Extracting Drinking Water from Salt Water: An Overview of Desalination Options for Developing Countries

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There is a significant need to increase the supply of drinking water in developing countries. Common sources estimate that 1 billion people in the developing world drink unsafe water. When all other viable sources of water have been utilized, extracting drinkable water from salt water can help solve this problem. Technologies available for desalination (also known as desalting) range from family sized solar stills to city sized treatment facilities. This technical brief presents an overview to assist the reader in deciding whether it is worthwhile to investigate desalination for a specific project. It is primarily the technical aspects of desalination that are addressed, leaving the important issues of policy and culture to be handled on an individual project basis. A brief background of desalination is given, followed by a description of each major desalination technology. Guidelines are given for deciding which options to investigate further, along with references to more information.

Background

The general process of desalination is shown in Figure 1. Desalination uses a large amount of energy to remove a portion of pure water from a salt water source. Salt water (feed water) is fed into the process, and the result is one output stream of pure water and another of wastewater with a high salt concentration. Proper handling of the wastewater is an important environmental concern when a large salt water body is not already in existence. The distillation process must be sized such that the pure water output supplies the drinking needs of the people served. The efficiency of energy usage depends upon which desalination technology is used, the size of the plant, and the salt concentration in the feed water. An important physical principle is that when water vapor condenses it "gives back" the heat used to vaporize it. Several desalination technologies capture a portion of this heat and re-use it.

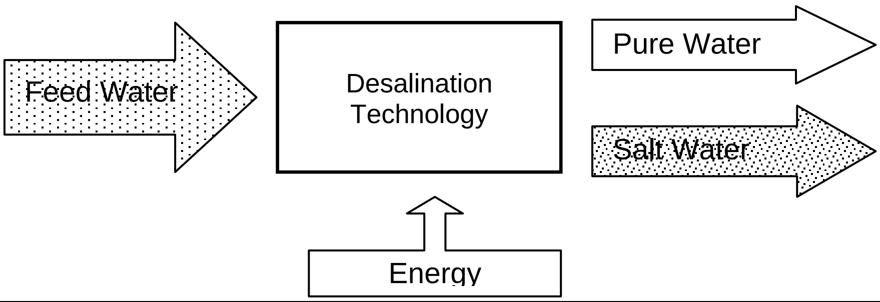

Figure 1: Desalination Process Diagram

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Salt water is classified according to the amount of total dissolved solids (TDS) measured in grams / Liter. Water is generally considered as drinkable in developing countries with up to 1g/L of dissolved salts, it is brackish with up to 30 g/L, and it is considered seawater with more than 30g/L of TDS (Sandec, 1997). The term *salt water* is used here to refer to both brackish water and seawater.

Table 1: Classification of Water According to Dissolved Salt Content

Water Type	Total Dissolved Solids (TDS)
Fresh water	Less than 1 g/L
Brackish water	From 1 to 30 g/L
Seawater	More than 30 g/L

Desalination Technologies & Energy Sources

The six major desalination technologies available are summarized in

Table 2. The first four of these are *thermal distillation processes* that heat the salty feed water to accelerate the formation of vapor. This vapor then condenses and is collected as essentially pure water. The remaining two desalination technologies are referred to as *membrane processes*, because they rely upon a membrane that either enhances or inhibits the flow of salt particles (as shown in Figure 3).

Table 2: Major Desalination Technologies

Technology	Description	Characteristics
Solar Stills	Uses solar energy to elevate the temperature of salt water and enhance evaporation. Captures condensate as pure water.	Uses solar energy. Simplicity and independence makes it appropriate for small-scale.
MSF **M**ultiple **S**tage **F**lash	Feeds heated water into low-pressure vessel causing it to "flash" into vapor, which is condensed and collected as pure water. Captures heat from condensing vapor to supply heat for feed water.	Uses heat. Appropriate for medium to large-scale projects.
MED **M**ultiple **E**ffect **D**estil.	Heats water to boiling, and collects vapor as pure water. Captures heat from condensing vapor to supply heat for next stages (effects).	Uses heat. Appropriate for medium to large-scale projects.
VC **V**apour **C**ompression	Compresses water vapor to cause condensation as pure water. Uses heat from condensation to heat feed water and generate vapor.	Uses electricity. Appropriate for small to medium scale. Simplicity & reliability make it attractive for small installations.
ED **E**lectro **D**ialysis	Uses electric current to force salt through membrane, separating it from the feed water.	Uses electricity. Normally used only for Brackish.
RO **R**everse **O**smosis	Uses electric current to force pure water through membrane, separating it from the feed water.	Uses electricity. Can be appropriate for any scale.

