Recommendation on a suitable desalination process for the South African environment.

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Abstract

Supplies of potable water from traditional sources have been increasingly depleted due to increasing world population and per capita water use. In South Africa fresh water is a vital, but scarce resource, distributed unevenly in time (frequent droughts alternate with periods of good rainfall) and space (the eastern half of the country is markedly wetter than the western half). Increasing demand for water, and decreased water quality, make careful water management a priority.

Water use in South Africa is dominated by irrigation, which accounts for around 60 per cent of all water used in the country. Domestic and urban use accounts for about 30 per cent, while mining, large industries and power generation account for some 7 per cent. Commercial forestry plantations account for a little less than 4 per cent of total use by reducing runoff into rivers and streams (DWAF).

Desalination of sea water is a promising technology available for the provision of fresh water to the arid regions of South Africa. However, as the technology develops, there is a need for the adequate customization of its technological processes to suite particular geographical regions.

This research work is focused on the determination of an adequate desalination process by the use of a decision tree. The research will explore in qualitative format, the different types of desalination processes available, their pros and cons as well as discuss the factors affecting the selection of desalination processes.

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Glossary of Terms

A$	Australian Dollar
Brackish Water	Water that has a salinity of 1000 – 3000 mg/L TDS
Brine	Waste water that has a high concentration of dissolved salts
Concentrate	Concentrated salt solution
Desalination	The process of removing salts from saline water
Distillation	A process of water purification where feed-water is heated to steam and then condensed to produce high purity water.
DWAF	Department of Water Agriculture and Forestry
ED	Electro Dialysis
EN	End Node
Feed Water	Water that is feed into a desalting system
H2S	Hydrogen Sulphide
IWMI	International Water Management Institute
KL	Kilo Litre
KWh	Kilo Watt Hour
MED	Multi Effect Distillation
Mg/L	Milligrams per Liter
MSF	Multi Stage Flash
NGO	Non Government Organisation
Osmosis	Diffusion of molecules through a semi-permeable membrane from a place of higher concentration to a place of lower concentration until the concentration on both sides is equal
PPM	Parts Per Million
PPM	Parts per mil
RO	Reverse Osmosis
RSA	Republic of South Africa
Salinity	Relative portion of salt in a solution
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
VC	Vapour Compression
VCD	Vapour Compression Distillation
W&RM	Weight and Ranking Method
WRC	Water Research Commission

Chapter 1: Introduction

1.0 Introduction

This research is concerned with the selection of an adequate desalination process for South Africa with the aid of a decision tree. The research will explore available desalination processes, their applications, as well as factors that encourage the implementation of these processes.

1.1 Water Supply in South Africa

South Africa is a semi-arid country of which freshwater is the most limiting natural resource. South Africa, only receives about half the average rainfall of other countries, and this is spread disproportionately across the country from east to west. Already, available freshwater resources are almost fully-utilized and under stress. At the currently estimated population growth and economic development rates, it is unlikely that the projected demand on water resources in South Africa will be sustainable (DWAF 2009).

Water will increasingly become a limiting resource in South Africa, and current methods of supply will require an upgrade in order to secure the future socio-economic development of the country, in terms of both the quantity and quality of water available (DWAF 2009).

There are three main driving forces affecting South Africa's freshwater resource availability;

Firstly, the natural condition, particularly climate is characterized by low rainfall and high evaporation rates which together create low available run-off.

The mean annual runoff for South Africa is currently estimated at some 50 million m^3 a^{-1}. This is not distributed evenly throughout the country, with the Eastern seaboard having some 80% of the country's runoff, whilst the western regions tend to have low runoff.

The scarcity of freshwater resources and high variable hydrological conditions has led to every major river in South Africa being regulated in order to ensure adequate water supply for development. However, because of the spatial variability of water resources and the scarcity of water throughout South Africa, in many catchments the need for water exceeds the supply (DWAF 2009).

Second is the rapid population growth, accelerated industrial development and the increased commitment to meeting of basic needs. These socio-economic activities encourage water use and lead to greater water demand and increased pollution of available resources. Typical pollutants of South Africa's freshwater environment include the following;

- Industrial effluents,
- Domestic and commercial sewage,
- Acid mine drainage,
- Agricultural run-off and litter.

As many of these sources are spread out across the country, it is difficult to estimate the magnitude of the pollution problem. However, KwaZulu-Natal, Eastern Cape, Western Cape, and the Vaal rivers have major problems with Total Dissolved Solids (TDS), and most of South Africa's rivers have eutrophication problems. Population growth, increased economic activity and intensification of land use practices all lead to increased water demand, and increasing degradation of the resource.

The final driving force is the policy concerning national management of water resources, which determines the approach taken by relevant authorities at all levels of government to managing freshwater resources. There are various responses at different levels in order to manage the water resources in a sustainable manner, including developing and adhering to international initiatives, setting relevant policy through legislation, implementing policy at an operational level and implementation of special programmes to combat specific problems. Most legislation pertaining to the environment indirectly or directly affects water resources. The most important are the Water Services Act (Act 108 of 1997) and the National Water Act (Act 36 of 1998), which falls under the authority of the Minister of Water Affairs and Forestry. As a result of the uneven distribution of the water resources of the country and previous inequitable policies, the Water Services Act is important in ensuring that people's basic needs are met, for instance sanitation water and fresh water supply (DWAF 2009).

1.3 Desalination in South Africa

Potential sources of water, such as desalinization of seawater are perceived to be too expensive, however, recent studies show that due to improvements in the desalination process, water can be produced for less than \$0.40 per m^3 and that overall production costs could be further reduced by proximity to seawater, minimized piping, utilization of specific desalination processes and by the use of renewable energy sources (El Bana 2000).

In May 2007 GE Water and Process Technologies proposed to build a desalination plant in South Africa. The plant was expected to recover salt from waste water in the COEGA Industrial Zone, Port Elizabeth, South Africa. This new 600 tonnes-per-day refinery would be owned and operated by Strait Chemicals and would meet the growing global demand for chlor-alkali and its derivatives.

There also exist the operation of small scale brackish and industrial waste desalination plants like the Albany Coast water board desalination plant in Bitterfontein, the desalination unit implemented by Eskom at the Tukuta power station, the unit implemented by Sasol Mining in Secunda and the Emalahleni water reclamation project in Witbank.

1.4 Problem Statement and Substantiation

Consumers in South Africa are faced with the potential problem of not having enough water to cater for domestic, industrial and agricultural use. However, in coastal cities and towns saline water is readily available. It is being regarded by the water research commission (WRC) and department of water affairs and forestry (DWAF) as alternative and supplementary sources of fresh water.

DWAF and WRC have indicated, in the publication of report TT 266/06, the need to devise desalination guidelines and procedures to select and evaluate suitable treatment options for the desalination of seawater and brackish water.

With the enormous investments required to implement and operate a desalination system, issues pertaining to justifying these investments have been expressed in the form of the questions listed below;

- What is the value of desalination?
- Which processes and technology is best suited to the South African environment?

The answer to these questions would enable stakeholders to make wise and informed decisions on the implementation of a water supply solution in South Africa.

1.5 Research Aims and Objectives

This research is motivated by a need to proffer an environmentally friendly, alternative fresh water source that would cater for the projected increase in fresh water demand in a nation with potentially depleting fresh water resources.

The intended final deliverable of this research will be a recommendation that is motivated by an adapted decision tree as well as information gathered during the course of the research. The research will attempt to provide guidance and illumination on the best choice of desalination process that should be used for seawater desalination in South Africa.

The aim of this research is thus geared towards the following;

- Presenting the value of desalination.
- Presenting a comparative technological description of various desalination technologies.
- Indicating the factors to be considered in technology selection.
- Develop a suitable desalination decision tree.

- Recommending a desalination technology best suited to the South African environment by using the adapted desalination decision tree.

Beneficiaries of this research will be;

- The South African people, government and all agencies responsible for the management of SA water resources.
- Engineering body of knowledge through contributions regarding the outcomes of this research work and its relevance to subsequent regional projects.
- The researcher, through the knowledge that will be gained from desalination research.

1.6 Research Methods, Procedures and Techniques

This research work will consult the following sources for information which will be used to carry out a comprehensive literature survey:

- Library sources (related books e.t.c)
- Journal articles and publications (South African Journals, Overseas journals, Online journals e.t.c).
- Newspapers, magazines, and reports (NGOs proceedings, conferences e.t.c)
- Thesis and dissertations (Review related work and findings in this field of study).
- Project reports (Benchmark the reports of similar projects implemented in Middle East Asia, South Africa and Australia).
- Department of Water Affairs and Forestry (DWAF), South Africa.

    - Department of Minerals and Energy, South Africa.
    - Research and development NGOs - Water Research Commission (WRC), International Water Management Institute (IWMI)

- Data collated through relevant sources as indicated above will be analyzed and presented to validate the use of desalination as an alternative fresh water source.
- Write outcomes and give recommendations.

Chapter 2: Literature Review

2.1 Overview

This chapter gives a description of desalination with specific emphasis on the various technology comparisons required for technical assessments. It looks at the process characteristics required to provide a technological comparison of each desalination process in order to identify one which works for any specific scenario. It also explores alternative 'efficiency driven' hybrids designed for the optimization of fresh water production in the desalination industry.

2 .2 Introduction

Of all the Earth's water, 94 percent is salt water from the oceans and 6 percent is fresh water. Of the latter, 27 percent is in glaciers and 72 percent is underground. Water desalination has become the famous technical process to solve the shortage in water resources with acceptable water quality. More than two billion people over the world have no access to regular supply of potable water. In the developing countries 10,000 to 20,000 people die every day from preventable water-related diseases (Buros 2000).

The available fresh water gives us the opportunity to get a sustainable life on this planet. However, in areas like South Africa potable water for domestic use is less than abundant. While 25litres per person/day has been set as the minimum basic water supply and while many consumers receive far in excess of this amount, there are areas of the country where water of acceptable quality is not available for household use. However, in coastal cities and towns adequate quantities of saline water are readily available (DWAF 2009).

Desalination as a source for potable water can relieve water shortages mainly in dry regions along seacoasts (like South Africa). But it will be more costly in cities far from a seacoast or in mountains. Thus, desalination is still considered as the only realistic and best technological practice for dealing with fresh water shortages in coastal cities.

Over the past forty years, its uses have grown, particularly in the Middle East where two-thirds of the world's 7500 desalination plants are located. For example, about 82% of the United Arab Emirates domestic water is supplied from desalination. This option, however, is often too expensive for most developing countries (Gleick 1998).

The increasing demand on fresh water required to supply the worlds growing cities is becoming more and more crucial. The estimated amount of renewable fresh water is 40,000 cubic kilometers. Out of this amount, only 10% is withdrawn and 5% is consumed (Goodman 1994). The problem is that the resources are not evenly distributed geographically and seasonally. Figure (1) shows the global water on the earth.

