratified and some layers are able to reach 60 °C, a temperature that can only be found in some geothermal lakes (Garg, date unknown). Using this faculty of high salinity lake, solar ponds can be used to collect energy from the sun, the lowest zone being able to be heated up to 90°C, whereas it is usually at about 30°C in non salty water (Mongillo and Zierdt-Warshaw, 2000).

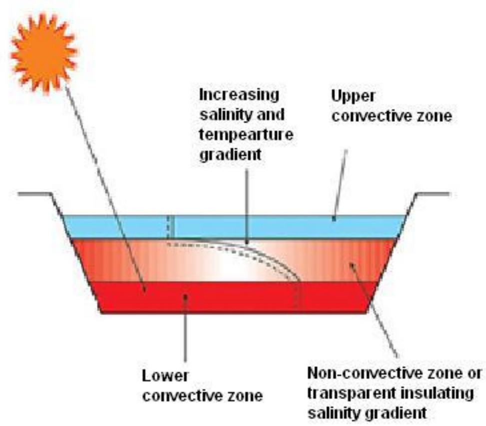

Figure xxx. Principle of solar ponds. (after TERI, 2009)

By placing a specific material at the bottom of the pond, energy can then be retrieved and stored for another use.

Existing applications

This process is used to produce energy, whether in the form of heat for building for instance, or to generate electricity thanks to Rankine cycle turbines for instance. Numerous applications of this process exist, the biggest large scale use of this process is in Israel, in the Dead Sea, were the sea is used as a solar pond to produce electricity, up to 6MW for the Ormat Turbines Company pond (Garg, unknown). Several research and development programs aiming an industrial application of solar ponds exist, such as in the University of Texas at El Paso (initiated in 1983), focused on desalination and brine management technologies (Agha, 2008), and the Royal Melbourne Institute of Technology in Australia. The second project started more recently in 2000, and includes a real world project at Pyramid Salt, Pyramid Hill, Northern Victoria (Solar Pond project, RMIT, Australia).
In developing countries, the Bhuj solar pond project is a reference. This project began in 1987 and finished in 1993 (TERI, 2009) and is the first large-scale pond experimented in India for an industrial use. Between September 1993 and April 1995, it produces 15 millions litres of hot water per day at an average temperature of 75°C. Sadly, due to a lack of financial support and government policy, it lies in disuse (Ceylan Serhadoglu and Büjükkidik, 2004).

Limitations

Solar ponds are particularly suitable for areas where there is a combination of high level of solar energy, salt, a very large supply of brackish water and a lot of land area available for a low cost. Proximity with natural salt lakes is encouraging for implementing it. Suitable places are thus desert areas which are near coasts and in salinised agricultural areas. That way, "there seems to be no technical or economic reason why solar pond produced power and water is not done more often. The reasons seem to be geographical and political." (Hignett et al., 2001)

Table 33. Cost comparison of solar pond-powered systems versus conventional reverse osmosis (After Al-Karaghouli et al., 2009).

System type	**Capacity (m^3/day)**					
	Conventional seawater reverse osmosis		**Solar-pond powered distillation**		**Solar-pond hybrid system**	
	20,000	200,000	20,000	200,000	20,000	200,000
Investment (mil.$)	20.0	160.0	48.0	380.0	32.0	250.0
Specific investment ($/$m^3$/day)	1,000	800	2,400	1,900	1,600	1,250
Unit water cost ($/$m^3$)	0.77	0.66	0.89	0.71	0.79	0.65

Finally, the solar pond approach could be interesting for developing countries to supply at least a whole village in rural areas. This is a low-cost alternative to produce energy for desalination but its application is only suitable for large scale. Only the cost of the clay or the plastic pond liner is necessary for implementing solar collectors over a very large area.

Table 34. Summary of advantages/disadvantages for a solar pond

Advantages	**Disadvantages**
○ Material needed to line the pond easily available. ○ Operation and maintenance cost low. ○ Naturally occurring in some places, especially in presence of salt lakes.	○ Large area of land needed. ○ More suitable for a large-scale use, i.e. for a whole village at least. ○ Capital cost relatively high. ○ Only possible if a particular combination of condition is gathered.

A3. Reverse osmosis and Renewable energy

A4.1. Solar-powered reverse osmosis

Principle

Solar-powered reverse osmosis uses solar radiation as energy source and converts it in electricity thanks to photovoltaic cells (PV) in order to run a reverse osmosis system. Its scale of use could be large or small scale. Numerous examples of PV-RO systems used in remote areas exist as it is the case in Australia (Fedrizzi et al., 2009).

Potentials and limitations

However PV technology is often considered as not suitable for remote areas in developing countries as "issues related to the local specificities and technology transfer methods are not taken into account".

Nevertheless, regarding to technology progress, PV could be a possible alternative solution in the near future. Production of PV cells still demand sophisticated materials and technologies but its price is decreasing and it is easy to use. Also the use of solar panels constitutes a capital investment but it will be written off over the lifetime of the unit (Water research commission South Africa, 2001). A solution could be to provide PV cells at the beginning as a temporary solution, waiting for the technology to become more accessible.

Existing projects

Numerous successful experimentations of solar-powered reverse osmosis for remote locations exist such as in the Sultanate of Oman (Al Suleimani and Rajendran Nair, 2000) and in India (Ansari et al., 2002). A simulation for the Sultanate of Oman over a 20 year-lifetime of the plant showed that its overall cost will be 25% lower than by using diesel and still 6% lower over a 10 year-use, although use of diesel implies longer operation and higher productivity. For Indian conditions, the biggest challenge with this technology is the management of RO plants in rural areas which can suffer of little support of the local authorities.

Table 35. Summary of advantages/disadvantages for a PV system (After Al Karaghouli et al., 2009)

Advantages	Disadvantages
○ Small scale ○ Limited maintenance cost ○ Ease of transportation/installation	○ Need of an energy storage system (batteries) ○ High capital cost of PV ○ Long-term management has to be supported by authorities ○ Strongly depending on the weather

A4.2. Wind-powered reverse osmosis

Principle

Another cheap source of energy for reverse osmosis is wind. As solar energy, use of wind as a source of energy is not new as the oldest windmills have been found in China around 3000 BC and wind-powered water pumps appeared in Babylon around 1600 BC (Spang, 2008). Indeed, kinetic energy of the wind can be converted in mechanical strength (windmill) or in electricity (wind turbines) that could be used for running a membrane unit (Garcia-Rodriguez et al., 2000).

Depending on the local context, wind-powered desalination units can be connected to the closest grid or autonomous. In the first case, extra energy can be supplied by the grid if needed or surplus of electricity produced by wind turbines can be sold back to the grid. In the second case, off-grid systems are suitable for remote communities with no substantial electrical infrastructure where standalone systems are more economically viable (Spang, 2006).