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Solar still distillation uses the heat of the sun to heat salt water, and human labor to periodically change the water. Solar radiation heats the salt water in a basin with a clear cover, and water vapor condenses on the underside of the cover. The condensate then drips into a pure water collection area. Although numerous enhancements of solar stills have been proposed and tested, most sources suggest a basic single-basin design as the most economical and proven. In hot climates, single-basin stills generally produce 2 to 3L/day (roughly $1m^3$/year) for each m^2 of area. Although labor requirements are high, the simple and independent operation of solar stills suits them for small-scale, remote applications.

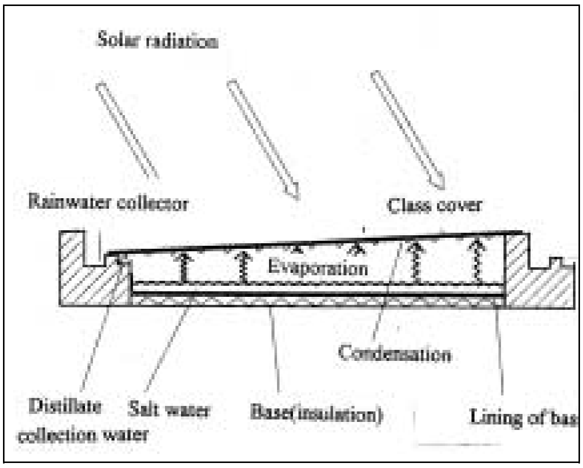

Figure 2: Solar Still Concept Diagram (Scharl, 1993)

Multiple Stage Flash (MSF) distillation causes heated salt water to quickly boil or "flash" into vapor in a series of steps called stages. The vapor is condensed and collected as nearly pure water, and the heat resulting from the condensing process is used to assist heating the feed water. The release of vapor in each stage causes the hot feed water to cool slightly, and thus boiling ceases momentarily until the water reaches the chamber of the next stage with an even lower pressure. Each stage is at a lower pressure and temperature than the previous, so that the flashing process will continue as long as possible without adding heat. The water that has not boiled by the last stage exits the process as wastewater with high salinity content. A large number of stages results in high process efficiency; but requires more land, capital, and maintenance. Special measures must be taken with MSF plants to minimize the formation of scale caused by mineral deposits from the water. MSF plants are large and complex, requiring skilled operation and maintenance.

Multiple Effect Distillation (MED) heats the feed water with steam from a boiler. The process occurs in a series of steps called effects. Similar to MSF, each successive effect operates at a lower temperature and pressure to cause further vaporization. A portion of the feed water vaporizes in each effect, and the remaining water passes to the next effect. The vapor is condensed and collected as nearly pure water, and the heat resulting from the condensing process in one effect is used to provide heat for vaporizing water in the next. Special measures must be taken with MED plants to minimize the formation of scale caused by mineral deposits from the water. MED plants are large and complex, requiring skilled operation and maintenance.

Vapor Compression (VC) distillation uses a compressor to compress water vapor. As the high-pressure vapor is condensed into pure water, the heat released is used to vaporize additional water. An important feature of vapor compression is the ability to operate with only electrical or mechanical energy, without a heat source. The process is favored for small and medium applications due to its simplicity and reliability.

Electro Dialysis (ED) is a membrane process, which applies an electric current to force dissolved salts through membranes. As shown in Figure 3, the

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membrane keeps the salt stream separated from the fresh water. The feed water must be filtered of small debris to avoid clogging the tiny water passages in the ED membrane. The energy required to obtain pure water depends upon the amount of salt that must be removed; thus the process is more effective with brackish water.

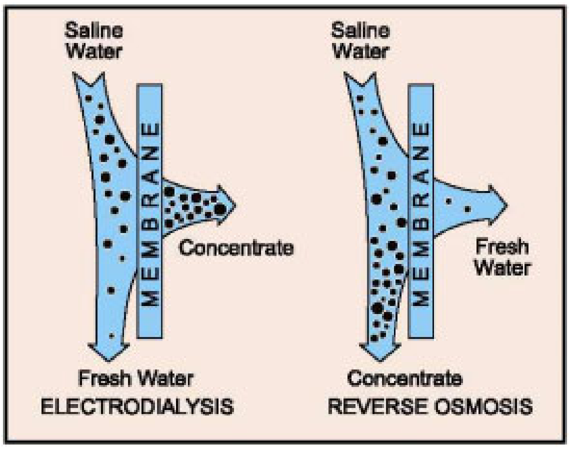

Figure 3: Membrane Desalination Processes (Buros, 2000)

Reverse Osmosis (RO) pressurizes the feed water to force pure water through a membrane, and the dissolved salts remain in the feed stream. The membranes must be kept clean for this process, which often requires fine filtration and the use of chemicals in the water. The energy required to obtain pure water depends partially upon the amount of salt that must be removed. For this reason the process is more effective with brackish water; however, it is often used with seawater as well. Reverse osmosis is considered more economical than thermal distillation for desalting brackish water (Background, 1999).