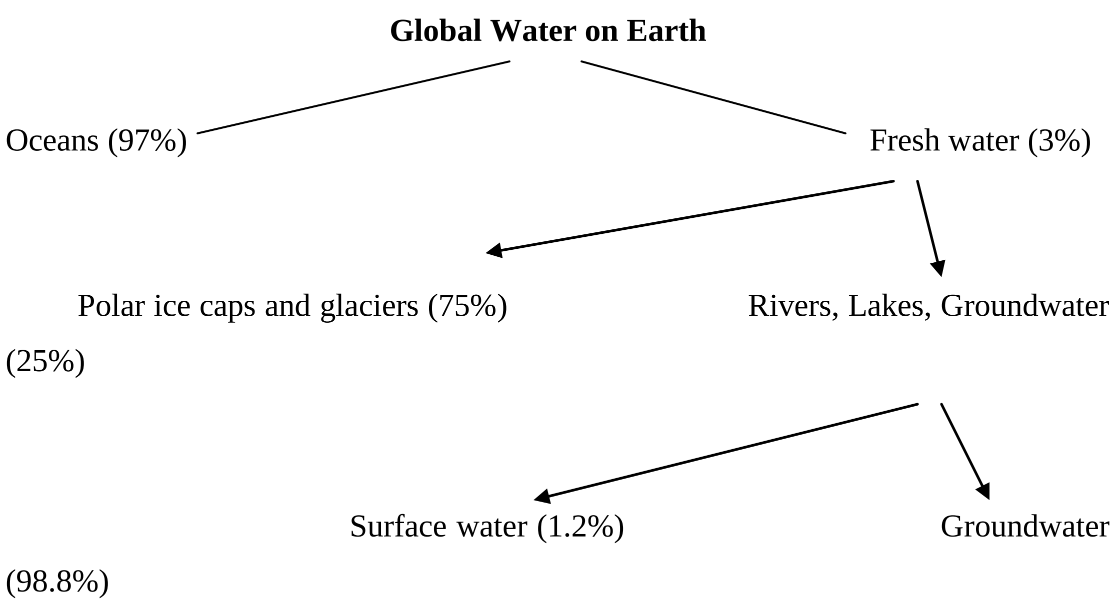


Figure (1) Distribution of water on earth (Source: Goodman, A.S., 1994)

Goodman, A. S., (1984) explained, "The distribution of water over the earth, he indicates that much of groundwater is located far from points of needs. Population intensities and water availability often are not compatible. As such, the water resource planner is expected to overcome the problem".

Department of Environmental Affairs (2000), states, "South Africa's most limiting natural resource is water. The majority of existing rivers are either dammed or included in water abstraction programmes for supply to domestic users and for agricultural and industrial uses.

2.2.1 Desalination Concept

Desalination is a physical process that aims to remove dissolved minerals (including, but not limited to salt) from either brackish groundwater or seawater (El Bana 2000). About 97 percent of water on the earth is in salty seas or oceans. The process aims to produce water with a quality that is accepted for domestic use, or other uses, such as industrial or agricultural use (Angelo 2000).

The produced water is divided into two streams, one as potable water with a low Total Dissolved Solids (TDS) and the second with high percentage of dissolved salts (brine). The need for desalination as an alternative option is to secure water for drinking and agricultural purposes (Benjamin 2002). A typical desalination process diagram is illustrated in the next page.

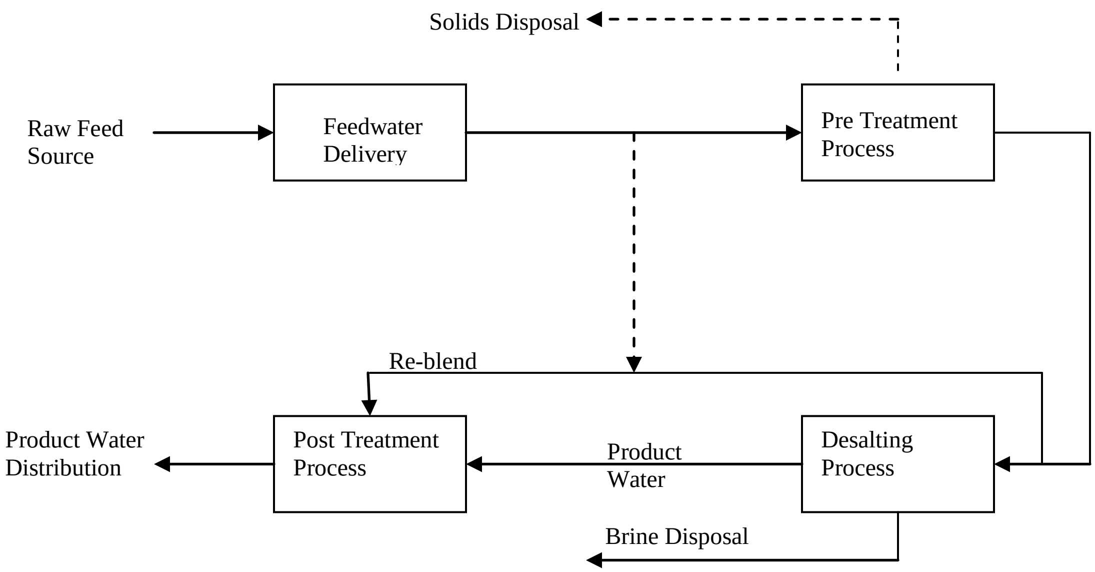


Figure 2: Typical desalination flow diagram

2.3 Desalination Technologies

Water desalination can be accomplished by different techniques that can be classified into three categories according to the process principle used (Buros 2000):

1. Thermal distillation processes
2. Membrane processes
3. Alternative processes

Table 1: Desalination Processes (El Bana, 2000)

Desalination Process		
Thermal Distillation Processes	**Membrane Processes**	**Other Processes**
Multistage Flash Distillation (MSF)	Reverse Osmosis (RO)	Ion Exchange
Multiple Effect Distillation (MED)	Electro-dialysis (ED)	Solar Humidification
Vapor Compression (VC)		Freeze Separation
		Nuclear Distillation

The desalination processes investigated in this assessment are as detailed below.

Major Processes

Thermal Distillation Processes

- Multi-Stage Flash Distillation (MSF)
- Multiple Effect Distillation (MED)
- Vapour Compression Distillation (VC)

Membrane Processes

- Reverse Osmosis (RO)
- Electro-dialysis

Alternative Processes:

- Renewable Energy Powered Conventional Desalination
- Solar Humidification
- Freezing

2.3.1 Thermal distillation processes

The thermal distillation processes are basically:

- Multi-Stage Flash (MSF) Distillation;
- Multi-effect Distillation; and
- Vapour Compression Distillation

Thermal distillation is a phase separation method whereby saline water is heated to produce water vapour, which is then condensed to produce freshwater. The various distillation processes used to produce potable water, including MSF, MED, VC, and waste-heat evaporators, all generally operate on the principle of reducing the vapour pressure of water within the unit to permit boiling to occur at lower temperatures, without the use of additional heat. Distillation units usually utilize designs that conserve as much thermal energy as possible by interchanging the heat of condensation and heat of vaporization within the units. Thus the major energy requirement in the distillation process is to provide the heat for vaporization to the inlet feed-water (Benjamin 2002).

Distillation is the most common desalination process. Over 70 percent of all desalination facilities in use today use some variation of the distillation process. High temperature distillation facilities that operate at temperatures greater than 200 degrees Fahrenheit are the most prevalent desalination facilities in the world today. There are three methods of vaporization: flash vaporization; submerged tube vaporization; and thin-film vaporization. Submerged tube vaporization enables the performance of easy maintenance, but is the least efficient vaporization technique. The submerged tube vaporization system is often used in exhaust gas waste heat recovery distillation systems (El-Dessouky et al., 2002)

The flash vaporization technique is currently the most common technique in existing distillation units. The spraying of hot brine within the evaporator unit causes the erosion and corrosion of most metals. By using the thin-film spray vaporization process, the feed water is introduced at slightly less than atmospheric pressure through an orifice onto heat exchanger tubes for immediate vaporization. Although the corrosive environment is reduced from the flash vaporization system, scaling can still occur on the heat transfer surfaces.

Multiple-effect (ME) evaporation and multistage flash (MSF) evaporation are the two major high temperature distillation processes that use these vaporization techniques.

a. Multiple-effect evaporation units. To optimize the thermal energy efficiency within a distillation/condensation system, several effects are utilized. The heat from the condensation process of one unit (effect) is used to supply vaporization heat for the next unit. The next adjoining unit (effect) will have a lowered pressure and temperature. The process of gradually reducing the temperature by heat transfer results in a much greater yield of product water from a given quantity of thermal energy. This process is further elaborated in section 2.3.1.2 (Alatiqi 1999).

b. Multistage flash-evaporation units. Advancements in distillation technology were achieved through the development of multistage flash evaporation units. Flash evaporation is effected in stages using heat from an external source. In each successive stage pressure is reduced gradually to ensure the continuation of flash evaporation at successively lower temperatures and pressures. This design has become a popular and rife distillation process because internal scaling is not a serious problem. However, corrosion of flash-evaporation units is of concern. This process is further elaborated in section 2.3.1.1 (Al-Mutaz 1996).

Distillation facilities that operate at temperatures less than 200 degrees Fahrenheit are low-temperature units. In operations where there is abundant waste heat, low temperature waste-heat-recovery evaporation units are used. Waste steam (low pressure) from power generation facilities can provide the necessary thermal energy for desalination systems. The most recent developments in distillation technology involve the use of waste heat or low pressure steam with evaporation units and a mechanical vapour compression system. Multiple stages ensure that maximum vapour and product water are produced from the system (Al-Mutaz 1996).

Alternatively the use of mechanical methods for vapour production and heat transfer can result in a highly efficient desalination system. These mechanical methods operate at temperatures less than atmospheric boiling point and use a variety of methods to vaporize raw waters.

Mechanical methods commonly use multiple effects to maximize the efficiency of the applied mechanical energy.

The technique of vapour compression uses a mechanical energy source, such as an engine or electric motor, to power a compression turbine. This turbine draws vapour from the distillation vessel and compresses it, which raises the temperature of the exhaust vapour. The vapour is then passed over a heat exchanging condenser, where it returns to the liquid state as product water. Heat absorbed by the heat exchanger, during condensation, is returned to the feed water to assist in the production of more vapour. The more recent vapour compression multiple-effect units produce a concentrated brine by-product that has had its excess heat reduced by the multiple effects.

2.3.1.1 Multistage Flash Distillation

This is a process where seawater is heated to its boiling temperature and passed thru a series of heat exchange stages and flows into large chambers in which the pressure is low. The low pressure causes some of the water to flash (turn quickly) into steam. The flashed steam is condensed into salt-free water. The feed-water passes through several distillation chambers (Van der Bruggen & VandeCasteele 2002). Multistage Flash (MSF) distillation is used for most of the desalinated fresh water in production worldwide and is used primarily for desalting seawater. A basic illustration of the MSF process is shown in the next page.

