Desalination – An introduction

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Introduction:

'Water, water, every where,
Nor any drop to drink.' -Samuel Taylor Coleridge:
The Rime of the Ancient Mariner

These words encapsulate one of the biggest challenges facing mankind: a growing population experiences scarcity in fresh water supplies, yet 70 % of the earth's surface is covered by water in the form of oceans. This vast resource may be put to good use using modern technologies -at a price.

Purpose:

The purpose of this white paper is to introduce the reader to some of the desalination techniques available for water purification and consider their relative merits according to cost.

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Background:

As we journey into the 21st century, we are becoming increasingly aware that the planet on which we live constitutes a finely balanced environment, and that its resources must be carefully managed. For instance, only 3% of all water on earth is freshwater, while the worldwide demand for freshwater continues to increase in line with population growth, and the needs of industrial processes and agriculture.

Today, almost one fifth of the world's population lives in areas where fresh water is a physical scarcity. In these circumstances it is not practical or desirable to continue to exploit existing sources of freshwater such as lakes, rivers or underground aquifers, so we must look at other methods. For those living in coastal areas, one of these is desalination, which means removing impurities such as salt and other minerals from brackish water or seawater so that it is suitable for human consumption.

Desalination is one of many stages in the production of clean water. Other stages include raw water intake and treatment, post production permeate treatment and distribution, water quality control and brine discharge. Most of these will also apply to other sources of water. The process of desalination is, however, costly, and this cost must be borne in mind when comparing it to other methods of obtaining fresh water.

Desalination methods

Thermal Desalination.

The most widely occurring method of desalination is part of the natural cycle of water. The action of the sun on the salt seawater causes evaporation and subsequent condensation in the atmosphere results in precipitation of fresh water.

Ironically, mankind has been using this method for centuries -to manufacture salt!

To produce drinking water, thermal desalination uses excess heat to create water vapour from salt water. This heat source would typically be provided by an oil or coal-fired power plant.

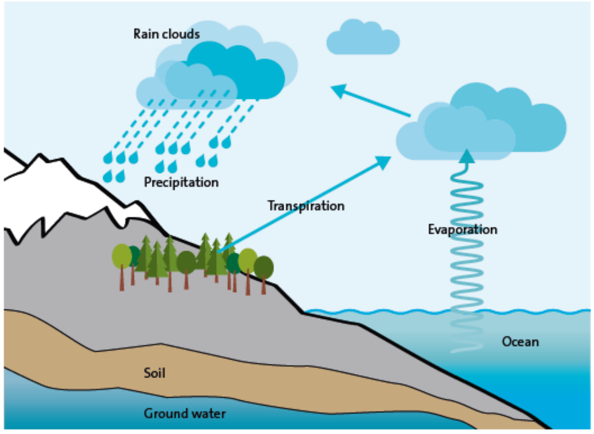

Figure 1 The natural cycle of water in the environment

Most thermal desalination plants in use today are in the Middle East, as the need for fresh water is increasing in line with growing populations, rising expectations of the middle class and increasing industrialisation - the cost of oil is also relatively low.

Broadly speaking, there are two types of thermal desalination: Multi-Stage Flash (MSF) desalination and Multiple Effect Desalination (MED).

Multi-Stage Flash

Multi-Stage Flash (MSF) desalination is the most common process for turning seawater into drinking water. The process uses the excess heat from big thermal power plants.

Typical capacity is from 200,000 to 800,000 m^3/day.

MSF distillation is based on condensing low-pressure steam as a heat source for the evaporation of seawater. It is still considered the simplest and most common technique in use. The technique is based on passing seawater through long, closed pipes passing through a series of flash chambers where hot seawater allows flashing along the bottom of the chambers. Vapour from the flash chambers heats the feed water flowing in the pipes. More heat is added in order to increase the temperature of the feed water to the initial high temperature, around 110 °C. This is done with the use of low pressure steam, usually taken from a back-pressure turbine in a power station. The vapour condenses on the heating pipes and is pumped out as product. Usually, the concentrated brine is recycled with the feed to improve recovery ratio. Part of it is pumped out to sea.

