Desalination for the Power Industry **(Applications, efficiencies and costs)**

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Why is desalination used in the power industry? A good question that firstly requires a quick review of water uses in the power industry for answering.

Water in the power industry is utilised in many ways, these include:

1. steam production for spinning turbines,
2. humidifying air flow into gas-turbines
3. inter-cooling air in gas-turbine plants,
4. steam injection for NOx control,
5. acting as a heat transfer medium in some nuclear plants,
6. condenser cooling in steam plants (coal, gas and nuclear fuel fired), and
7. plant maintenance, including blow-down, and hydraulic ash disposal.

The water quality for each use will vary according to the standards required for that application, and deviation from the required water quality will lead to loss of performance, possibly plant failure, and misery for operators, accountants, owners and the power users. The lack of suitable water will quickly lead to loss of power production and stakeholder and management misery.

The water quality application line:

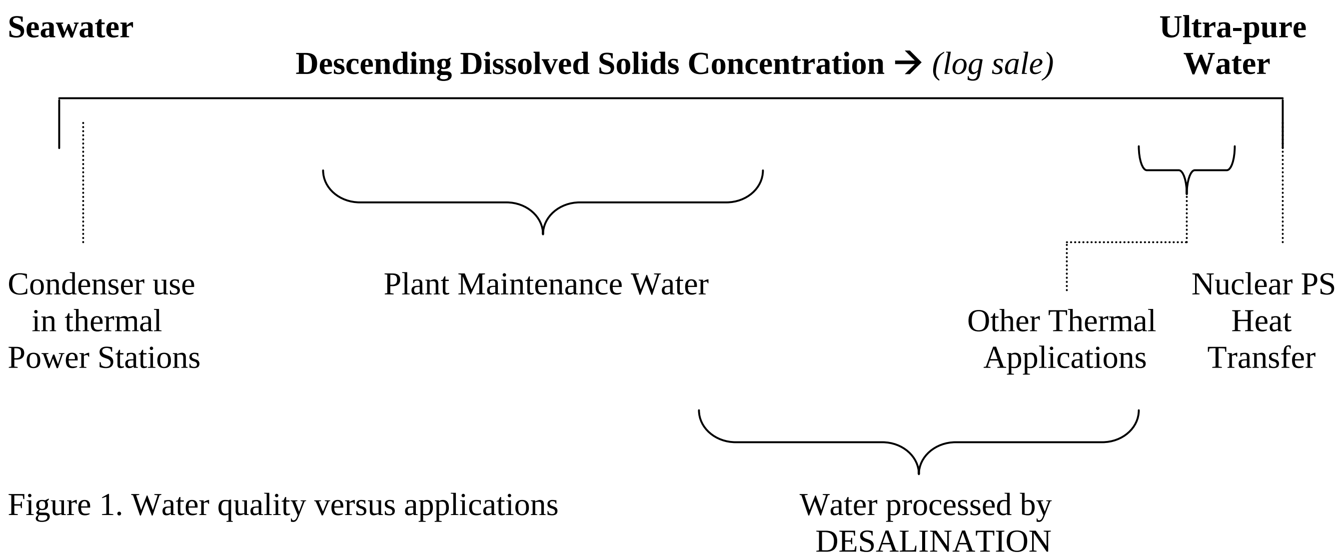


Figure 1. Water quality versus applications

Some water quality definitions:

- Seawater, around 35,000 ppm (mg/L), Total Dissolved Solids (TDS) plus Suspended Solids (SS)
  - Seawater for condenser cooling in steam plants, as above with screening of large SS.
- Ultra-pure water, <0.1 ppm (< 100 μg/L), NO suspended solids,
- Plant maintenance water, primarily water use for cleaning, say potable (<500 ppm TDS) to brackish, say 3000 ppm TDS, and low suspended solids, and
- Other thermal applications, say 1 -10 ppm TDS, and NO suspended solids.