Potentials and limitations

Two main limitations for wind-powered systems can be highlighted: the high initial capital cost and space requirement. Indeed for the latter, site selection is essential: not only wind velocity and its timing have to be suitable to the requirements but also obstructions need to be avoided for an optimum performance (Spang, 2006).

Anyway, development of wind power generation systems could provide a cheap source of energy that can be used for other purposes. And even better, surplus electricity produced can be sold to another country which could help amortize the relatively high capital cost needed. Furthermore, wind energy can be coupled with PV system as an energy backup to avoid fossil fuels according to Spang (2006). Nevertheless, whereas PV depends on variability of solar radiation, wind variability is not a problem: extra water produced during periods of high winds can be stored for periods of low winds. Another argument for wind-powered systems is that, in coastal environments, wind is relatively constant and additionally, use of offshore turbines will make it possible to obtain a better land occupation if the technology is affordable.

Existing projects and potential developments

From February 1996 to May 2001, the SDAWES project in Canary Islands, Spain, had “to identify the best desalination system for connection to a standalone wind farm” by testing three different processes, reverse osmosis included (Carta et al., 2004). The total nominal production obtained was 440m^3 per day, which is relatively large scale.

Since 1997, the University of Hawaii at Manoa also conducted research modelling, laboratory testing and field testing of wind-powered reverse osmosis desalination systems (Liu, 2000). The system obtained can produce about 160 L/hour of freshwater with an average wind speed of 5m/s and a brackish feed water of 3.100 mg/L TDS initially.

Finally in more practical terms, the company ENERCON based in Germany (ENERCON, 2009) has developed a “flexible operation range” technology using piston for improving energy recovery (usually, only 25% of the energy in the RO process is used to produce drinking water) and enabling variable levels of energy input. One of its targeted applications is to be installed quickly in remote and underdeveloped coastal areas.

Table 36. Summary of advantages/disadvantages for wind-powered reverse osmosis systems.

Advantages	Disadvantages
○ Small and medium scale (flexibility of use by adding membranes and turbines if productivity need to be higher) ○ Production of electricity in surplus ○ Low operating cost ○ Possibility to store water for future needs	○ Site selection (land availability) ○ High initial capital cost

A4. Comparison of low cost desalination technologies

In addition to the comparison provided in the discussion of the literature review, the following tables give elements of reflection for choosing an appropriate technology. The first one compares several criteria related to the operation of defined technologies, whether in terms of energy requirements or operation complexity. The use of chemicals is also an interesting criterion to take into account as these chemicals are rarely produced on site, which cause higher operation cost, and as they generate waste that need to be stored properly. Processes that are chemicals demanding thus need technicians with higher skilled. Operational complexity is considered as “simple” when expertise initially available in villages is sufficient.”Operation flexible within limits” means that, in a defined range of values where the technology is expendable, the conditions of functioning can be easily adapted to the demand.

Table 37. Comparison of low cost desalination technologies in terms of operation criteria.

Technology	Renewable energy available	Energy use	Energy requirements	Use of chemicals	Operational complexity	Operational flexibility
Solar distillation	Solar	Heat	Weather dependant	No	Simple	Strongly weather dependant
Solar thermal MED	Solar	Heat	Lower energy requirements compared to MSF	No	Simple	Operation flexible within limits
Solar distillation along pipes	Solar	Heat	Weather dependant	No	Simple	Strongly weather dependant
Reverse Osmosis	Solar, wind or strength	Electricity, mechanical	Relatively high, but possibly supplemented by renewable energy	Yes	Training needed, automation possible	Operation flexible within limits
Forward Osmosis	Solar, wind or strength	Electricity, mechanical	Relatively high, but possibly supplemented by renewable energy	Yes	Training needed, automation possible	Operation flexible within limits
Nanotechnologies	Solar, Wind	Electricity	Lower electrical energy requirements than RO, possibly supplemented by renewable energy	Yes	Training needed, automation possible	Operation flexible within limits

Technology	Renewable energy available	Energy use	Energy requirements	Use of chemicals	Operational complexity	Operational flexibility
Ion Exchange	-	Electricity	Lower than RO	Yes, for maintenance	Simple but training needed, automation possible	Operation flexible within limits
Capacitive Deionisation	Wind	Electricity	Lower than RO	No	Simple but training needed, automation possible	Operation very flexible within limits
Membrane Distillation	Solar	Heat, Electricity	Relatively low energy requirements	Yes	More complex than other membrane processes	Rather flexible
Electrodialysis	Solar	Electricity	Lower than RO	No	Simple but training needed, automation possible	Operation very flexible within limits

As for the table below, it considers three other parameters that could weight on the decision-making process and the potential sustainability of a technology. The first parameter is maintenance complexity, taking into account the level of skill needed for common maintenance and replacement. It is considered as low if it can be carried out by anybody, even a child (simple cleaning for instance). When higher requirements are expected, a trained technician is designed for these processes. As indicators of the importance of existing experimentations and the interest of further research on application, process maturity and potential for further development are considered. Process maturity is low when the technology is still in development and high if several successful implementations exist during several years in a row. Potential for further development is high if significant improvements are expected in the next few years, e.g. production of membranes more efficient and locally produced.

Table 38. Other indicators for assessing the sustainability.

Technology	Maintenance complexity	Process maturity	Potential for further development
Solar distillation	Low, daily	High	Medium
Solar thermal MED	High maintenance requirements	High	Medium
Solar distillation along pipes	Low, daily	Low	High
Reverse Osmosis	High maintenance requirements	High	High
Forward Osmosis	High maintenance requirements	High	High
Nanotechnologies	High maintenance requirements	Low	High
Ion Exchange	High maintenance requirements	High	Medium
Capacitive Deionisation	Low, yearly	Medium	High
Membrane Distillation	High maintenance requirements	Low	High
Electrodialysis	Low	High	High

A5. List of contacts

Respondents:

Organisation	Activity	Contact name	Phone number	E-mail	Location	Internet link
CSMCRI (Central Salt & Marine Chemicals Research Institute)	Several various systems	[1]A.V.R. Reddy, [2]Pushpito K. Ghosh, [3]M. R. Gandhi	[1]+91(0)278-2566511; [2]+91(0)278-2569496; [3]+91(0)278-2566547	[1]avreddy@csmcri.org; [2]pkghosh@csmcri.org; [3]mrgandhi@csmcri.org	India	http://www.csmcri.org
A+ trading	RO with handpump	George Rose	(Ph.) +44 (0) 1903725634	george.rose@aplustrading.net jason.green@aplustrading.net	UK	www.aplustrading.net
Aquaplus water purifiers P Ltd	Small solar distillation device	Rahul Pathak, Watsan CSR & Disaster Management Cell	(Ph.) +91 20 25434133 (Cell) +91 9420482945	sales@aquaplusltd.com, aquaplus_rahul@yahoo.co.in	India	
Durham University	MED with solar trough	Dr. Khamid Mahkamov	(Ph.) +44 (0)191 33 42429	khamid.mahkamov@durham.ac.uk	UK	http://www.dur.ac.uk/directory/
EcoAeon	CDI specifically designed for developing countries	[1] Alykhan Tharani and [2] Roddy MacDonal, directors	[1] +44 (0)7972336785; [2] +44 (0)7816933643	atharani@ecoaeon.com	UK	http://ecoaeon.com
Geonoria	A specific distillation system using solar energy	Olivier Grossat	(cell) +33 1 47 07 33 10 (call after 20pm, GMT+1)	info@geonoria.org	France	http://geonoria.org
Remote Area Developments Group, Murdoch University	PV RO	M.Anda, research manager at the RADG, Murdoch University	(Ph.) +61 9360 6123	M.Anda@murdoch.edu.au	Australia	http://www.etc.murdoch.edu.au/etcV03/pages/radg/radgpages/radghome.html
Seawater Greenhouse	Red Bird tech (Seawater greenhouses)	Abdulrahim Al-Ismaili (former PhD student)	(Ph.)+968 24415228, (Fax) +968 24413418	a.al-ismaili.so5@cranfield.ac.uk , abdrahim@hotmail.com	Oman	http://www.seawatergreenhouse.com/
Skyjuice	Supplier for NGOs (SkyHydrant: microporous membranes)	Jann Hughes	(Ph.) + 61 2 92524420, (Mob.) + 61 400 062 265	jann.hughes@skyjuice.com.au	Australia	http://www.skyjuice.com.au/
the Lawrence Livermore National Laboratories	Carbon nanotubes	Olgica Bakajin		bakajin1@llnl.gov	Canada	https://st.llnl.gov/?q=missions

Contacts not responding:

Organisation	Activity	Contact name	Phone number	E-mail	Location	Internet link
University of Texas at El Paso	solar ponds and solar desalination including MD	[1]Pr. John Walton, [2]Pr. Huanmin Lu, [3]Pr. Charles Turner	[1] (915)747-8699; [2](915)747-6904,Fax:(915)747-5019; [3](915)747-6908;(915)747-8037	walton@utep.edu; lhuanmin@utep.edu; cturner@utep.edu	USA	http://www.utep.edu/
Centre for Rural Development and Technology, IIT, Delhi	small-scale MED in India	Padma Vasudevan Sen		padmav@rdat.iitd.ernet.in or padmav10@hotmail.com -		-
ENERCON	Wind-powered RO				Germany	
Mechanical Engineering Department, CET (IFTM Campus), Moradabad	small-scale MED in India	A. Mudgal		anurag_mudgal@yahoo.com		-
NanoH2O	Nanotech membranes			info@nanoh2o.com	USA	http://www.nanoh2o.com
Solco Ltd	PV RO		(Ph.) +611800 454 161	info@solco.com.au	Australia	www.solco.com.au
University of Sheffield	Human-powered FO	Pr Richard Jones	(Ph.) +44 (0)114 2224530, (Fax) +44 (0)114 2728079	r.a.l.jones@sheffield.ac.uk	UK	http://www.shef.ac.uk/physics/people/rjones/
Yale University	FO	Pr. Menachem Elimelech/former PhD student: McCutcheon		menachem.elimelech@yale.edu / jeffrey.mccutcheon@yale.edu	USA	http://www.yale.edu/env/elimelech/bio.html
Saehan Industries	Nanofiltration membranes	available at http://www.saehan.com/common/contactUs.asp			Korea	http://www.saehan.com/
Department of Applied Mechanics, IIT, Delhi	small-scale MED in India	P. K. Sen	Contact details not found		India	
Indira Gandhi National Open University, Delhi	small-scale MED in India	S.K.Vyas	Contact details not found		India	
Physicotechnical Institute, NPO Fizika-Solntse, the Akademy of Sciences of the Republic of Uzbekistan	MED with solar trough	J. S. Akhatov	Contact details not found		Uzbekistan	

A6. Questionnaire

Brief description of the technology

Technical details

1	Average daily flow/size of the population served with one unit
2	Origin of source water
3	Quality and salinity of source water (please precise the unit used)
4	Quality of water produced
5	Space requirements
6	Material requirements
7	Technical requirements (technical skill needed)
8	Cost of a single unit (building)

Long-term management

1	Expertise required for operation
2	Source of energy used
3	Amount of energy needed
4	Operation cost
5	Maintenance/ spare parts replacements needed
6	Frequency
7	Technical skills required for maintenance and spare parts replacements
8	Maintenance and replacement cost
9	Is there a need to train staff for operation and maintenance?
10	How many people needed for maintaining?
11	How many people needed for training?

Socio-cultural acceptance

1	Are you aware of any feedback about its use after implementation?
2	If so, what problems have occurred and how did you manage it?
3	How the population accepted the technology

Additional information

1	Are you aware of any technology, research or field experiment in the field of desalination?
2	Any other details that you want to add
3	What information would you allow to communicate in an Oxfam report?

A7.Questionnaires completed

Name : Aquaplus Company/ ~~Research laboratory~~
Contact : Rahul Pathak
E-mail : aquaplus_rahul@yahoo.co.in
Phone number : +91 20 25434133, Mobile phone : +91 9420482945
Technology : Small solar distillation device

Brief description of the technology

Desalination By Evaporation & Condensation using Solar Energy: The system uses a Solar Parabola to concentrate the solar energy at a single Focal point. A Pressure Cooker is mounted on the Focal point & Water to be desalinated is stored in the cooker. As the Focal point generates intense heat the Water is converted in steam which is then further passed on to the condensation unit which converts this steam into water. Hence desalination is achieved.