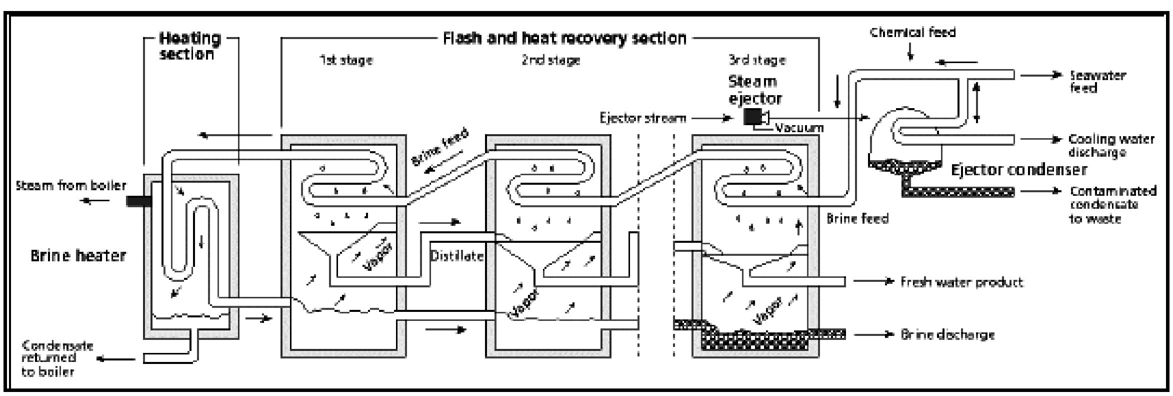


Figure 3: Basic Illustration of MSF Process (Buros, 2000).

The MSF process is energy intensive due to the requirement to boil feed water although energy efficiency is substantially enhanced via the heat recovery process. The advantages of MSF plants lie in their ability to be constructed in large capacities, their reliability over a potentially long operating life, and the design and operational experience in operating these units that has been accumulated over many years. A further advantage lies in the fact that boiling does not occur on a hot surface, as it flashes instead, thereby reducing the incidence of scaling (Foldager 2003).

2.3.1.1.1 Advantages and disadvantages

In summary, the advantages of using multi-stage distillation for desalination are:

- MSF plants can be constructed to handle large capacities.
- Feed-water salinity does not have much impact on the process or cost.
- Very high quality product water is produced (less than 10 mg/L TDS).
- There is a minimal requirement for the pretreatment of the feed water.
- Compared to other processes the operational and maintenance procedures for MSF are less rigorous.
- There is a long history of commercial use and reliability
- It can be combined with other processes, for example, using heat energy from an electricity generation plant.

The disadvantages of using multi-stage flash distillation for desalination are:

- They are expensive to build and operate and require high level of technical knowledge to maintain.
- Highly energy intensive due to the requirement to boil the feed water, although energy efficiency is substantially enhanced via the heat recovery process.
- The recovery ratio is low, as such, greater feed water is required to produce the same amount of product water compared to other processes.

- The plant cannot be operated below 65-75% of the design capacity.

2.3.1.2 Multi Effect Distillation

Multiple Effect Distillation (MED) is a process were vapour produced by an external heating steam source is passed through several evaporators (effects) in series under successively lower pressures, and using the vapour produced in each effect as a heat source for the next. Multiple effect distillation units operate on the principle of reducing the ambient pressure at each stage, allowing the feed water to undergo multiple boiling without having to supply additional heat after the first stage. The evaporated saline water, now free of a percentage of its salinity and slightly cooler, is fed in to the next, lower- pressure stage where it condenses to fresh water product, while giving up its heat to evaporate a portion of the remaining seawater feed.

Usually, there is a series of these condensation–evaporation stages taking place, each one being termed an ‘effect’. The evaporation-plus-condensation process is repeated from effect to effect, each at successively lower pressures and temperatures. MED plants are typically built of units ranging from 2,000 to 20,000 M3/day. Lower operating temperatures (70^{o}C) reduce potential for scaling and energy consumption, but require large heat transfer areas, which add to the physical size of the plant and increase capital costs.

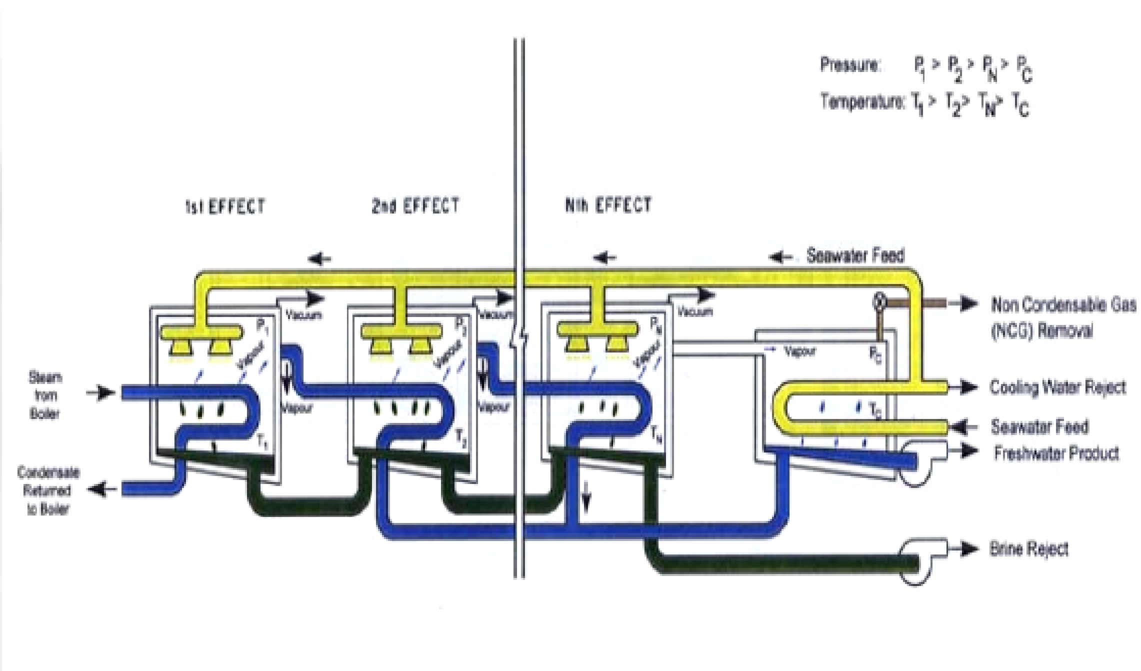


Figure 4: Basic Illustration of MED Process (Buros 2000)

2.3.1.2.1 Advantages and disadvantages

The advantages of using multi-effect distillation for desalination are:

- The pre-treatment requirements of the feed water are minimal.
- Product water is of high quality
- MED plants are very reliable even without a strict adherence to maintenance.
- The plant can be combined with other processes, for example, using the heat energy from a power plant.
- The plant is able to handle normal levels of biological or suspended matter.
- Operating staff requirements are minimal.

The disadvantages of using multi-effect distillation for desalination are:

- They are expensive to build and operate- energy consumption is particularly high.
- In most cases the desalination plant can be susceptible to corrosion. This can usually be controlled by the choice of material used.

- The product water is at a very high temperature and will require cooling before it is used as potable water.
- The recovery ratio is low, but slightly higher than MSF.

2.3.1.3 Vapour Compression Distillation

The low temperature Vapour Compression Distillation (VCD) method is simple, reliable and highly efficient process. Its efficiency comes largely from a low energy requirement and its design that is based on the ‘heat pump’ principle of continuously recycling the latent heat exchange in the evaporation-condensation process.

The VCD process is similar to the MED process. The main difference being that the vapour produced by the evaporation of the brine is not condensed in a separate condenser. Instead a compressor returns it to the steam side of the same evaporator, in which it originated, where it condenses on the heat transfer surfaces, giving up its latent heat to evaporate an additional portion of brine.

The energy for the evaporation is not deprived from a prime steam source as in the preceding two distillation processes, but from the vapour compressor. In addition, the latter raises the temperature of the vapour by its compressive action, thereby furthering the driving force for the transfer of heat from vapour to brine. Typically these units are no smaller than 300 to 400 kL/day, and are most economic with feed water of high TDS levels, typically greater than 50,000 mg/L TDS (higher than seawater). High quality product water can also be achieved with VCD units, generally less than 10mg/L TDS, and in some cases even as low as 2mg/L TDS. Recoveries of approximately 50% can be achieved with these units (Brunner 1999).

2.3.1.3.1 Advantages and disadvantages

The advantages of using vapour compression distillation for desalination are:

- It has a high recovery ratio.
- The plants are very compact and can be designed to be portable.
- Minimal pre-treatment is required
- The capital cost of the plant is reasonable and operation is simple and reliable.
- The process produces very high quality product water.
- The energy requirements are quite low, but not as low as RO.

The disadvantages of using vapour compression distillation for desalination are:

- Large, expensive steam compressors are required, which are not readily available.
- An auxiliary heater is normally required to get the temperature of the feed water up to a point where some vapour is formed after which the compressor can take over.

2.3.2 Membrane Processes

This is used in two commercially important desalting processes:

- Reverse Osmosis (RO); and
- Electro dialysis (ED).

Each process utilizes the ability of the membranes to differentiate and selectively separate salts and water. The major difference between the two is in the nature of the physical process applied.

Reverse Osmosis is a pressure driven process, with the pressure applied used for separation, allowing the water to pass through the membrane while the salts remain.

Electro-dialysis on the other hand is a voltage driven process, and uses the electrical potential to selectively move salts through the membrane, leaving the product water behind (Winston and K.Sirkar, 2002)

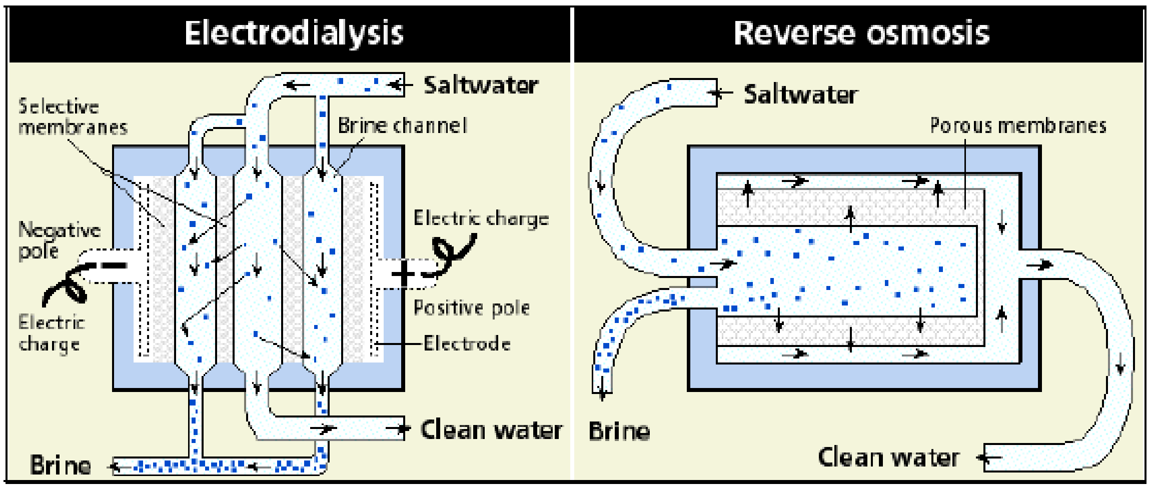


Figure 5: Basic illustration of membrane process (Winston & Sirkar, Membrane Handbook, 2002).