The energy that makes possible the evaporation is present in the brine as it leaves the heater. There is a good reason for letting the evaporation happen in multiple stages rather than a single stage at the lowest pressure and temperature. In a single stage, the feed water would only warm to an intermediate temperature between the inlet temperature and the heater, while much of the steam would not condense and the stage would not maintain the lowest pressure and temperature. Such plants can operate at 23-27 kWh/m^3 (approximately 90 MJ/m^3) of distilled water.

Because the colder salt water entering the process ‘counter flows’ with the saline wastewater/distilled water, relatively little heat energy leaves in the outflow; most of the heat is picked up by the colder saline water flowing toward the heater and the energy is recycled.

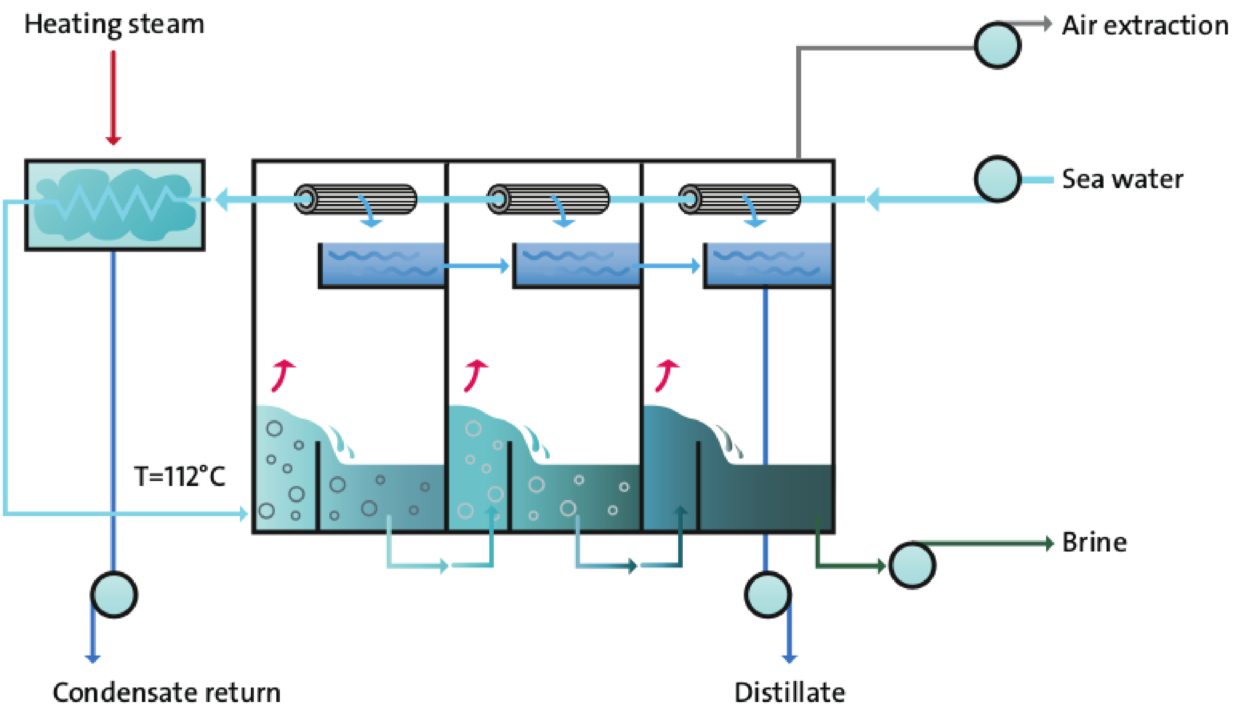

Figure 2 MSF desalination process

In addition, MSF distillation plants, especially large ones, are often paired with a power plant configuration. Waste heat from the power plant is used to heat the seawater, providing cooling for the power plant at the same time. This reduces the energy needed by half to two-thirds, which drastically alters the economics of the plant, since energy is by far the largest operating cost of MSF plants.