Water Treatment versus Water Purification

Treatment systems include, filtration including ultra-filtration, chemical treatment to facilitate the precipitation of specific salts, and thermal treatment to facilitate the precipitation of specific salts. Filtration essentially gets rid of the suspended solids (SS), whilst chemical and thermal treatments will precipitate troublesome salts like iron, calcium and carbonate ions.

Purification systems – essentially meaning DESALINATION, include, membrane systems including reverse osmosis (RO), nano-filtration (NF) electro dialysis (ED) and electro dialysis reverse (EDR), plus thermal systems, such as multi-effect distillation (MED), multi-stage flash (MSF), and mechanical vapour (re) compression (MVC - MVR), and exotics including ion-exchange and freezing with salt expulsion.

Treatment Systems applicable to the Power Industry

The removal of fine particulates including precipitates is usually achieved filtration including micro-filtration and ultra-filtration. Ultra filtration can also remove living organisms and to some extent organic ‘goos’ such as polysaccharides derived from organic matter breakdown. Nano-filtration a recent extension of ultra-filtration can remove most organic compounds plus some salts and may be classed as a water purification technology.

Chemical treatment to facilitate the precipitation of specific salts such as iron is useful with some feed waters, whilst thermal treatment to facilitate the precipitation of specific salts such as those causing hardness has long been a tool of water treatment.

Water treatment that includes precipitate formation and thence filtration is usually a precursor to water purification - desalination. It in effect protects the desalination system from suspended solids and goos.

Water Purification (Desalination Systems) applicable to the Power Industry

The membrane system that has revolutionised desalination is Reverse Osmosis (RO). From being an energy expensive and high materials usage system, RO has become a very cost effective and reliable desalination system for brackish water and a reasonably cost effective and generally reliable desalination system for seawater. The reliability of recent Seawater RO (SWRO) systems has been most challenged by failures in pre-purification operations caused by biological/organic agents.

Thermal desalination systems are necessary for and complementary to the power industry in many situations. They can supply water for steam cycle use, gas turbine operation and plant maintenance. Distillation plants can be designed into power and water production complexes, with a portion of waste heat from power generation being used in such desalination systems as Multi Stage Flash (MSF) and Multi-Effect Distillation (MED). MSF is big plant and produces large quantities of water 20 – 50 ML/day, with the largest at 1000 ML/day. MED plant sizes range from 5 – 10 ML/day. Both systems consume large amounts of energy as heat and electricity.

Mechanical Vapour (Re) Compression (MVC) is the baby of the thermal desalination systems, with production units ranging from 0.1 – 3 ML/day. It generally uses straight electricity as energy, however some supplementation with heat energy is possible. The quality of water produced by thermal systems as measured by TDS can be less than 10 mg/L, with NO suspended solids.

The water quality of thermal desalination systems is determined by the ability of the plant to prevent the carryover of dissolved salts through spattering in the evaporation section of the plant. Clever demisting screens can reduce the splatter effect to produce an almost 'boiler ready' product, ie <10 mg/L TDS. The water quality of RO is dependant on the quality of the separating membranes, the plant operation (pressure applied to the feed, the effectiveness of the pre-processing and maintenance regime for the membranes), and the number of stages that water is passed through in the plants. In Figure 2, the first stage of an RO plant is shown as producing a 'very clean' 60 mg/L TDS but with only a 50% recovery of water. The second stage produces a product of 200 mg/L TDS, which would be considered a good potable urban water.