Technical details

1	Average daily flow/size of the population served with one unit	Target ~ 25 LPD
2	Origin of source water	Tubewell/ Openwell/ Brakish/ Sea Water
3	Quality and salinity of source water (please precise the unit used)	0-36000 ppm
4	Quality of water produced	Desalinated Water 1ppm
5	Space requirements	1 Meter X 1 Meter
6	Material requirements	Solar Parabola, Pressure Cooker, Condensation tank, Condensation Tubing.
7	Technical requirements (technical skill needed)	None
8	Cost of a single unit (building)	~ USD 300 (Target Price)

Long-term management		
1	Expertise required for operation	None
2	Source of energy used	Solar
3	Amount of energy needed	to be calculated
4	Operation cost	None
5	Maintenance/ spare parts replacements needed	Cleaning of Cooker periodically
6	Frequency	depends on salinity
7	Technical skills required for maintenance and spare parts replacements	None
8	Maintenance and replacement cost	marginal (yet to be calculated)
9	Is there a need to train staff for operation and maintenance?	Yes
10	How many people needed for maintaining?	1
11	How many people needed for training?	1
Socio-cultural acceptance		
1	Are you aware of any feedback about its use after implementation?	No the project is still in R&D
2	If so, what problems have occurred and how did you manage it?	Condensation (R&D in Progress)
3	How the population accepted the technology	(Still in R&D)
Additional information		
1	Are you aware of any technology, research or field experiment in the field of desalination?	(Still in R&D)
2	Any other details that you want to add	None
3	What information would you allow to communicate in an Oxfam report?	All

Name : GeoNoria, Independant group ~~Company~~/ ~~Research laboratory~~
Contact : Olivier Grossat
E-mail : info@geonoria.org
Phone number : +33 1 47 07 33 10 (call after 20pm, GMT+1)
Technology : Distilation system using mirror along pipes

Brief description of the technology

Free process for converting sea water into fresh water using the means of solar heater.

Technical details

1	Average daily flow/size of the population served with one unit	Depending on the needs of the population.
2	Origin of source water	Indifferent
3	Quality and salinity of source water (please precise the unit used)	Indifferent
4	Quality of water produced	6.2 l/h
5	Space requirements	10m²
6	Material requirements	See the website: www.geonoria.org (available both in french and english)
7	Technical requirements (technical skill needed)	
8	Cost of a single unit (building)	Depending on the hourly rate and materials costs on site.

Long-term management

1	Expertise required for operation	A civil engineer + labour
2	Source of energy used	Solar
3	Amount of energy needed	Solar
4	Operation cost	
5	Maintenance/ spare parts replacements needed	Regular cleaning of the system/no spare parts necessary Without filter or chemical products
6	Frequency	Daily
7	Technical skills required for maintenance and spare parts replacements	Negligible
8	Maintenance and replacement cost	Negligible
9	Is there a need to train staff for operation and	Yes

	maintenance?	
10	How many people needed for maintaining?	1
11	How many people needed for training?	1

Socio-cultural acceptance

1	Are you aware of any feedback about its use after implementation?	no
2	If so, what problems have occurred and how did you manage it?	
3	How the population accepted the technology	

Additional information

1	Are you aware of any technology, research or field experiment in the field of desalination?	
2	Any other details that you want to add	*100% Ecological,100% Free* *without electrical installation* *without filter or chemical products* *no complex processes* *low maintenance cost*
3	What information would you allow to communicate in an Oxfam report?	YES

GeoNoria does not sell any product, the concept is freely made available to all.

Name : A+Trading Company/ ~~Research laboratory~~
Contact : George Rose
E-mail : george.rose@aplustrading.net
Phone number : +44 (0) 1903725634
Technology : PROtector (Pumped Reverse Osmosis)

Brief description of the technology

PROtector – **P**umped **R**everse **O**smosis: Self contained unit comprising two industrial reverse osmosis membranes rated for brackish water (BWRO), protected by 'bacteriostatic' ceramic pre-filters (10 micron and 1 micron). Unit is manually powered by cranking handle up and down to operate chain drive mechanism. Internal peristaltic pump, operated by chain drive, is able to generate over 120psi of pressure required to push water through the membranes and thus remove salts and excessive minerals such as fluoride. No fuel or electrical power required in operation, thus low cost per unit of water treated.

Technical details – PROtector 4500

1	Average daily flow/size of the population served with one unit	7,500 litres per 10 hour day (1,500 people at 5 litres per capita)
2	Origin of source water	Brackish well / borehole / lake / river
3	Quality and salinity of source water (please precise the unit used)	Raw well water at proposed Longech site: Conductivity 1,610µS/cm; TDS 810ppm; Fluoride 24ppm
4	Quality of water produced	Prototype unit for Longech installation features mineral adjustment valve – allowing an optimal rejection rate of 95%: TDS 41ppm ; Fluoride 1.2ppm *Please note that for other applications with geater salinity, the mineral adjustment valve can be set for a maximum rejection rate of 99.5%.*
5	Space requirements	Unit measures 1.2m x 1.2m on plan, with a height of 0.9m
6	Material requirements	Complete US manufactured unit is comprised of the following : RO membranes made from composite polyamide (CPA) Peristaltic Pump – Stainless steel construction, natural rubber hose Pre-filters - 0.07% pure silver (Ag) incorporated throughout ceramic shell Filter housings – 316L stainless steel Membrane housings – 304 stainless steel with GRP end caps Handle – Aluminium with replaceable CPVC grip Unit Housing & Frame – Powder coated steel
7	Technical requirements (technical skill needed)	None (Unit manufactured in USA by specialist company)
8	Cost of a single unit (building)	USD $17,170.00 (including commissioning, excluding shipping to site)

Long-term management		
1	Expertise required for operation	Low – very basic operation
2	Source of energy used	Manually powered by cranking handle up and down
3	Amount of energy needed	One child >10 yrs old will be able to operate the unit
4	Operation cost	$6.57 per day (based purely on annual maintenance costs - as no fuel, electrical energy or checmical reagents are required). This equates to 1.75¢ (<USD $0.02) per 20 litre jerry can.
5	Maintenance/ spare parts replacements needed	Grease lubrication of handle, chain drive and pump bearings / periodic replacement of pump hose and lubricant, ceramic filters, RO membranes and inline electrolytic scale inhibitor.
6	Frequency	Check handle hinges for adequate grease lubrication every 6 months Check external bolts for tightness every 6 months Replace peristaltic pump hose annually Replace peristaltic pump hose lubricant annually Replace ceramic pre-filters annually (or after 60 backwash cycles) Replace RO membranes every 3 years (or whenever fouled) Replace electrolytic scale inhibitor every 6-8 years
7	Technical skills required for maintenance and spare parts replacements	Low skills required for lubrication and periodic replacement of parts (use of grease gun and spanners)
8	Maintenance and replacement cost	Peristaltic pump hose – USD $225.00 Peristaltic pump hose lubricant (2 pints) – USD $30.00 Ceramic pre-filters (10 and 1 micron) – USD $1,620.00 RO membranes – USD $1,645.00 Electrolytic scale inhibitor – USD $50.00 *Please note that the unit has been overdesigned in anticipation of a life expectancy several decades long (exact timescale to be determined).*
9 10 11	Is there a need to train staff for operation and maintenance? How many people needed for maintaining? How many people needed for training?	Upon commissioning of the installed unit, a minimum of two appropriately elected people (based upon their availability and NOT skill level) would be trained on how to and where to apply grease ; and how to use the attached spanners to remove and replace the ceramic filters, RO membranes and peristaltic pump hose. They would also be trained on how to perform the backwash cycle, although this is illustrated in a pictorial diagram on the side of the unit for anyone to see and understand. Only one person is required to perform maintenance at any one time.