Multiple Effect Desalination

Multiple Effect Desalination (MED) is used in smaller sized thermal power plants or other plants with excess heat available.

Capacity is 2,000 to 200,000 m^3/day.

Consider the plant as a sequence of closed spaces separated by tube walls, with a heat source at one end and a heat sink at the other end.

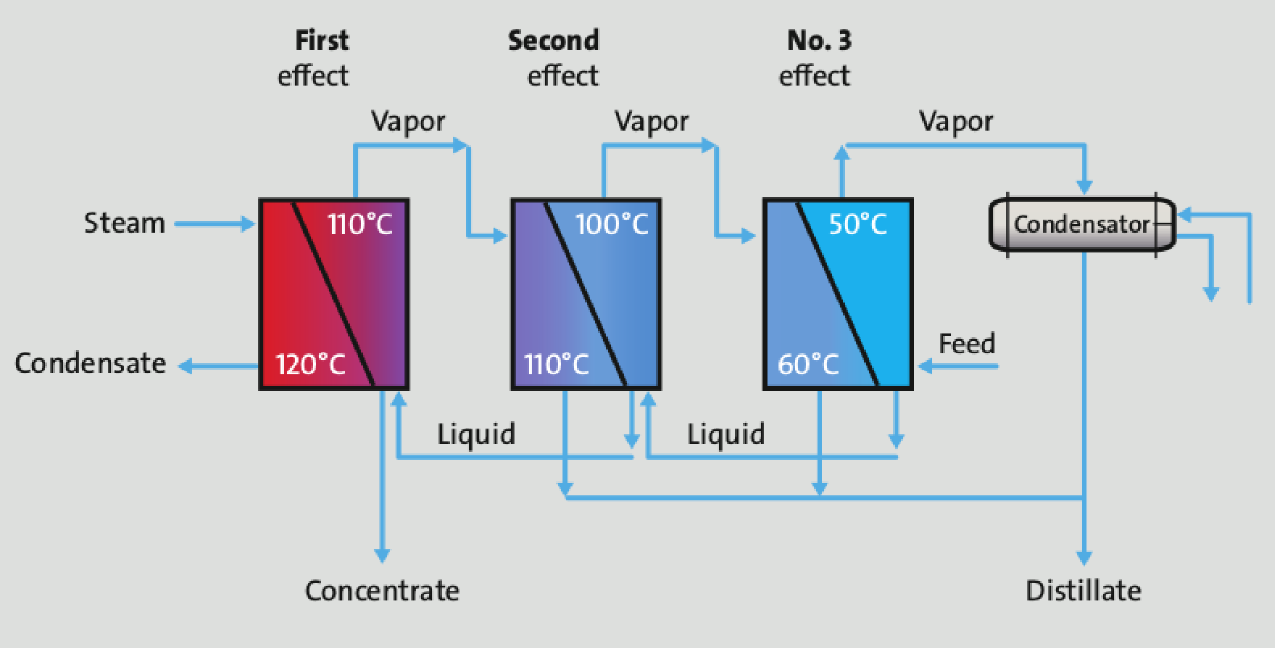

Figure 3 MED desalination process

Each space has a lower temperature and pressure than the previous space. If the pressure is too low or the temperature too high in the first subspace, the water evaporates. In the second subspace, the pressure is too high or the temperature too low and the vapour condenses. This carries evaporation energy from the warmer first subspace to the colder second subspace and so on.

As the name implies, thermal desalination requires the use of energy to cause the water to evaporate and condense. This makes the technology relatively. However, another option exists: Reverse Osmosis (RO).