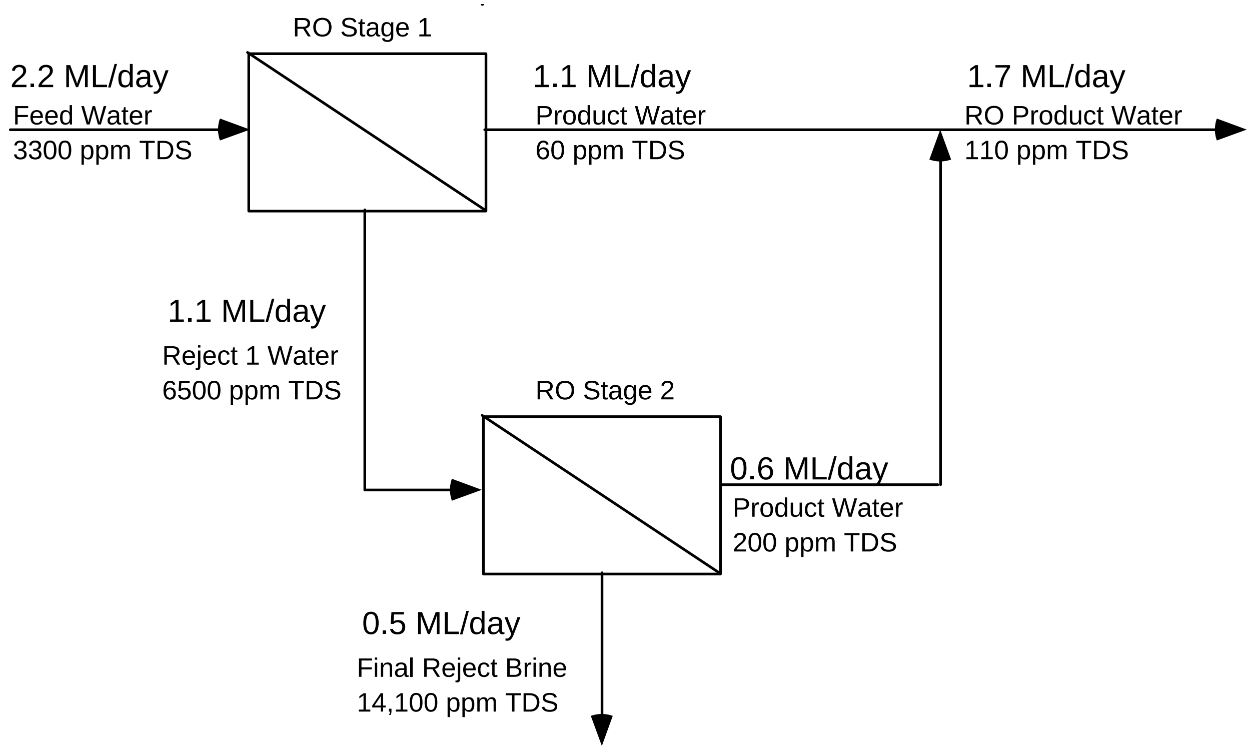


Figure 2. A Reverse Osmosis Flow Sheet for a Brackish Water Purification Application

Costs and benefits

RO wins by a country mile for producing purified water of 'average' quality at a 'good' price. For SWRO around 70% of the total cost of water is energy use(30%) and capital amortisation (40%). The remaining costs; membrane replacements, pre-treatment (filer cartridges), chemicals, labour and maintenance parts, together, amount to only around 30% of the total cost. For brackish water RO (BWRO) the figures are loaded more towards amortisation and consumables, with around 90% of the total cost of water being capital amortization (65%), pre-treatment (filer cartridges), chemicals, labour and maintenance parts (25%) and energy use (10%).

The cost of water from a SWRO plant and a BWRO plants are respectively ¢150/kL and ¢60/kL based on a 1700 ML/day, with $3.5m SWRO capex plant and $2m BWRO capex plant; but are these figures possible to achieve? Yes, so long as nothing goes wrong.

Table: Progress of Seawater RO Desalination Plants (1)

		1980s	1990s	2000s
Recovery	%	25	40-50	55-65
Operational pressure	MPa	6.9	8.25	9.7
Product water	TDS mg/L	500	300	< 200
Energy consumption	kWh/kL	12	5.5	4.6

1. Moch, Pre-prints of ADA Conference in Lake Tahoe (2000). Cited by Drioli, 2005

Industry Figures for 2006 are suggesting a SWRO energy consumption of < 2.5 kWh/kL.