		Any number of people can undergo training, as it is a relatively simple process. We have suggested a minimum of two, so that there will always be somebody available to perform maintenance when required. From a microenterprise perspective, if each family was charged USD $1.00 per month for their treated drinking water, there would be a surplus of USD $176.25 after accounting for the maintenance cost each month (for a PROtector 4500). This could be put towards salary and overheads for a person or persons to take responsibility for maintaining the unit, collecting money from the residents and purchasing the consumables. For a roll-out programme of a number of PROtector units throughout the Turkana region a system would be put in place to co-ordinate the delivery of replacement components to each site from a centralised store or depot (such as in Lodwar). A regional support team of couriers and store keepers would operate from the depot, ensuring that all components were dispatched in a timely manner and that bulk supplies from the international supplier (A+ Trading) were of sufficient quantity and frequency. The size of the team would be based upon the number of **PROtector** installations throughout the region, the distances between them and the time taken to reach them all over a twelve month period. The regional support team would liaise with the various stewards upon delivery of the components, to ensure that the replacement of the filters and membranes was completed without any problems. The team would also be able to take the old components away from the site, for proper disposal at the depot. The cost of running the regional support team (staff salaries, fuel, vehicle maintenance etc.) would be added to the maintenance cost of each **PROtector**, although it would be offset by the savings of buying components in bulk to supply multiple installations (as opposed to the one pilot unit). For a national roll-out program, there would be a network of regional support teams located throughout the country. In Kenya, Davis & Shirtliff, a reputable water equipment supplier and installer established throughout East Africa would be appointed to commission new installations and co-ordinate the bulk supply of components into the country from the international supplier (A+ Trading).

Socio-cultural acceptance		
1 2 3	Are you aware of any feedback about its use after implementation? If so, what problems have occurred and how did you manage it? How the population accepted the technology	As the prototype unit has not yet been installed, we do not have any results from the field thus far. However, the unit was designed especially for the Longech site in Turkana in liaison with Brian McSorley – based upon his suggestions and concerns as a result of witnessing the success / failure of other technologies in Turkana. We therefore anticipate that the technology will be widely accepted with few problems.
Additional information		
1	Are you aware of any technology, research or field experiment in the field of desalination?	There are various types of desalination technologies available, such as distillation, deionisation (DI) and reverse osmosis (RO). Each of these has their pros and cons when gauged against various criteria for sustainable use in poor rural communities; and it should be noted that the 'lowest tech' method is not always the most appropriate. Distillation for instance, requires a great deal of energy per litre of water produced. For solar still applications, this translates to the need for a vast amount of area and care must be taken when draining and collecting the condensate to a central point. Furthermore, distilled water is prone to rapid re-contamination and/or becoming slightly acidic (pH 6.2) through the absorption of atmospheric carbon dioxide (CO_2).
2	Any other details that you want to add	Whilst the RO treatment process is relatively simple, some commercially available systems are not simple enough to be used in remote, rural locations. Automatic pressure switches and 'autoflush' features may be ideal for domestic applications where automation is preferred, but they are very sensitive and can easily fail when used 'in the bush'. Knowing that a suitable RO system for use in Turkana would need to be as robust, simple and easy to use as possible, we decided to develop a unit that would be operated by a hand powered pump. This would mean that there would be no need for any circuitry or electronic gadgetry; no possibility of power interruption; and no need to install or maintain any renewable energy equipments such as solar panel arrays or wind turbines. Furthermore, most commercial RO systems remove nearly all dissolved salts and minerals from water, making it almost completely distilled or deionised (DI). Whilst this water may be of a satisfactory standard for temporary or emergency situations, it is not suitable for potable use in the longer term. Instead of adding vital minerals *to* the body, DI water can actually leach them *from* the body. With all salts and minerals, there are optimal levels that are good (and even essential) for the human body as it

		develops. The **PROtector** system features a 'mineral adjustment' valve that allows a prescribed amount of filtered water to mix with the 'permeate' water to ensure an optimal mineral content. Whilst the safe limit for fluoride in drinking water (according to the World Health Organisation) is 1.5ppm, a level of 0.7 – 1.0ppm is actually beneficial to the development of teeth and bones. The mineral adjustment valve is preset in the factory, according the raw water quality at the site where it is to be installed.
3	What information would you allow to communicate in an Oxfam report?	We would happily allow all of the information given in this questionnaire to be communicated in a report.

Name : CSMCRI ~~Company~~/ Research laboratory
Contact : A.V.R. Reddy, Pushpito K. Ghosh, M. R. Gandhi
E-mail : avreddy@csmcri.org, pkghosh@csmcri.org, mrgandhi@csmcri.org
Phone number : 0278-2566511, -2569496, -2566547
Answers from this research laboratory are on 6 various technologies.

Name of the Technology	Salient Features of the Technology
Thin Film Composite (TFC) Reverse Osmosis Membrane	• Developed knowhow for making polyamide thin film composite (TFC) reverse osmosis membrane (1m wide x 100m long in a batch) low fouling membranes with antifouling coating and high product water recovery • TFC membrane removes salinity (94-96%) and other harmful contaminants like hardness, fluoride, nitrate, arsenic, etc, from water under standard test conditions • TFC membrane is suitable for desalination of brackish water and sea water • Potable water having < 500 ppm TDS can be obtained in single stage operation from brackish water having salinity up to 7000 ppm and in 2-stage operation from highly saline water (>7000 ppm TDS) and sea water • Installed several desalination plants (500-4000 litres/hour capacity) using the indigenously prepared TFC membrane • Setup a 1million litres/day capacity RO plant for water reclamation from tertiary treated sewage for industrial use
Flat Sheet Ultrafiltration Membranes	• Developed knowhow for making low fouling flat sheet UF membranes (1m wide x 100m long in a batch) having different cut off values (about 25, 60, 90 KDa) and longer membrane life • Membrane removes harmful pathogens, turbidity and colloidal materials from drinking water • Low energy requirement with very high recovery (up to 90%)
Hollow fiber Ultrafiltration Membranes and HF Cartridges	• Developed knowhow for making low fouling hollow fiber UF membranes having cut off value of about 90 KDa • Developed knowhow for making HF cartridges of different sizes for use in domestic to very large size water purification plants • HF membrane removes harmful pathogens and other contaminants like turbidity and colloidal materials from drinking water • Operates without any external pressure or at very low pressure (<20 psi) • Low energy requirement • Low fouling and longer membrane life • Can be used as point of use (POU) units for drinking water purification
Nanofiltration membranes	• Developed knowhow for making nanofiltration membrane which is suitable for water purification and other applications • Membrane removes hardness and other contaminants from drinking water • Membrane has higher rejection for divalent anionic salts compared to monovalent anionic salts • Removes reactive dyes from aqueous solutions
Spiral Module Development	• Developed expertise for making spiral modules of different size (2, 4 & 8" dia. x 40" long and Domestic) from flat sheet membranes for desalination and water purification applications