Reverse Osmosis (RO)

RO uses high-pressure pumps to force the seawater through semipermeable membranes to separate the water molecules from the larger salt molecules. The membranes allow a permeate of water to pass through the system, while expelling the salt concentration as brine.
Osmosis is the natural tendency of water with a low concentration of total dissolved solids (TDS) to travel through a semi-permeable membrane into a solution of higher TDS in order to balance the solute levels on both sides of the membrane.

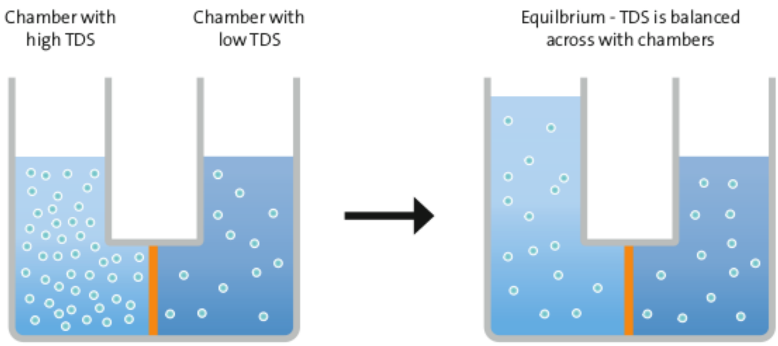

Figure 4 Osmotic process

The illustration above illustrates how the water molecules from the low TDS solution migrate through the semi-permeable membrane into the high TDS solution to equalise the concentration levels on both sides. As more water molecules travel through the membrane, the fluid level in each chamber changes. Once the TDS concentrations in both chambers have reached equilibrium, the osmotic process stops, as enough pressure has built up to stop the flow of water from one chamber to the other. This pressure is known as osmotic pressure.

Reverse Osmosis is a process where pressure greater than the natural osmotic pressure is applied on the high concentration side of the membrane, forcing the water to travel through the membrane from the higher TDS to lower TDS chamber, thus 'reversing' the natural tendency of water flow.

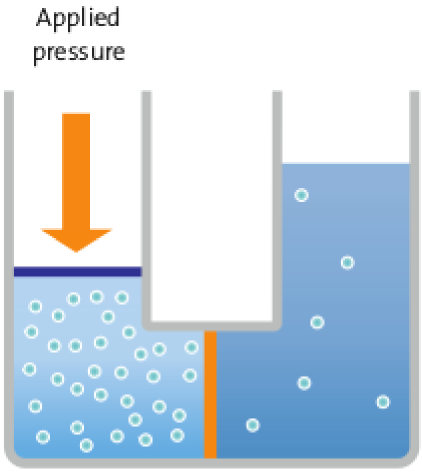

Figure 5 Reverse Osmosis

Reverse osmosis membranes used in desalination operate on this principle, to draw fresh water through a semi-permeable membrane from high TDS solutions such as seawater, brackish water, industrial effluent and other sources.

Clearly, the key to RO systems lies in the filter membrane and the way this is combined with the pump. The membrane is housed in what is called a spiral wound module. The spiral wound module is the dominant module available in the drinking water market, and the most widely used module type.