Other distillation technologies have been proposed such as freezing, membrane distillation, and the use of microwaves. So far these techniques have not been a commercial success on an appreciable scale. More performance data must be generated before the practicality of these processes can be determined for use in developing countries.

Various energy sources may be used to power the desalination processes. Table 3 outlines the energy supply options available for different technologies. Multi-stage flash, multi-effect distillation, and solar stills require primarily a source of heat; this may be provided with fossil fuel, waste process heat, or solar radiation. Vapor compression, electro dialysis, and reverse osmosis require a source of electricity; this may be provided with fossil fuel or renewables such as solar and wind. The presence or absence of waste process heat from power generation or industry can significantly impact the economics of large-scale desalination operations.

Table 3: Possible Energy Sources for Various Desalination Technologies

Energy type	Heat Energy	Electric Energy
Energy sources	• Fossil fuel • Waste process heat • Solar	• Fossil Fuel • Renewable (Solar, Wind)
Desalination Techology	MSF MED Solar Still	VC ED RO

There is interest in using renewable sources of energy for desalination to enhance environmental compatibility and decentralization. The feasibility of using renewables often depends upon the cost of renewable energy compared with the cost and availability of fossil fuel sources. Renewable energy is often more expensive than conventional power sources, and so is generally not recommended for use with desalination when conventional power sources are

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available. However, renewables may be the option of choice in areas without a central power supply, especially for small-scale applications. The possibilities of using renewable energy sources for desalination are investigated in depth in the reference by Teplitz-Sembitzky, 2000.

Choosing a desalination technology

Small-scale desalination options (200m^3/day or less*) include: solar stills, reverse osmosis, and vapor compression. These should generally be considered only when all other sources of water are fully utilized and salt water is available. Even in these cases, the water is often only used for drinking since it is too costly for agricultural and industrial purposes. The capital and labor requirements to desalinate water on this scale are usually much higher than those of treating polluted water or developing fresh water sources through traditional methods. For comparison, the cost of water from stills producing 3m^3/day or less is typically in the range of $5-25USD/m^3 when averaged over the life of the still (Sandec, 1997). Therefore, the feasibility of other methods of obtaining water should be evaluated before small-scale desalination is considered. The reference section suggests manuals on rainwater catchments and the purification of polluted water. Additional options include: improving existing wells, transporting water by vehicle or ship, and long distance pipelines.

In situations in which all other sources of water are fully utilized and salt water is available, solar stills should be considered as a small-scale source of drinking water. Solar stills are typically only appropriate in hot climates and when the total water need is 3m^3/day or less. An expensive or unreliable fuel supply and high water transportation costs contribute to the attractiveness of solar stills. Conditions that favor the use of solar stills are summarized in Table 4. Several excellent papers on solar stills are cited in the references, including "Solar Distillation" by Scharl, 1993.

Table 4: Conditions favoring solar stills

- Salt water available, other sources fully exploited
- Total water need is less than of a few m^3/day
- Hot climate (plentiful sunlight)
- Expensive and/or unreliable fuel supply
- Rainfall below 0.5m/year (rainwater catchments impractical)
- High water transportation costs (generally, more than $10USD/m^3)

For water needs exceeding 1m^3/day, photovoltaic powered reverse osmosis should also be considered. If centralized power is available or the water need exceeds 3m^3/day, reverse osmosis or vapor compression technologies are likely to be the best options (Energy Options, 1991; Background, 1999).

Medium to large-scale desalination projects (200 m^3/day or more) may employ any of the major desalination options discussed, other than solar stills. (Solar stills are not appropriate for projects of this size due to economies of scale). The technology choice for medium and large projects is heavily influenced by site-specific economic factors. These factors include the availability of: waste process heat, centrally generated grid power, fuel supplies, and places to dispose of high salinity wastewater. The condition of the feed water and local economic conditions also affect which choice is the most economical, and the final cost of desalinated water. As an example of typical costs, in the USA brackish water

* Technical Note:
Determining the daily water need is one of the first steps in deciding which desalination options to investigate. Persons in developing countries typically use 20L/day of water for various purposes; however, only 5L/day or less needs to be drinkable (Energy Options, 1992). One m^3/day is 1000L/day, or approximately enough drinking water for 200 people.

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recovery ranged from $0.25 to $0.60USD/m^3 for plants producing 4,000m^3/day or more in 1999. Costs for desalinating seawater were 3 to 5 times higher.

Choosing the “best” technology for large projects is a difficult problem that depends heavily on local conditions. Professional assistance should be sought before making commitments regarding desalination. A recent trend in large desalination facilities has been contracts in which developers Build, Operate, and Own (BOO) plants (Buros, 2000). This can shift responsibility for choosing the desalination technology to the developer, since they are responsible for plant design and operation. The reference by Buros, 2000 further explores options for medium to large-scale projects.

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