2.3.2.1 Reverse Osmosis (RO)

RO is a widely used method for desalting seawater by using pressure driven techniques. Water is forced to flow through small pores under high pressure through semi-permeable membranes or filters, while salt is rejected. The differential pressure must be high enough to overcome the natural tendency of water to move from the low concentration side of a membrane to the high concentration side, as stipulated by osmotic pressure. Pre-treatment is important in reverse osmosis because the membranes must be clean. Therefore larger particles are filtered and often multiple stages of membranes are used (Magara et al., 2000).

No heating is necessary, but the major energy requirements come from pressure. Small pores require high pressure and consequently more energy. The quality produced depends on pressure, salinity of source and efficiency of the membranes. Development of more efficient membranes and energy recovery devices has significantly improved the operating cost of RO plants in the past decade and great potential growth in seawater desalination has been recorded (Baker 2004).

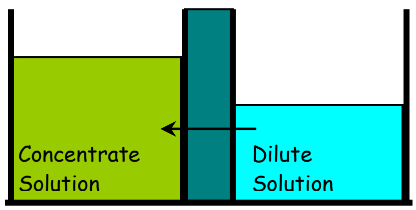


Figure 6: Simple diagram showing how osmosis works.

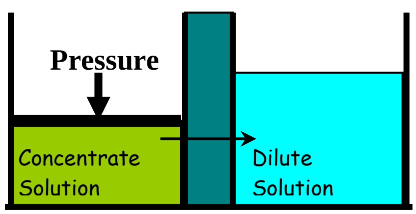


Figure 7: Simple diagram showing how ‘reverse osmosis’ works.

In practice the saline feed-water is pumped into a closed vessel where it is pressurized against the membrane. As water passes through the membrane, the salt concentration of the left-over feed-water increases. The high saline water is discharged from the vessel in a controlled manner. This is done in order to ensure problems such as precipitation of supersaturated salts and increased osmotic pressure across the membranes does not occur in the system (Eisenberg & Middlebrooks 1992).

The amount of water discharged to waste in the brine stream varies from approximately 20% to 70% of the feed flow, depending on the salt content of the feed-water, the pressure, and type of membrane.

Pre-treatment of the feed-water is an essential component of the RO plant in order to prevent scaling of the membranes by scale-forming foulants such as salt precipitation and microbial growth.

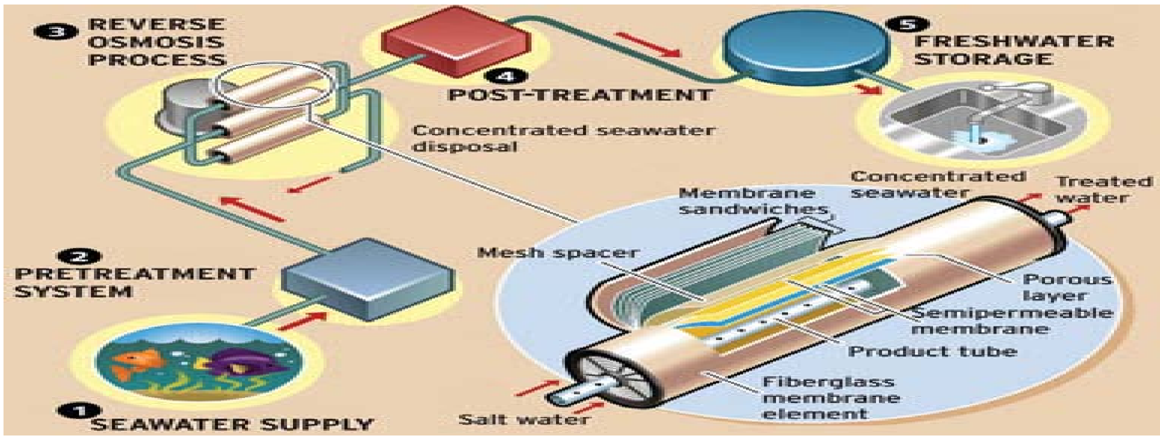


Figure 8: Illustration of a Reverse Osmosis Process (Winston & Sirkar, Membrane Handbook, 2002).

The disadvantages of reverse osmosis technology compared to thermal technologies include sensitivity to the pre-treatment system capability and operator capability. Both of these disadvantages can be easily overcome with sufficient pre-treatment design and operating training programs.

2.3.2.1.1 Advantages and disadvantages

The advantages of using the RO system for desalination are:

- They are quick and cheap to build and easy to maintain. There are few components, durable plastics and non-metal materials are mainly used-pre treatment of the feed water to prevent fouling of the membrane is the only potential problem.
- It can handle a large range of flow rates, from a few liters per day to 800,000 KL L/day for brackish water and 450,000 L/day for seawater. Capacity upgrades can be done, if required, by adding on extra modules.
- It has a high space/production capacity ratio, ranging from 30,000 to 70,000 L/day/m^2.
- Energy consumption is lower compared to distillation processes.
- Contaminants and salts can be removed from the water.
- Minimal use of cleaning chemicals is required.
- Due to modular design, there is less delay in the start up and shut down of plants.

The disadvantages of using the RO system for desalination are:

- RO membranes are expensive and have a life expectancy of 3-6 years
- If the plant uses seawater there can be interruptions to the service during stormy weather. This can cause re-suspension of particles, thereby increasing the amount of solids suspended in the water.
- The process requires high quality standard of materials and equipment for the operation of the plant.
- The availability of an extensive spare parts inventory is required.
- The plant operates at high pressures and as a result there are occasional problems with mechanical failure of equipment due to high pressures used.

2.3.2.2 Electro-dialysis (ED)

Electro-dialysis is mainly used to desalt brackish groundwater (slightly salty). The process of electro-dialysis is based on the fact that salt water breaks up electrically to sodium and chloride. It uses a large chamber divided into many compartment by stacks of thin plastic sheets called membrane. Instead of using pressure to overcome the membrane's resistance, pre-treated water is pumped between electro-dialysis cells under the influence of a low voltage direct current electrical field (Nicolaisen 2002).

An EDR unit operates on the same general principle as a standard electro-dialysis unit, except that both the product and the brine channels are identical in construction. Several times per hour, the polarities of the electrodes are reversed and flows simultaneously switched so that brine channel becomes the product water channel and vice versa. The result being that, ions are attracted in the opposite direction across the membrane stack. During this interval, the product water is dumped until the stack and lines are flushed out and desired water quality is restored. This flush normally takes 1 to 2 minutes, with the unit returning to normal operation on completion of the flushing process (El Bana 2000).

2.3.2.2.1 Advantages and disadvantages

The advantages of using electro-dialysis plants for desalination are:

- They can produce a high recovery ratio (85-94%)
- Can treat feed water with a higher level of suspended solids.
- Pre-treatment has a low chemical usage and does not need to be as precise
- The energy usage is proportional to the salts removed, instead of the volume of water being treated.
- A life expectancy of 6-9 years is expected for EDR membranes which is longer than for RO membranes.
- EDR membranes are not vulnerable to silica scaling or bacterial attack.
- Scaling can be controlled by treating the membrane while the process is still on-line.
- EDR can be operated at low to moderate pressure.

The disadvantages of using electro-dialysis for desalination are:

- It is required that the membrane is periodically cleaned with cleaning chemicals.
- Leaks occur occasionally in the membrane stacks.
- Bacteria and non-ionic substances are not affected by the system and can therefore remain in the product water. These factors make it necessary for the product water to be further treated before it can be used as drinking water.

2.4 Comparison of distillation and membrane processes

To summarize the above descriptions of the major desalination processes, a comparison of each approach is provided below.

The advantage of using membrane processes over distillation processes are:

- Membrane plants usually have lower energy requirements.
- Membrane plants normally have lower investment costs, as compared to distillation plants.
- Membrane plants normally have a higher production capacity ratio with respect to production area.
- Membrane processes operate at normal temperature. This minimizes the scaling and corrosion potential, which increases with higher temperatures.
- Due to their modular design membrane plants can be modified by taking sections out of the plant.

The disadvantages of membrane processes when compared to distillation process are:

- Membrane processes do not destroy biological substances, unlike distillation processes. Therefore they must be removed in either pre-treatment or post treatment if the water is to be used for potable water or process water.
- Membranes that are of the polyamide type can be used if there is chlorine in the water. The chlorine must, however, be chemically removed later in the process.
- Due to fouling of the membrane, the performance of membrane plants tends to decline progressively with time.
- Regular cleaning is required for membrane plants as opposed to distillation plants.

The advantages of distillation plants over membrane plants are:

- Distillation plants are the longest operated desalination process available and have a record of being a reliable process.
- Distillation plants produce a quality of product water that is higher than that produced by membrane plants.
- Less cleaning is required for distillation plants as compared to membrane plants.
- A minimal amount of operating staff is required to operate distillation plants.

The disadvantages of distillation plants when compared to membrane plants are:

- Due to their lower recovery ratio, distillation plants require more feed water to produce the same amount of product water as membrane plants.
- Greater attention is assigned in the selection of materials for the distillation process because distillation plants are more vulnerable to corrosion than membrane plants.
- Distillation plants have a higher space to capacity ratio than membrane plants.
- Capital costs associated with distillation plants are higher than those for membrane plants.

- Traditionally distillation plants require a much higher operational energy than membrane plants.
- The temperature of product water is higher than for membrane plants. This means that the product water needs to be cooled before being used as potable water.

2.5 Alternative Processes

- Freezing Process

During the 1970's, several plants were experimented with freezing as a method of desalination. When seawater freezes, the ice crystals that are produced form fresh water in solid form. The salt is extracted, but trapped between the ice crystals. The ice crystals are separated from the salt by washing it off with fresh water. The ice crystals are then melted and become fresh liquid water. High costs and engineering problems have prevented the commercial use of freezing as a desalting method (Benjamin 2002).

- Solar distillation

A very simple process that could be used to have potable water is by solar distillation. It can be done simply by filing a basin with seawater and covering it with sloping plastic or glass sheets. The collecting solar energy turns seawater into vapour and very salt water; the vapour will condense on the surface of the plastic sheet and be collected in special basin. This type of distillation produces a little water and it is expensive and less efficient compared with other desalination process (McCarthy & Leigh 1999).

- Nuclear distillation

Application of nuclear power for desalination was used with beginning of 1960 by various national nuclear agencies. Nuclear reactors have some general characteristics, which differ, from conventional energy sources. The prospects of using nuclear energy for seawater desalination in a large scale are attractive since desalination is an energy intensive process. The heat from nuclear reactor and/or the electricity produced by such plants can be used at a desalination facility. The safety, regulatory and environmental concerns in nuclear desalination is related directly to nuclear power plants (Peterson 2006).