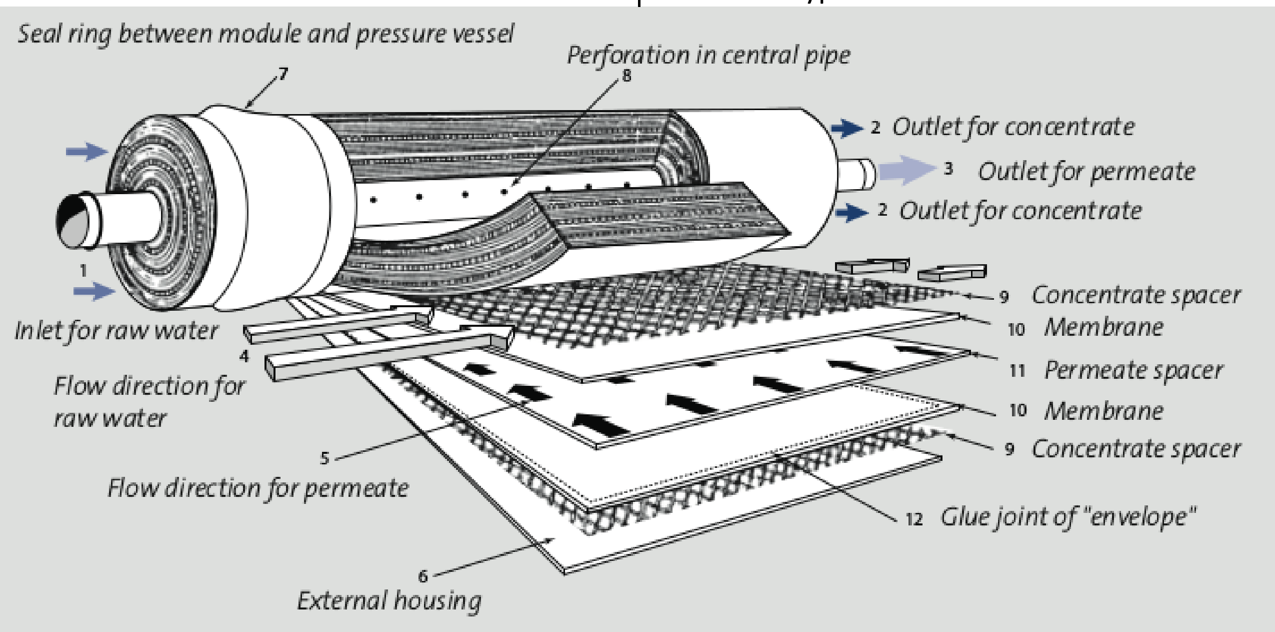

Figure 6 Reverse osmosis: Structure of a spiral wound module

The structure is substantially more complicated than other types. The filter consists of a large ‘envelope’, which is glued tightly together along three edges, with a porous mesh (the ‘letter’) inside, and with the actual membrane surface on the two external sides of the envelope. A mat, ‘spacer’, of open mesh is on top of the envelope. Another envelope and another mat then follow, and so on.

Each of the open ends of the envelope is glued to a perforated tube, the permeate tube, so that the openings are right against the rows of perforation. All the layers are then rolled up around the permeate tube, which now resembles a rolled carpet.

Finally, a tubular housing cover, the supporting sleeve, is placed around the whole ‘carpet’.

Figure 7 Typical RO installation

Modules are installed in series of up to seven in a pressure tube, known as the ‘pressure vessel’. This is crucial to ensure the modules withstand the often very high system pressure.

During operation, the raw water is directed into the end of the module and flows axially through the module through the above-mentioned spacers. The permeate penetrates the membranes and enters the spacers inside the ‘envelopes’, where it flows in a spiral until it reaches the central permeate pipe, from which the permeate can be drained at the ends.

Membrane cleaning

Reverse Osmosis membranes must be rinsed and chemically cleaned periodically, when stopped or when performance decreases by 10-15%.

Seawater flows tangentially along the membrane, creating a salt concentration gradient along the membrane's length, where the last element has the most concentrated brine bulk.

When the RO is stopped or in stand-by, natural osmosis will happen between the permeate side and the concentrate side containing high salinity brine. This can damage the feed spacers by creating a vacuum in the permeate line, as water will naturally flow back to the concentrate side, driven by osmotic pressure.

To avoid this natural damaging osmosis happening, seawater and brine are flushed off the membranes after service by permeate water taken from the permeate tank (before chlorination) and pushed in the membrane by a low pressure pump (i.e., feed pump, distribution pump or specific cleaning pump).

Membrane chemical cleaning

Seawater flows tangentially along the membrane, creating a boundary layer on the membrane surface.
The reverse osmosis membranes filter away everything but water molecules (Figure 8). Therefore, it is necessary to regulate the pH value and add essential minerals afterwards, for instance by letting let the water pass through limestone filters. Again, precise dosing systems and dosing pumps are essential to ensure the final product is perfectly safe to drink.