SWRO Challenges and Risks

The TAMPA BAY 95,000 kL/day SWRO plant was the shining light of the US desalination industry. Conceived in the 1990s to provided a much need water security to Florida, built and commissioned 2002/3, failed hand-over trials late 2003, mothballed 2004, and looking for a ‘fix’ late 2006.

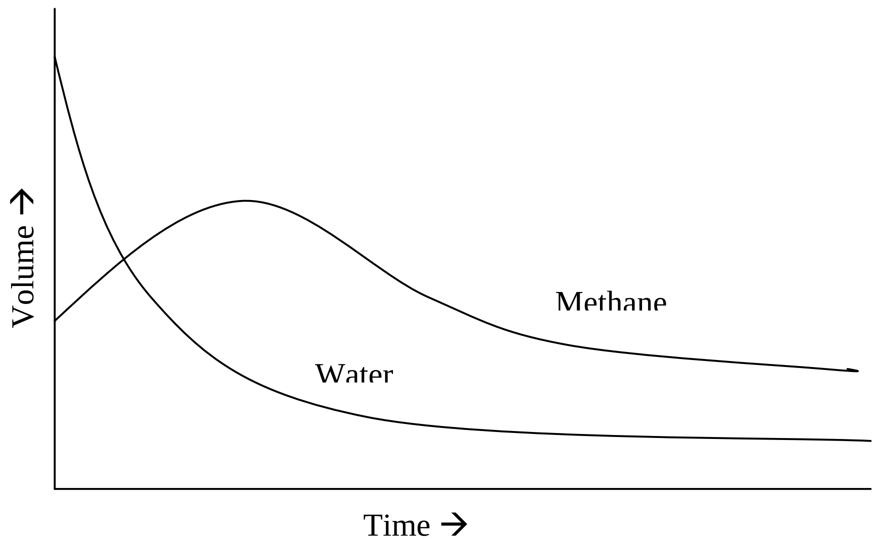
The primary hazard to SWRO has been failure of the pre-conditioning system through biological contaminants. In the case of Tampa Bay it was the growth of Asian Green Mussels on the inlets and fouling of the filtration cartridges. Tampa’s filtration cartridges were designed for a three month minimum life, but in the end only lasted days. The membranes were also challenged by organic goos, possible from the decay of fish eggs. Other SWRO plants have also had similar problems with water pre-treatment and occasionally membrane fouling.

The solution to these problems is firstly in the location of the SWRO plant. The avoidance of sewage and other high BOD water for the feed systems appears to be good sense. The use of ‘cool’ feed water is another location consideration. The provision of surplus capacity in the pre-treatment plant seems advisable, whilst basing plant economics on a worse case scenario for filter maintenance and replacement, chemical usage and membrane maintenance and replacement is advisable.

BWRO Opportunities in Queensland (and other Australia?)

During the late 1990’s and the last five years there has been the development of the Coal Seam Methane (CSM) industry in Queensland and to a lesser extent in New South Wales. By 2004 CSM accounted for greater than 25% of Queensland’s gas supply. The gas is clean (>98% methane), is distributed in the region of existing pipelines and is plentiful. Origin Energy a major player in the Queensland energy scene has stated that, ‘there is potentially more than 25,000 PJ of recoverable CSM in Queensland.’ That is a lot of gas to generate electricity in the Sunshine State.

Although natural gas and especially Australian CSM has excellent environmental credentials in terms of comparative greenhouse gas emissions from power generation, it does come with an environmental headache. The headache is co-produced saline water. The flows from individual gas wells vary from 16kL/day to 80kL/day, with examples from the Surat Basin being as high as 0.5 ML/day. The salinity content of the water varies from say 1000 mg/L TDS to 5000 mg/L TDS. The ‘salinity’ consists of a mixture of salts, with sodium being the predominant cation and either chlorine or bicarbonate being the predominant anion. (Where bicarbonate is the predominant anion the production of Sodium Bicarbonate could be a viable co-product from a desalination system, where salt fractional crystallisation was practiced.)