2.6 Existing desalination plants in South Africa.

Plans for the construction of a desalination plant at Zinkwazi, on the KwaZulu-Natal north coast are being explored by the Department of Water Affairs and Forestry (DWAF) in conjunction with the Faculty of Engineering in the University of Stellenbosch (DWAF 2009).

The Water Research Commission (WRC) also launched a 'media release' on the 16th of February 2007, indicating their intentions to install a seawater and brackish water desalination plant for the augmentation of municipal water supply in the Western Cape.

2.7 Cost Comparisons

Theoretically, all desalination processes, including those yet to be invented, have certain minimum requirements for energy. Despite this, problems arise in all desalination processes due to the movement of matter in the process, or movement of energy at phase boundaries. These problems increase the energy requirements of desalination methods, thus raising costs (Ammerlaan 1982)

It is difficult to make simple economic comparisons because desalination processes can use several combinations of energy sources and can be developed for different levels of energy efficiency. However, it is clear that the cost of desalination is determined by a combination of technical and economic factors. It is therefore recommended that further research be done on this topic.

The major categories are operating costs, capital costs and maintenance costs. These three categories are interdependent; that is, if one component is increased the other components usually decrease. The review presents an extensive list of technical and economic factors that influence the desalination cost and the choice of desalination process. The three factors affect the cost of desalination per unit of fresh water are, the feed-water salinity level, energy costs, and economies of scale.

2.7.1 Feed-water Salinity Level

Increasing the salt content of the feed-water increases the operating costs as more apparatus (such as membrane area or the number of stages of distillation) is needed. The cost of desalting seawater is about 400% higher than the cost of desalting brackish water from the same size plant for both thermal and membrane methods (Buros 2000). Desalination of brackish water is most economically achieved by the use of membrane processes, reverse osmosis, presently the cheapest process (Glueckstern & Kantor, 1983).

2.7.2 Energy costs

A major characteristic of all desalination processes is their requirement for thermal or electric energy input, which can represent 50 to 75 percent of operating cost (Mesa, Gomez & Azpitarte 1997). The form of energy available and environmental constraints related to the energy source contributes to the cost of energy for desalination. Currently, reverse osmosis has the lowest energy demand and this consequently makes it a more attractive process, as compared to the older multistage flash distillation. Rising world energy prices will alter the relative costs of different desalination methods, increasingly favoring technologies with low energy consumption (Wood 1982).

2.7.3 Economies of Scale

Economies of scale arise when increases in the plant size (kilolitres of water produced per day) bring decreases in the unit fresh water cost. Economies of scale are evident in all desalination processes, but to different extents. Reverse osmosis exhibits little scope for economies of scale, while distillation processes show the greatest economies of scale. The operating and maintenance costs are not subject to economies of scale, but are directly affected by the water quality to be treated. Utilizing the economies of scale for distillation methods has been proven an effective means of reducing the cost of desalting water (Hammond 1996).

Due to their lower energy costs, reverse osmosis has been shown to be the most economical process available. Membrane life and energy cost determine the unit water costs. RO plants have greater operational flexibility when fluctuating water demand exists and also benefit a little from economies of size.

Economic trends for multistage flash distillation plants include the relative investment cost, benefits from economies of size, site specific costs (have a direct affect on the unit water costs, and low flexibility in response to variable water demand, meaning that freshwater production cannot be adapted to fluctuating demand. The main economic drivers for multistage flash distillation are costs of materials and increasing plant capacity to take advantage of economies of scale (Morin 1999).

Comparing reverse osmosis and multistage flash distillation, the distillation process has been the preferred method over the years due to its perception as a more reliable process. However, reverse osmosis plants are currently replacing the older distillation plants of the Middle East and being the first choice for desalination implementation in other parts of the world. Reductions in energy consumption and consequently, cheaper unit costs of fresh water are responsible for the preference (Birkett 2002).

The overall cost of fresh water from a reverse osmosis plant is often significantly less than that produced by means of distillation, mostly because of the significant reduction in energy costs. As the technical advancements of membrane processes continue to improve their costs and efficiency, they will increasingly be the preferred choice for countries moving into desalination. However in countries were energy is affordable and readily available distillation is still the preferred option for large scale water production.

Presently, depending upon the process, location and the potential for blending with marginal quality ground-water, the cost of desalting water using current technologies fall within the range A$0.80/kL to A$2.10/kL. These costs do not include distribution or disposal costs (Buros 2000).

2.7.4 Additional Costs

Economic evaluation of the total cost of water delivered to a customer must include costs for environmental protection, particularly disposal of brine (highly concentrated saline water) which is a by-product of the desalination processes. There are also costs of losses in the storage or distribution network. Typically the total cost of desalted water reported by desalination plants or literature is a combination of investment costs and operation and maintenance costs. Few attempts are made to include the costs of environmental protection or water distribution.

The disposal of brine into the ocean is generally considered to be safe because the major solute in the brine is salt, however, in some cases marine impacts may need to be considered .Disposal of brine inland presents further potential complications as it may either worsen groundwater salinity, or result in additional expenses for other means of disposing (for example, lined evaporation basins or impounding underground). In some cases the brine may have an economic value (for example, salt production), but the potential scale of this would probably be small relative to the production of brine if desalination becomes a major source of fresh water. Further research and information is required to fully understand the environmental impacts caused by desalination processes and to develop regulatory measures (Squire et al., 1996).

2.7.5 Reductions in the Cost of Desalination

One of the ways to reduce the cost of desalinated water is to improve the desalination technology. Improvements would increase the performance ratio (the ratio of fresh water to the amount of energy consumed). By advances in membrane technology for reverse osmosis and thermal energy optimization in thermal desalination processes the performance ratio can be increased (Drioli et al., 2002).

Recent research has shown that the coupling of thermal and membrane desalination processes improves the total efficiency and decreases desalination costs. Improvements to both technologies will continue due to increasing demand for fresh water and the popularity of desalination (Baker 2004)

An alternative method of reducing the cost of desalinated water is by reducing the cost of energy required to operate the process. Most methods focus on the use of renewable energy to provide the required power to the desalination process, with the most popular source being solar energy. Alternatively the use of dual-purpose plants, where the desalination plant is connected to an electricity plant, utilizing the waste heat from the electricity plant, is currently being adopted. It has been claimed that, under favorable conditions, dual-purpose plants decrease the cost of desalinated water below those of conventional desalination methods, primarily through energy conservation (Tay et al., 1996).

Due to the erratic nature of international energy prices and the increasing attention and concern for global pollution problems interest in the application of clean renewable energy sources has been intensified. In remote regions with adequate availability of sunlight, solar desalination can be cheaper than conventional desalination methods for small scale production of water. This is primarily due to the significant reductions in fuel consumption as a result of the solar alternative (Voivantas et al 1999).

Solar systems reduce pollution by not utilizing fossil fuels. Also, they are easy to operate and maintain. South Africa has high levels of radiation in remote regions making solar desalination a potentially viable option. Desalting of brackish water (if available) using solar energy powered desalting plants is potentially the cheapest way to provide new fresh water resources in remote areas. The costs of operation and installation depend heavily on appropriate climatic conditions, as such; solar processes are largely restricted to remote areas needing small scale desalination systems (McCarthy & Leigh 1999).

When compared to the fuel needed for two separate plants, dual-purpose plants show a remarkably reduced consumption of fuel. The energy costs for desalination from a dual-purpose plant are significantly less than that of a stand-alone desalination plant (Hammond 1996).

2.8 Summary Analysis

In the current chapter an attempt has been made to capture the popular desalination technologies currently being deployed around the world. There has been an effort to present the advantages and disadvantages of each technology with a view to providing the reader with information required to partly identify a suitable desalination process based on the comparative information provided.

The table in the next page shows a tabular representation of the literature presented in this chapter. Key indicators are measured on a high to low ranking order. For instance if capital for MSF is high then fill 'high', if recovery ratio for MSF is low then fill 'low'.

Weighting elements required to do an analysis of the data will be presented in the next chapter as well as other knowledge areas required for decision making.

The 'vapour compression' and 'electro-dialysis' processes have been added for the purpose of the summary analysis, but will not be used for decision analysis because they are typically not used for large scale salt water desalination.

Table 2: Decision Matrix Ranking Elements

CRITERIA	**MSF**	**MED**	**RO**	**VC**	**ED**
Capital Cost	High	High	Medium	Low	Low
Energy Consumption	High	High	Low	High	Low
Reliability	High	High	High	Medium	Medium
Recovery Ratio	High	High	Medium	Medium	High
Operation & Maintenance	Medium	Medium	High	Medium	Medium
Product Water Quality	High	High	Medium	High	Low

MSF - Multi Stage Flash

MED - Multi Effect Distillation

RO - Reverse Osmosis

VC - Vapour Compression

ED - Electro-dialysis

Chapter 3: Desalination Process Selection

3.1 Factors Affecting Process Selection

By beginning of 1960s, water desalination technology had been viewed as an alternative conventional water resource. The main challenge at that time was the high cost of produced water. The limiting factor that is still affecting the price of a cubic meter is the power cost and the water quality of the produced water. In the last decade, rapid progress and high competition has happened in the RO desalination technique and technology to decrease the power consumption.