Brackish water & Sea water Desalination Plants	• Designed, fabricated and installed brackish water & sea water desalination plants (500-6000 litres/hour product water) in India and abroad (Kenya-1 SW plant; Afghanisthan-11 BW plants) • Setup desalination units based on alternate energy sources like animal-power and solar-power • Designed & fabricated a mobile van consisting of desalination and water purification technologies developed by the Institute along with water analysis facility and relevant scientific & educational material • No chemicals employed in the pre-treatment of raw water for RO feed • Developed a simple process for safe disposal of RO reject having excess fluoride

Animal Powered RO Technology-1

Technical Details

1	Average daily flow/size of the population served with one unit	500 Lit/hr, 500 x 20hrs = 10000 lit/day
2	Origin of source water	
3	Quality & salinity of source water	Clean water having a TDS of < 3500 PPM.
4	Quality of water produced.	Safe Drinking water having a TDS of ~ 500 PPM
5	Space requirement	Plain ground of 24 meter diameter.
6	Material Requirement	Tap water connection to draw source/ feed water.
7	Technical requirements (technical skill needed)	No
8	Cost of single unit	6500.00 $

Long term management

1	Expertise required for operation	NIL
2	Source of energy used	Animal
3	Amount of energy needed	1.25 hp
4	Operation cost	Almost negligible
5	Maintenance/spare parts replacements needed	Yes. RO membrane module
6	Frequency	Once in 2-3 years
7	Technical skills required for maintenance and spare parts replacements	Not required
8	Is there a need to train staff for operation and maintenance	Yes. Training is needed for the dismantling and assembly of RO unit.
9	How many people needed for it?	Only one person.

Socio – cultural acceptance

1	Are you aware of any feed-back about its use after implementation	Yes, those who have procured from us are satisfied with the quality of water.
2	-problems that might occur and how you managed it.	Scale formation on the membrane surface. Use source water, < 300 ppm hardness as Ca CO3.
3	-how the population accepted the technology	Safe drinking water which is free from bacteria, easy operation and maintenance.

Additional Information

1	Are you aware of any technology, research or field experiment in the field of desalination?	Yes. ED technology at CSMCRI, Bhavnagar
2	Any other details that you want to add	For brackish water desalination, RO plants have been set up in many places of India under societal mission to provide safe drinking water to the people.
3	What information would you allow to communicate in an Oxfam report?	As indicated above

Mobile RO Desalination Technology-2

Technical Details

1	Average daily flow/size of the population served with one unit	1500 Litres/hr for sea water desalination 3000-4000 Litres/hr for brackish water desalination
2	Origin of source water	Sea water or Surface water
3	Quality & salinity of source water (please precise the unit used)	Clean water having a TDS up to 35000 PPM total dissolved salts (TDS)
4	Quality of water produced.	Safe Drinking water having TDS < 500 PPM
5	Space requirement	Mobil Van
6	Material Requirement	Source water; Fuel (Diesel) for running bus engine for running the RO unit
7	Technical requirements (technical skill needed)	No specific skills are required
8	Cost of single unit	USD 100000

Long term management

1	Expertise required for operation	No specific skills are required
2	Source of energy used	Diesel engine which runs the van
3	Amount of energy needed	50 KWH for sea water desalination
4	Operation cost	USD 1.5-2 per 1000 liters of water
5	Maintenance/spare parts replacements needed	Yes. RO membrane module
6	Frequency	Once in two years if it is operated as per instructions.
7	Technical skills required for maintenance and spare parts replacements	Primary technical skills in operation of RO units
8	Is there a need to train staff for operation and maintenance	Yes. Primary training is needed for the dismantling and assembly of RO unit.
9	How many people needed for it?	Two persons.

Socio – cultural acceptance

1	Are you aware of any feed-back about its use after implementation	Yes. The mobile van was in service at several places during emergency situations like drought, natural calamities.
2	-problems that might occur and how you managed it.	General membrane fouling. Proper pretreatment of raw feed water is required
3	-how the population accepted the technology	Well received as it provides safe drinking water which is free from bacteria, easy operation and maintenance.

2-Stage Sea Water RO Desalination Technology-3

Technical Details

1	Average daily flow/size of the population served with one unit	2000-6000 Litres/hr for sea water desalination
2	Origin of source water	Sea water
3	Quality & salinity of source water (please precise the unit used)	Clean water having a TDS up to 40000 PPM total dissolved salts (TDS)
4	Quality of water produced.	Safe Drinking water having TDS < 500 PPM
5	Space requirement	50-100 m^2 depends on the plant size
6	Material Requirement	Standard materials used in RO plants
7	Technical requirements (technical skill needed)	No specific skills are required
8	Cost of single unit	USD 60000-110000 depend on plant capacity

Long term management

1	Expertise required for operation	No specific skills are required
2	Source of energy used	3-phase AC power
3	Amount of energy needed	30 & 60 KWH for 2000 & 6000 LPH
4	Operation cost	USD 1.5-2 per 1000 liters of water
5	Maintenance/spare parts replacements needed	Yes. RO membrane module
6	Frequency	Once in 2-3 years if it is operated as per instructions.
7	Technical skills required for maintenance and spare parts replacements	Primary technical skills in operation of RO units
8	Is there a need to train staff for operation and maintenance	Yes. Primary training is needed for the dismantling and assembly of RO unit.
9	How many people needed for it?	Two persons.