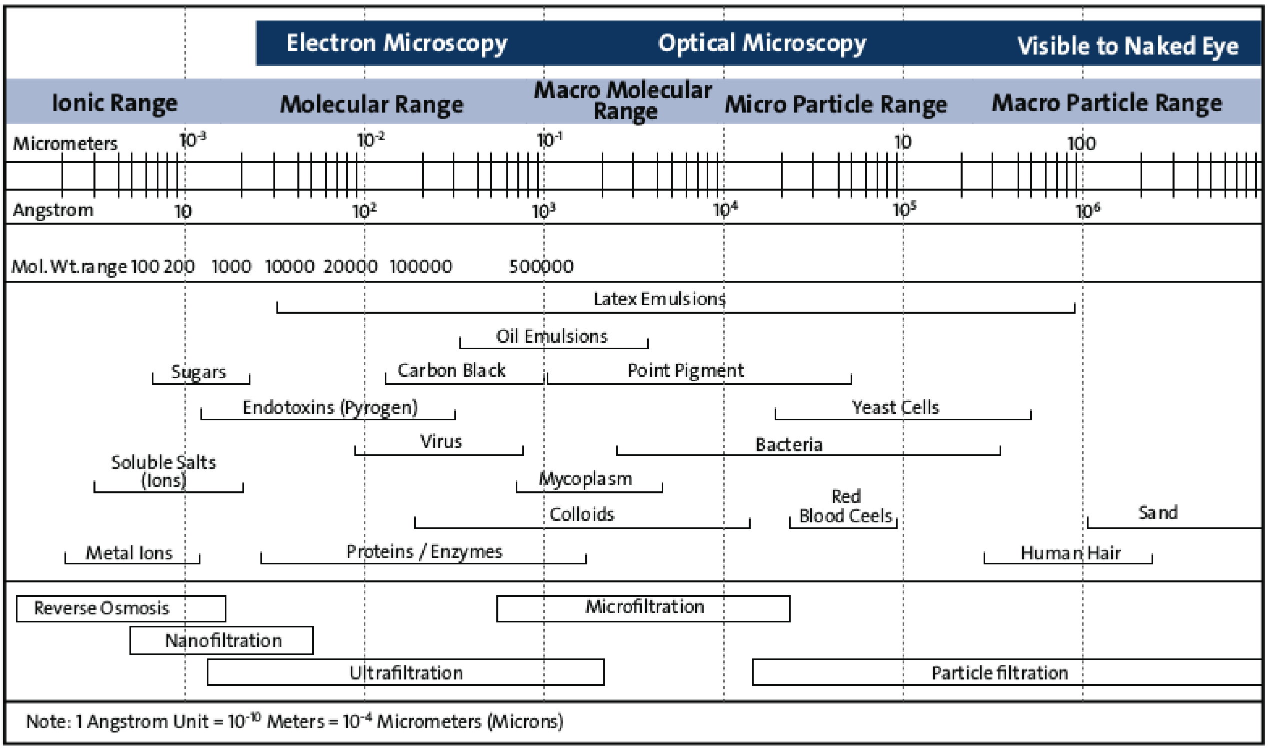

Figure 8 Filtration processes according to particle size

Conclusion:

This document is meant as a brief introduction to desalination. It is not possible in the scope of a white paper to consider all aspects of planning and implementing a desalination plant. The type of technology used in each case will depend to a large degree on the respective costs of energy, interest rates, and labour and associated civil engineering costs. Low power costs and high labour costs such as is typical in the USA, are not usually found in traditional seawater desalination areas. This combination of economic parameters will challenge plant designers to push desalination technology to its limits. We shall consider this, together with energy recovery, filter cleaning techniques and aspects of brine discharge and water treatment in another white paper on desalination.