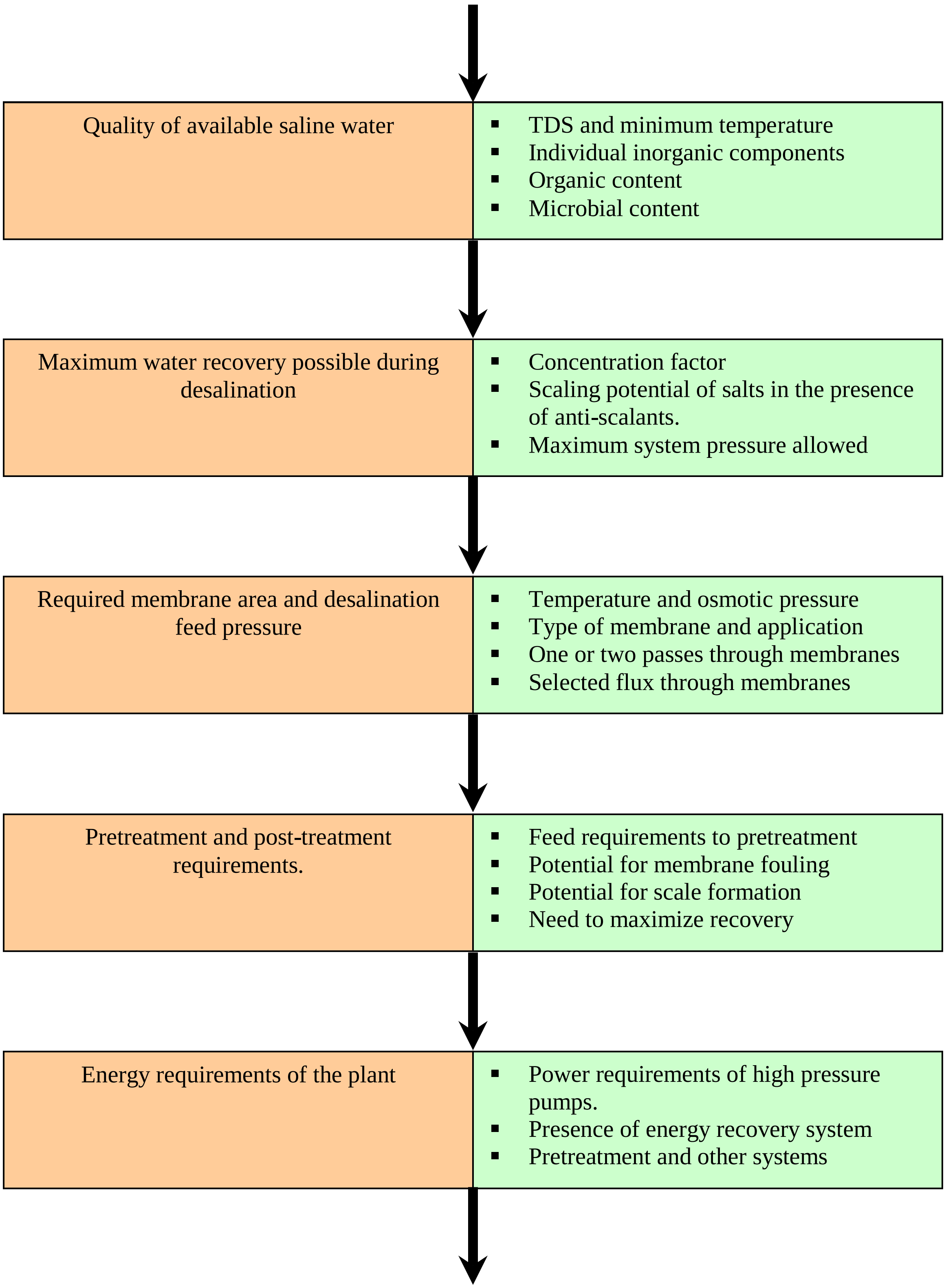
New studies and figures argue that to produce one cubic meter of desalinated water 3.5 KWh or less are needed. Aside from the factors discussed in the previous chapter, there are many other factors that influence the cost and selection of desalination technology. These factors are listed below (Brunner 1999):

- **Seawater Intake and Outflow –** This represents the distance from the feed-water source to the desalination plant, as well as, the distance from the plant to the brine disposal point. The longer the distances between these points, the higher the capital costs.
- **Performance Ratio –** This represents the ratio of freshwater produced to the amount of energy consumed. Lower performance ratios are only acceptable in energy rich countries with low energy and fuel costs.
- **Plant Costs –** This refers to the capital costs of procuring and installing desalting machinery. There are significant variations between different desalination processes.

- **Site Costs** – The cost of the land secondary determinant of the location preference. The primary consideration is the cost of transporting water to its point of demand.
- **Chemical Costs** - The necessity and cost of chemicals will affect the maintenance costs of pre-treatment and post-treatment processes, especially in reverse osmosis plants.
- **Feed-water Quality** – This represents the salinity and constitution of the feed-water. This usually affects the type of desalination process, extent of pretreatment required and consequently the fresh water cost.
- **Energy Sources –** These are major components of operating costs. Desalted water costs are affected by fluctuating energy prices; therefore cheaper energy sources are required.
- **Plant Load Factor –** This is the percentage value of the total production for the year compared to the rated capacity. It provides a measure of the overall utilization of the plant also known as the production efficiency. Increasing the load factor decreases the cost of water per unit output.
- **Brine Disposal** – For coastal plants, brine is commonly discharged into the sea and for inland plants brine disposal may be in the form of a stream, salt ponds or underground reservoirs.
- **Plant capacity –** Due to economies of scale, the cost of desalting water generally decreases with increasing plant capacity, as a result of capital, labour and maintenance charges being distributed over a larger capacity.

The diagram below illustrates the factors to be considered in desalination process selection.

Determine	Consider
Treatment technology required (desalination vs. conventional) Required plant capacity and the needs of the community	▪ Available water resources ▪ Sources of available saline water ▪ Economic standing of community ▪ Required availability of plant ▪ Hours per day of operation ▪ Seasonal variation of needs


Quality of available saline water
TDS and minimum temperature
Individual inorganic components
Organic content
Microbial content
Maximum water recovery possible during desalination
Concentration factor
Scaling potential of salts in the presence of anti-scalants.
Maximum system pressure allowed
Required membrane area and desalination feed pressure
Temperature and osmotic pressure
Type of membrane and application
One or two passes through membranes
Selected flux through membranes
Pretreatment and post-treatment requirements.
Feed requirements to pretreatment
Potential for membrane fouling
Potential for scale formation
Need to maximize recovery
Energy requirements of the plant
Power requirements of high pressure pumps.
Presence of energy recovery system
Pretreatment and other systems

Discharge of concentrate, CIP effluent and other environmental impacts.	▪ Dilution and distribution if discharged to sea ▪ Potential evaporation ponds ▪ Sensitive environmental aspects
Installed capital cost	▪ Desalination section ▪ Pretreatment section ▪ Intake, outfall and post-treatment ▪ Environmental assessments and other contractual items.
Unit cost of desalinated water	▪ Capital redemption ▪ Energy ▪ Membrane replacement ▪ Chemicals and consumables ▪ Labour and maintenance

Figure 9: Process Selection Factors.

3.2 Key Cost Drivers

3.2.1 Location

The location of the feed water source dictates the viability of a desalination plant with reference to the following:

- Remoteness – the cost of transporting water to and from, the cost of power transmission and infrastructure may detract from viability; and
- Environmental constraints – the location of the source may dictate that certain environmental constraints would be imposed, for example: noise, brine disposal, groundwater flow system and aquifer yield, disturbance to marine

life, seafloor ecology and other factors which would detract from the viability of the project.

Summarily the further away the feed-water is from the desalination plant, the higher the construction and operating costs associated with the plant.

3.2.2 Feed-water quality

Feed water sources represent a significant concern in the choice of desalination technology selection. The most common feed-water sources are:

- Seawater
- Brackish water
- Saline Water
- Effluent

However, in nearly all cases where a desalination process is chosen, seawater is the feed source (El Bana 2000).

The quality of feed-water is a major factor in the choice of desalination technology selected. However, in general, distillation technologies tend to be more flexible than membrane based technologies with feed-water that is of low quality. This is partly due to the fact that distillation processes require less rigorous pre-treatment than membrane processes (Buros, 2000)

The key water quality parameters in the design of the pre-treatment and main process systems of a desalination plant are:

- Salinity (TDS)
- Turbidity
- Organic content
- pH; and
- Concentrations of scale forming salts and non-ionic fouling species.

In membrane processes there is generally a direct relationship between salinity and capital/operating costs. Turbidity and organic content are generally key concerns with surface water and seawater feed sources, and can cause significant problems in membrane processes with membrane clogging without adequate pre-treatment being put in place.

Feed-water pH is important in distillation processes in terms of potential pipe work and pump corrosion, and is of concern with membrane based processes when sub-optimum pH feed conditions exist as this may potentially reduce membrane life.

The main scale forming species of concern in desalination plants are calcium, manganese, bicarbonate, sulphate, ferrous ion, and silica.

Only minor variations in the feed-water chemical constituents mentioned above are necessary to create significant fouling and operational problems that can increase pre-treatment costs and potentially cause major problems in concentrate disposal requirements. As such, feed water sources are carefully assessed (Brunner 1999).

South Africa with its long coastline has an almost infinite water resource available to the coastal towns and cities of the country, albeit of a high saline nature. Three seawater zones with potentially different water qualities are identified and briefly discussed below.

- East Coast

The East Coast of South Africa can be described as the area between East London up to the Mozambique border. All marine systems in this region are dominated by the Agulhas current, which brings warm, nutrient-poor water from the tropics to the east coast. The region can be subdivided into a tropical coast (north of Port Edwards) and a subtropical coast (DWAF 2009).

- South Coast

The coastal region between East London and Cape Agulhas, referred to as the South Coast, acts as a transitional zone between the warm east-coast waters and the cold west-coast waters, with no clear boundaries. Boundary conditions might shift a few kilometers in either way, depending on prevailing atmospheric conditions (DWAF 2009)

- West Coast

The West Coast is generally referred to as the region between Cape Agulhas and the mouth of the Orange River. Seawater quality in this region can be rather variable and special care should be taken when assessing water supply in areas such as False Bay, St Helena Bay and the Saldanha Bay / Langebaan system. Due to the north-bound flow of the Benguela Current from the Antarctic, the west-coast water is normally very cold and associated with low dissolved oxygen levels. Prevailing wind conditions frequently result in an up-welling of cold, nutrient-rich bottom water into the warmer surface water, triggering the associated red-tide phenomenon and the potential presence of H_2S in the water. The low water temperature demands higher operating pressures and lower membrane fluxes as well as higher vapourisation temperatures for distillation processes, while the high concentrations of nutrients and potential compounds such as H_2S cause processes with pretreatment to be demanding. Therefore, desalination of west-coast water would normally be more expensive than on the East Coast (DWAF 2009)

3.2.3 Energy Source

All desalination technologies require energy to facilitate the separation of low salinity product water from saline feed-water. The form of energy available, the associated cost and the environment constraints related to the energy source, will all play a major role in the desalination technology selection (Maheswari 1995)

Electrical energy generated from national power grids are the most common source of energy, however, with rising energy cost and inadequate supply of energy in African countries (South Africa inclusive) other energy sources are used to reduce the operating cost and thus the product cost of desalinated water.

Some of the alternatives to grid generated electricity are;

- Renewable Energy: Is energy generated from naturally occurring resources which are renewable or self regenerating, such as wind, rain, tides, sunlight. Renewable energy technologies thus include solar power, wind power, hydro-electricity, bio-mass and bio-fuels.

- Bio-energy: Bio-energy produced from the break-down of organic matter, is a potential source of energy that may be utilized to power desalination plants. However, in order to maintain a high level of energy supply throughout the year, a substantial volume and reliable supply of biomass is required (Libert 1992)

  This requirement, and the cost of implementing the energy recovery technology, could be prohibitive to the undertaking of bio-energy production in areas outside of large metropolitan centers or where there are no commercial or industrial activities producing significant quantities of organic waste byproducts. Bio-energy technology has been in use for some time in

Europe and in North America, primarily due to the high cost of waste disposal, population density and regulatory requirements (Kufahl 2002) .

3.2.4 Brine Disposal

The by-product of all desalination processes is water highly concentrated in those elements removed during the desalination process, called brine. This includes dissolved salts, but also any chemical treatments that are used in desalination processes to control the formation of mineral scale and biological growth (Mahi 2001).