Socio – cultural acceptance

1	Are you aware of any feed-back about its use after implementation	Yes. The unit has been working well with about 40% recoveries of the initial sea water uptake
2	-problems that might occur and how you managed it.	General membrane fouling. Proper pretreatment of raw feed water is required
3	-how the population accepted the technology	The unit was well received in coastal villages as it provides safe drinking water

RO for high recovery defluoridation-cum-desalination integrated with fluoride management in reject water-4

Technical Details

1	Average daily flow/size of the population served with one unit	1000-2000 Litres/hr potable water from brackish water containing up to 6 ppm fluoride
2	Origin of source water	Surface water containing brackishness & fluoride
3	Quality & salinity of source water (please precise the unit used)	Clean water having a TDS up to 3000 PPM total dissolved salts (TDS) and fluoride up to 6 ppm
4	Quality of water produced.	Safe Drinking water having TDS < 500 PPM and 1 ppm fluoride
5	Space requirement	40-80m^2
6	Material Requirement	Standard materials used in RO plants
7	Technical requirements (technical skill needed)	No specific skills are required
8	Cost of single unit	USD 20000

Long term management

1	Expertise required for operation	No specific skills are required
2	Source of energy used	3-phase AC power
3	Amount of energy needed	10 KWH
4	Operation cost	USD 1-1.5 per 1000 liters of water
5	Maintenance/spare parts replacements needed	Yes. RO membrane module
6	Frequency	Once in about 3 years if it is operated as per instructions.
7	Technical skills required for maintenance and spare parts replacements	Primary technical skills in operation of RO units
8	Is there a need to train staff for operation and maintenance	Yes. Primary training is needed for the dismantling and assembly of RO unit.
9	How many people needed for it?	Two persons

Socio – cultural acceptance

1	Are you aware of any feed-back about its use after implementation	Yes. Health improvements due to defluoridation
2	-problems that might occur and how you managed it.	General membrane fouling. Proper pretreatment of raw feed water is required
3	-how the population accepted the technology	Well received as it provides safe drinking water which is free from salinity & fluoride

Solar Powered RO Desalination Technology-5

Technical Details

1	Average daily flow/size of the population served with one unit	Average daily flow: 700-900 l/day Size of population:1500
2	Origin of source water	Ground
3	Quality & salinity of source water (please precise the unit used)	2000-4000ppm
4	Quality of water produced.	Safe Drinking water having a TDS of about 100-300ppm
5	Space requirement	5mX5m(room size for RO),1 0mX1 0m(terrace/open space size for solar panels)
6	Material Requirement	SS316, CPVC, FRP etc (for RO), silicon solar panels, MS iron rods for structural support, battery bank, charge controller, inverter, cables etc (for solar PV)
7	Technical requirements (technical skill needed)	Electrician cum RO plant operator
8	Cost of single unit	about USD 34000 (including RO plant, solar panels, battery bank, inverter and other accessories)

Long term management

1	Expertise required for operation	Skilled Operator
2	Source of energy used	Solar power/Battery bank
3	Amount of energy needed	as per RO plant
4	Operation cost	Nominal
5	Maintenance/spare parts replacements needed	Yes
6	Frequency	3-4 years
7	Technical skills required for maintenance and spare parts replacements	Yes
8	Is there a need to train staff for operation and maintenance	Yes
9	How many people needed for it?	2

Socio – cultural acceptance

1	Are you aware of any feed-back about its use after implementation	Yes, those who have installed the plant are satisfied with the quality of water.
2	-problems that might occur and how you managed it.	During monsoon (about 3 months in a year), solar insolation is so low that output of RO plant is greatly reduced. This does not fulfill water requirement of villagers. This problem can be tackled by using diesel generator sets. This has not been tried yet, but is necessary for continuous, uninterrupted operation of the plant.
3	-how the population accepted the technology	Very well

Additional Information

1	Are you aware of any technology, research or field experiment in the field of desalination?	Yes
2	Any other details that you want to add	N.A
3	What information would you allow to communicate in an Oxfam report?	Solar powered RO plants can be a boon for isolated communities lacking grid power and at the same time facing problem of drinking water. Available brackish water can be easily treated to produce drinking water with the help of power produced from solar photovoltaic panels. This power can be tapped to run booster and high pressure pumps for operation of RO plant.

Domestic ED Technology-6

Technical Details

1	Average daily flow/size of the population served with one unit	10 Lit/hr, 10 x 20hrs = 200 lit/day A family of 4 persons requires 20 lit. water per day.
2	Origin of source water	Tap water available in the house
3	Quality & salinity of source water (please precise the unit used)	Clean water having a TDS of < 2500 PPM.
4	Quality of water produced.	Safe Drinking water having a TDS of ~ 500 PPM
5	Space requirement	50 cm x 50 cm x 60 cm
6	Material Requirement	Electrical power supply, Tap water connection to draw source/ feed water.
7	Technical requirements (technical skill needed)	No
8	Cost of single unit	250 US$ with out pump.

Long term management

1	Expertise required for operation	NIL
2	Source of energy used	A C / D C power supply
3	Amount of energy needed	~ 0.7 kWhr / kg salt removed
4	Operation cost	1.5 k Whr/ m^3 water produced including the power consumption of ozonator
5	Maintenance/spare parts replacements needed	Yes. Ion exchange membranes
6	Frequency	Once in two years if it is operated as per instructions.
7	Technical skills required for maintenance and spare parts replacements	Not required
8	Is there a need to train staff for operation and maintenance	Yes. Training is needed for the dismantling and assembly of ED unit.
9	How many people needed for it?	Only one person.

Socio – cultural acceptance

1	Are you aware of any feed back about its use after implementation	Yes, those who have procured from us are satisfied with the quality of water.
2	-problems that might occur and how you managed it.	Scale formation on the membrane surface Use source water, < 300 ppm hardness as Ca CO3. Pass dilute HCl once in 15 days to remove the scales.
3	-how the population accepted the technology	Safe drinking water also free from bacteria, easy operation and maintenance.

Additional Information

1	Are you aware of any technology, research or field experiment in the field of desalination?	Yes. Another membrane technology – Reverse Osmosis (RO) at CSMCRI, Bhavnagar
2	Any other details that you want to add	For brackish water desalination up to 3000 PPM TDS, different capacity Electrodialyis plants have been fabricated, installed and operated in many places of India under societal mission to provide safe drinking water to the people.
3	What information would you allow to communicate in an Oxfam report?	ED technology has been using indigenously developed interpolymer ion exchange membranes. In addition to desalination, this technology is also used for the separation and concentration and purification of chemicals, to treat the industrial effluents to reduce the pollution. etc

A8. Face-to-face meeting

Name : Seawater Greenhouse Company/ Research laboratory
Contact : Abdulrahim Mohammed Al-Ismali, PhD at Cranfield University

E-mail : abdrahim@hotmail.com

Phone number : phone:+968 24415228, Fax: +968 24413418

Technology : Seawater Greenhouse

Website : http://www.seawatergreenhouse.com

General

Context: energy sources available in Oman? Which desalination technology do you know? (in Sultanate of Oman, especially low-cost, village scale)
Technology studied: seawater greenhouses for agriculture and domestic needs (high quality water, mow salt) using solar energy to grow plants and distillate saline water
In the Arabian countries, seawater is traditionally used for domestic needs without treatment, and for agriculture. However, seawater is no more used for agriculture due to saline intrusion.
The use of renewable energy is only at very large scale, mainly solar for freshwater production and electricity.
Desalination represents about 10% of domestic use. Reverse osmosis and photovoltaic are the main tech for desalination.
Do you know some interesting contacts?
Publications at Cranfield Library (MSc, PhD thesis)

The Seawater greenhouses technology

How did you choose to study such a system?
I carried on after my MSc thesis whose subject was ….. I now study the simulation of greenhouses (temperature, moisture addition)
What is the scale of use? (flow, plant size, space requirements)
Spanish project: 20 greenhouses
Emirates and Oman's projects: only one greenhouse for each
What are the material used and technology dependence?
The efficiency can be improved especially at the level of the cooling system. Thus, the material used for condenser is very important, i.e. metals used, which is relatively expensive.
Implementation
-Is it easy to construct? Not easy
-Cost? High
Operation:
-Complexity? Not very (condenser design: fragile for Oman)
-Flexibility?
-Energy requirements?