Depending on its physical and chemical content, brine can sometimes be returned, untreated or diluted, to its source of origin or a nearby water body (e.g. outfall to sea or surface water system, or injecting into a saline aquifer). These options are generally the cheapest and easiest to implement, particularly if the desalination plant is located near the maintenance costs of this infrastructure, are the only significant cost items.

Alternative innovative methods of disposal of the brine stream have been developed in recent times in order to manage saline resources into a more effective economic opportunity (Tsiourtis 2001)

3.3 Selection Methodology

Based on the available information provided in the preceding literature, an evaluation will be done to aid in determining the best technology for desalination. The methodology that will be used is the weighting and ranking methodology (W&RM) which gives a certain weight to each element. However, the weighing and ranking methodology is only valid based on the assumption;

1. That the ranking number should depend on negative or positive merits of each item. Positive merits will have high numbers and high rankings and negatives should have low numbers and low rankings.
2. Comparisons are only valid for certain locations and scenarios. A weighting number should be assigned to identify the importance of a particular criterion. This is because the importance varies from one project to another.

Step 1: Selecting the criteria required

- minimum specific power consumption
- minimum capital cost of process
- minimal operation and maintenance cost
- reliability
- required quality of product water
- high recovery ratio

Step 2: Select required criteria, similar to, but not restricted to that in 'Step 1'. Gather all the information with respect to the above criteria.

Step 3: Convert all the information to one reference and rank them.

Step 4: Rank each criteria as follows;
For benefits high =5, medium=3 and low=1,
For liabilities high =1, medium = 3, low = 5

For instance if ‘product water quality’ is high then it will be ranked 5 because it’s a benefit, however, if ‘capital cost’ is high it will be ranked 1 or 3.

Step 5: Assign a weight to each criteria depending on the importance of the criteria and its relevance to the particular scenario.

5 = Very significant

4 = Significant

3 = Moderate significance

2 = Low significance

1 = Not significant

For instance for some projects capital cost may not be a significant consideration and as such will carry a low weight, however, reliability may be of high significance and as such carry a high weight.

Step 6: Compare the total scores for each technology/ process.

The considerations for a desalination plant in South Africa will include factors such as minimum power consumption, low capital cost, minimum operation and maintenance, high reliability, adequate product water quality and commercial recovery ratio.

The table below highlights the key selection criteria as well as the process alternatives being considered, with the appropriate weight factors for each of the criteria. The aim of this exercise is to identify which of the following alternatives best addresses the needs of the particular environment in terms of the criteria mentioned above.

Table 3: Ranking Table

	MSF			**MED**			**RO**			**Weight**
Capital Cost	1	4	**4**	1	4	**4**	3	4	**12**	**4**
Energy Consumption	1	5	**5**	1	5	**5**	5	5	**25**	**5**
Reliability	5	4	**20**	5	4	**20**	5	4	**20**	**4**
Recovery Ratio	5	3	**15**	5	3	**15**	3	3	**9**	**3**
Opr & Mtce	3	4	**12**	3	4	**12**	1	4	**4**	**4**
Product Water Quality	5	5	**25**	5	5	**25**	3	5	**15**	**5**
TOTAL			**81**			**81**			**85**	

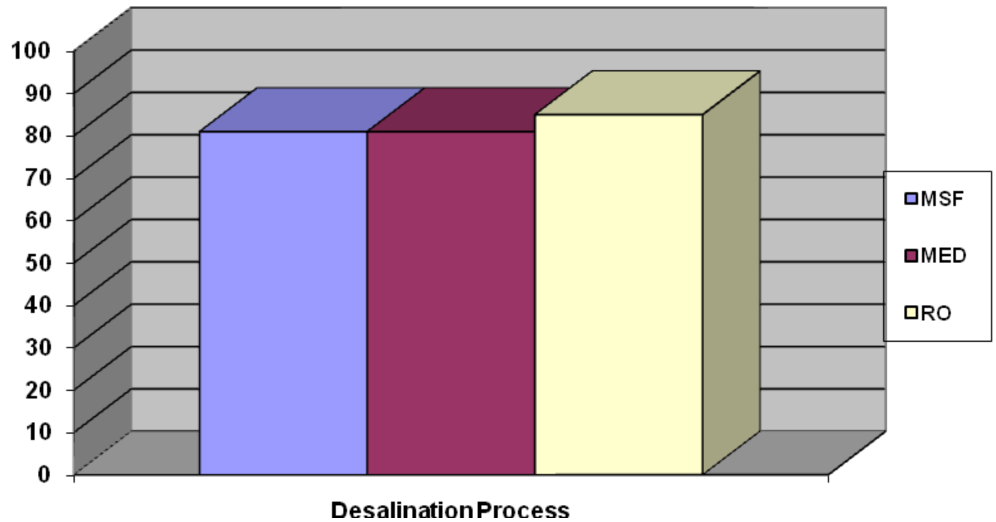
Results

MSF = 81

MED = 81

RO = 85

It is important to note that the results will change from one site to another based on the criteria considered in the analysis and the priority given to such criteria (the weighting factor). For instance high product water quality may not be required if the plant is being designed for production of water for agricultural purposes. As a result in certain areas, based on the application, scale and available resources, any of the above listed desalination technologies can be used for desalination of salt water.



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igure 10: Ranking Chart

3.4 Summary Analysis

This chapter has attempted to discuss the various factors that directly and indirectly affect desalination process selection. Factors that influence the cost of implementing the technology such as location, feed-water quality, energy source and brine disposal where also discussed.

A weighting and ranking methodology was also used to determine the most suitable process, based on selected key criteria, and deductions where made. The result of the W&RM simply serves as a guide to the most suitable process, based on the importance of selected criteria, within a particular environment.

Chapter 4: Desalination Process Decision Tree

4.1 Decision Tree

In operations research, specifically in decision analysis, a decision tree is a decision support tool that uses a graph or model of decisions and their possible consequences, including chance event outcomes, resource costs, and utility. Decision trees are used to determine the path require to reach a goal or solve a problem. Another use of trees is as a qualitative means for calculating conditional probabilities.

By using the information gathered in the preceding chapters, a decision tree has been adapted to suite this research and is being used to provide a recommendation for desalination technology selection. The desalination decision tree provides information with an indication as to whether desalination is an appropriate salinity management tool and if so, the type of desalination technology that is best suited for the South African environment.

The decision tree is designed using key process selection parameters, as indicated in chapter three, such as, the quality of fresh water required from the process, the quality of feed-water available for the process as well as the identification of energy sources. Expected recovery ratios and product water quality is highlighted at the end of each node.

The decision process starts with an inquiry into the quality and quantity of fresh water available compared to the quality and quantity that is needed in order to ascertain if desalination should be used or if current supplies should be relied on. Next energy sources are determined and a choice is made between mains energy and waste heat. A process is then determined based on the quality of feed water and the quality of product water.

The end nodes of the tree describe what the best choice of desalination should be having taken all the factors and steps into consideration. In the alternative there is also a node that indicates the possibility of no economic option being available to suit the prevailing factors.

The decision end nodes in this research have been colored in the decision tree below for ease of identification. The result at the end of each node is based on the outcome of the following;

- Energy source
- Feed-water quality
- Plant Capacity
- Product Water Quality
- Recovery Ratio

4.2 Terms

The list of terms used in the decision tree is listed below;

- MED/VC-
- PPM- Parts Per Mil
- TDS- Total Dissolved Solids
- SWRO- Sea Water Reverse Osmosis
- Kl/d – Kilolitres per day

4.3 Decision Tree Analysis

The decision tree above is designed with certain assumptions:

1. It is assumed that there is sufficient feed water available to produce the required product water. This assumption is supported by the vast RSA coastline (approx. 2798km) that runs through the south of the country.

2. The cost of building the plant cannot be classified as a ‘yes’ or ‘no’ item because of the several factors that contribute to the start up and operation cost of a plant. As such cost considerations are not included in this tree. The tree as well as the decision matrix in chapter 2 and 3, however, should lead to the adoption of a desalination process which can then be based on the prevailing market rates of the plant location. It is, however, recommended that a thorough economic evaluation of selected plants be done by using a discounted cash flow approach for criteria ranging from the point of water sourcing to brine disposal and water delivery to users. Costs highlighted in section 3.1 would be included in such an evaluation.

3. It is important that the reader notes that there is no difference between the steps in the mains energy and the steps for waste heat. This is because the quality of the feed water and the scale of production still remain important factors irrespective of the energy source

4. Once each of the end nodes in the decision tree have been reached, there will be many additional considerations that need to be incorporated in order to assess the workability of the selected process. Such considerations include the feasibility of brine disposal, and the relative cost of the chosen desalination process in comparison to alternative forms of water supply

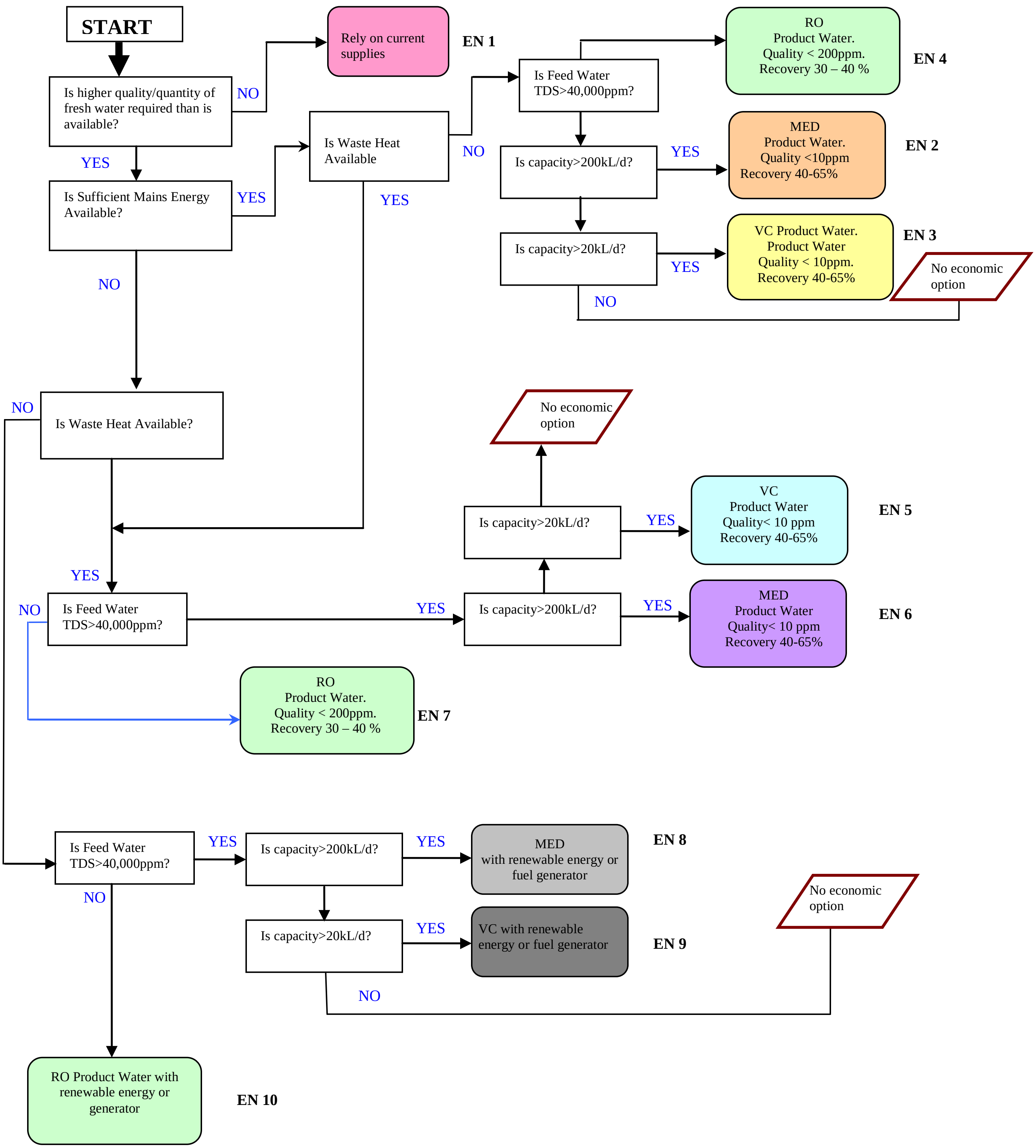

Figure 11: Decision tree (Adapted from AFFA 2002)

4.4 Result Analysis

The decision tree above leads to the adoption of one of ten end nodes. These are described below;

EN1 – This assumes that the available water is of a higher quality and /or higher quantity than that which can be derived from desalination.