-Energy source: only solar or wind also? Need to additional energy supply? Only solar

Maintenance and spare part replacements

-What is needed?

Fooling of tubes. This problem was solved by using plastic tubes but the conductivity decreased.

Need to fix tubes (avoid leakage?) I done, it can last 2 years without maintenance.

Are there pre- and post-treatment needed and which ones?

Pre-treatment might be necessary due to the salinity, depending on the plant growing (algae need salt to grow).

No post-treatment are required. As the unit is placed 100m from the sea, after temporary disposal in a septic tank, waste water is directly dumped to the sea.

What are the waste products? How is it disposed?

There is no other waste, salt water is directly dumped to the sea.

Other

Are there potential for further development according to you?

It is at the research stage since 2004, but still a lot of developments have to be done to be potentially commercialised, especially to improve overall efficiency. Hence, there may be no implementation and commercialisation in the future.

Additional information available: MSc Thesis, PhD thesis

A9. Phone interviews

Name : GeoNoria, Independant group ~~Company~~/ ~~Research laboratory~~
Contact : Olivier Grossat
E-mail : info@geonoria.org
Phone number : +33 1 47 07 33 10 (call after 20pm, GMT+1)
Technology : Distilation system using convectors along pipes
Website : http://geonoria.org

General

Could you please define GeoNoria
It is a composed of a group of friends in Paris, coming from engineering schools, working on this project during their free time. As an example, I am living in the 13th arrondissement of Paris and I work in the 15th. We are ready to help Oxfam by providing them explanation on our concept and by doing the calculations.

The GéoNoria technology

How did you develop such a system?
We wanted to do something to help people in developing countries to obtain safe water from seawater without depending on external energy source. We realized that most of them where between the tropic of Cancer and the tropic of Capricorn. Thus, regarding to the solar radiation received in such places, use of solar energy to distillate resulted simply. Consequently, the orientation of solar convectors is East-West.

<u>Implementation</u>
-What are the materials used? Various materials are possible: plate glass, steel slabs that are corrosion resistant. The design is flexible, for instance a waterproof low wall is needed to separate the retention basin (tide) and the convector can be covered of glass in a port.

<u>Operation</u>
-are there specific skills needed for operation? No, the process works by itself as the evaporation make it possible to bring water from the coast to the tank.

<u>Maintenance and spare part replacements</u>
What are the operations of maintenance needed?
Maintenance is simple as only cleaning of pipes (simple chimney) to avoid deposit and cleaning of mirrors to optimise its efficiency is needed daily. Indeed, there can be a deposit of salts at the edge of the heating zone (mirrors). A solution could be to sweep from the entrance (sea) or also to sweep at the big valves for the exit.
Are there any spare parts needed?
No, there is no specific technology, everything can be done on glass and steel, maybe available locally.

Any other technical precision that you think needs to be mentioned:
The water tower/tank has to be placed aloft (uphill for instance) for better results as it is gravity fed. Its location is along coast such as rivers, seas and lake. It is designed for a village as well as for a town.

Other: Potential for developing countries

Is there any implementation or field experimentation of your system already exsting?
No, nothing has been done in practice. We are expecting a first trial to make this system more widely known. Oxfam could be a good partnership for that.
Did you think of any specific measures to be taken regarding the population in order to improve it social acceptance/awareness?
The population has to be trained for avoiding plate glasses breaks. For instance, they should be aware that they cannot put things down as it could also reduce heating efficiency, or even stop it.

Name : EcoAeon Company/ ~~Research laboratory~~
Contact : Alykhan Tharani
E-mail :
Phone number :
Technology : Plimmer alpha
Website : http://ecoaeon.com

General

How was the Plimmer technology developed?
It is inspired from an Electronic Water Purifier that worked successfully for 7 years in the USA (Wyoming) without changes. This configuration has been developed for NGOs such as Oxfam, WaterAid or African Developing. Contrary to most desalination systems, its size is small with few operation and maintenance and no chemicals are used for treating.

The Plimmer technology

Implementation/Operation
-In practice, how will the Plimmer be implemented and operated?
A unit with the relevant configuration (for instance 8 cells in serial can treat a saline water of about 1000ppm initially while 8 cells in parallel, e.g. 4+4, can treat a water of 2500 ppm at a flow rate of 300L/h per 2 cells) can be designed in the UK, programmed by an trained Oxfam engineer (EcoAeon can provide this training) and then be sent to the targeted site. Once there, a test period is needed (1-2weeks) to tune the machine according to the conditions in site. The operation is hence automated.
-What are the elements removed by a CDI unit?
It can remove salt, fluoride and arsenic, as well as metals. Pathogens can also be treated at the same time thanks to a UV system implemented in serial. TDS can thus be lowered from 10,000 at maximum to 250ppm, which is far enough regarding the WHO guidelines (500ppm). Depending on the variation along the seasons, the flow rate can be adjusted. In one or two years, even salt water could be treated by such system.
-Are there specific skills needed?
Yes, an engineer is needed for programming the unit before being used. It can be done in the United Kingdom, at EcoAeon offices for instance. EcoAeon is additionally able to provide the corresponding training (one day long, subject: testing and changing of pass) at the factory in Italy. Several levels of expertise are provided, such as user and engineer. A software system is on development for automating the sending of s.m.s. to mobile phones when maintenance is needed.
-How are potential waste managed?
Waste produced is only composed of salts, which can be re-used.
-What energy source is used?
The Plimmer is run by electricity. The amount needed is smaller than the one for reverse osmosis. Additionally, a system using PV or wind turbines can electricity for running the unit.
Maintenance and spare part replacements

What are the operations of maintenance needed?
Maintenance is extremely simple as it is automated. In practice, the operator has to fill a container with acid citric crystals and then push a button. Even, since the container is full, maintenance can be ordered remotely. Thus, a unit should be able to be run 4-7 years without problems.
What will happen if there is a breakdown?
Everything can be checked remotely to identify the breakdown. However, sending a technician might be needed for replacing parts. Also, as there is no vibration with such system, contrary to classic membrane processes, these units are less noisy and the risk of breakdown is reduced.

A10. References of appendices

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