EN2 – This assumes that there is sufficient and affordable mains energy, that the feed water is of a high concentration and that a large quantity and quality of product water is required

EN3 - This assumes that there is sufficient and affordable mains energy, that the feed water is of a high concentration and that a relatively smaller quantity of feed water is required.

EN4 – This assumes that there is sufficient mains energy that the feed water is of a lower concentration and as such is ideal for the production of SWRO (sea water reverse osmosis) product water.

EN5 - This assumes that there is insufficient mains energy, but sufficient waste heat, that the feed water is of a high concentration and that a relatively lower quantity of product water is required.

EN6 - This assumes that there is insufficient mains energy, but sufficient waste heat, that the feed water is of a high concentration and that a large quantity of product water is required.

EN7 - This assumes that there is insufficient mains energy, sufficient waste heat and that the feed water is of a lower concentration.

EN8 - This assumes that there is insufficient mains energy, insufficient waste heat, that the feed water is of a high concentration and that a large quantity of product water is required. Energy requirements for this option are to be derived from renewable energy sources or fuel run generators.

EN9 - This assumes that there is insufficient mains energy, insufficient waste heat, that the feed water is of a high concentration and that a relatively lower quantity of product water is required. Energy requirements for this option are to be derived from renewable energy sources or fuel run generators.

EN10 – This assumes that there is insufficient mains energy, insufficient waste heat and that the feed water is of a lower concentration. Energy requirements for this option are to be derived from renewable energy sources or fuel run generators.

4.5 Deductions

There is no specific process that is more suitable than the other in all situations, and selection will be based on the availability of key production criteria as well as the expected deliverable of the process. Generally the costs for membrane plants tend to be lower than for distillation plants of similar capacity, but particularly for plants producing water of less than 300 to 400 kL/day where distillation is not financially feasible. Distillation is typically preferable for plants with higher product water capacity and particularly where a low cost, high quality waste heat source (i.e. from power plant or industrial process) is readily available. If the feed-water TDS is greater than 40,000 ppm and a low cost, high quality waste heat source is available, distillation processes are generally preferable.

Below is a tabular representation of the decision tree. Energy type has been excluded because all forms of energy apply to all the listed process.

Table 4: Decision Application Summary

Criteria	Sea Water RO	Multi Effect Distillation	Multi Stage Flash Distillation	Vapour Compression Distillation
Feed Water Salinity (TDS. PPM)	≤40,000	>>40,000	>>40,000	>>40,000
Product Water Salinity (TDS. PPM)	<200	<10	<10	<10
Minimum Product Water Volume	500L/Day	200kL/Day	200kL/Day	20kL/Day
% Recovery	≤ 40	40 – 65	40 - 65	≥ 50

Case Study One

Melkbosstrand is a coastal town in the western cape of RSA. It has an average population of approximately 5000 with annual rainfall of 375mm/year and low water availability. Water requirements exceed the available production and a higher quantity of production is required in order to meet growing demands. The town is located some 3kilometers from the coast and has a nuclear plant (Koeberg) with two 1800MW reactors producing 13, 668 GWh annually for the national grid. The saline conditions of the ocean water are approximately 40,000ppm and are prone to relatively high H_2S concentrations.

What desalination process can be used for the above situation?

- Higher quantity of fresh water is required than is currently available.
- Mains energy is available
- Waste heat is available
- Feed-water salinity is approximately 40,000ppm
- Product water quantity is above 200kL/day

Procedure: From the starting point continue down through the decision tree to the "Is mains energy available?" question, then follow "yes" path. Next "Is waste energy available?" question, then follow "yes" path. Next "Is feed-water TDS >40,000ppm?" question, then follow "yes" path. Next "Is water capacity >200kL/day?" question, then follow "yes" path.

Selection: By using the decision tree we arrive at the option [**EN6].** Multiple Effect Distillation with product quality less than 10ppm and product quality above 200kL/day at 40%-65% recovery.

Further Research Required:

- Feasibility of locating the desalination plant next to the nuclear plant in order to take advantage of the waste heat.
- The study of an environmental impact analysis on the area to establish the effect of brine disposal would aid identify a particular brine disposal method.
- Study special thermal conservation techniques that would ensure the recycling of waste heat from the desalination process as well.
- Product water storage and transportation methods should be explored as well as the methods for integrating desalination product water into existing supplies.
- Manpower requirements for the implementation and operation of the desalination plant in close proximity to a nuclear plant should be explored to ensure that the right labour force is available.

Case Study Two

Port Elizabeth is a coastal town in the eastern cape of RSA. It has an average population of approximately 1million with low annual rainfall. Water requirements exceed the available production and a higher quantity of production is required in order to meet growing demand. The town is located some 5 kilometers from the coast. The saline conditions of the ocean water are approximately 40,000ppm. The town does not have any significant sources of waste heat however the conservative use of mains energy is used for powering all production facilities in the area.

What desalination process can be used for the above situation?

- Higher quantity of fresh water is required than is currently available.
- Mains energy is available
- Waste heat is not available
- Feed-water salinity is approximately 40,000ppm
- Product water quantity is above 200kL/day

Procedure: From the starting point continue down through the decision tree to the "Is mains energy available?" question, then follow "yes" path. Next "Is waste energy available?" question, then follow "no" path. Next "Is feed-water TDS >40,000ppm?" question, then follow "no" path.

Selection: By using the decision tree we arrive at option [EN4]. Seawater Reverse Osmosis with product water quality less than 200ppm at 40%-65% recovery. The quantity of product water is flexible and has a wide range due to the modular nature of the process.

Further Research Required:

- The pretreatment requirements needed for preparing the feed water for desalination.
- The study of an environmental impact analysis on the area to establish the effect of brine disposal in the area would aid in identifying a particular brine disposal method.
- Product water storage and transportation methods should be explored as well as the methods for integrating desalination product water into existing supplies.
- Manpower requirements for the implementation and operation of the RO desalination plant should be explored to ensure that the right labour force is available.

Chapter 5: Conclusion and Recommendation

5.1 Findings

Thermal distillation systems account for the majority of the world's seawater desalination capacity, while membrane-based reverse osmosis systems (newer technology than distillation) are rapidly gaining ground due to their lower energy use and modular design.

Most distillation plants are located in the Middle East where low-cost energy is available and where these plants run in combination with electrical power stations (using low-pressure steam, discharged from the turbines, as energy source).

Technological advances in desalination processes has minimized the differences between thermal distillation and membrane process so much so that either of the two can be used for large scale fresh water production. In most cases, especially those in which there is an absence of significant waste heat, RO membrane treatment presents a viable option for the production of fresh water supply to supplement the existing water resources in RSA. Both capital and operating costs of RO plants have decreased significantly during the past two decades, making it an increasingly attractive option for coastal towns to supplement their drinking water supply.

5.2 Conclusions

The conclusions are linked to the aims and objectives in chapter 1.5.

- Presenting the value of desalination: The value of desalination is presented in the literature review in chapter 2.1 and 2.2.
- Presenting a comparative technological description of various desalination technologies: A comparative technological description of various desalination technologies is provided in chapter 2.3, 2.4, and 2.5.
- Indicating the factors to be considered in technology selection: Factors that influence technology selection were discussed in chapter 2.7 and 3.0.

- Develop a suitable desalination decision tree: a decision tree was developed in chapter 4 based on the relevant selection criteria adopted in chapter 2 and 3.
- Recommending a desalination technology best suited to the RSA environment: A recommendation if given in chapter 5.3

5.3 Recommendation

By using the decision tree in fig 11 it is apparent that in most situations the preferred technology for the desalination of seawater in RSA will be RO based. This is largely due to the relatively lower energy requirements vis à vis the affordable, but limited energy resources available within the country. In the South African context, thermal desalination processes would normally not be considered for desalination of seawater, unless sufficient waste heat or low cost fuels are available (e.g. in combination with nuclear power generation). This point is highlighted in 'case study one' above were thermal distillation is chosen in conjunction with waste heat from the Koeberg nuclear power station.

Therefore, considering the availability of electricity in South Africa and the typical capacity requirements of potential South African desalination plants, reverse osmosis (RO) would almost always be the process of choice.

From the research carried out, the following recommendations are made:

- Training and capacity building in desalination industry are essential for local staff mainly on Operations and Maintenance (O&M), and should be extendable to cope with any progress in the desalination market.
- Distillation experts should be contacted in cases where the municipal engineer is of the opinion that thermal desalination could be applicable.

- For small capacity plants (a few kL/day or less) located in remote areas, alternative technologies such as solar or wind powered desalination should be considered.
- Attention should be given to the effects of brine disposal on the environment and results should be communicated to the residents of the municipality.
- The semi arid climate of South Africa has a potential for wind energy that could be utilized for small-scale water desalination as an environmental friendly source of energy. Experimental wind power plant, funded by Eskom, is currently being tested in Klipheuwel.
- To make the RSA desalination industry more successful, DWAF should be engaged in a process of capacity building through the development of institutions that would actively engage in the improvement of international desalination technology and regulatory information.

5.4 Limitations of this research

Although this research was conducted with the sole aim of recommending desalination process suited to the South African environment several potential knowledge areas could not be covered in depth. Areas such as;

- the management and disposal of concentrate brine,
- the economic cost analysis of the recommended desalination process,
- as well as factors required for the operation and maintenance of the recommended process could not be highlighted.

These will, however, make for advancements of this research for those interested in pursuing this research further.

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