(Five years for individual wells, twenty years for a CSM development – Parsons Brinckerhoff, 2004)

Figure 3. Water versus CSM production (unscaled figure)

The Recovery and Utilisation of Coal Seam Methane Associated Water (CSMAW) in Power Generation

Water is required for thermal/gas fired power generation. In the case of Coal Seam Methane, water is produced during its extraction. To be used in power generation this water would usually need to be cleaned up. One option for such cleaning up is presented in the RO desalination scheme presented in Figure 2. Another is the use of Hybrid Desalination Systems, as shown in Figure 4 below.

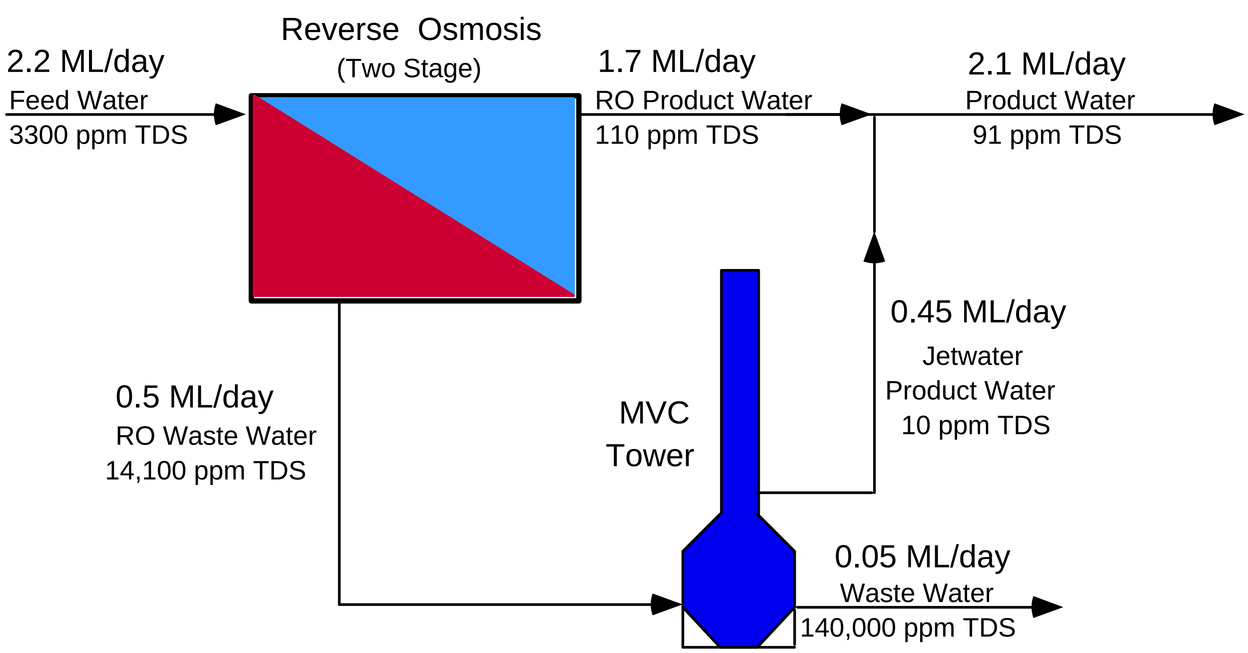


Figure 4. A hybrid desalination system.

In the hybrid desalination system, the major portion of the water recovery is achieved in the RO subsystem. The Mechanical Vapour Compressor desalination system is acting as a brine concentrator and a production unit for very pure water. For what purposes will CSMAW be used in power generation fuelled by CSM? These could include water for the steam cycle in a gas turbine combined cycle plant, for humidifying air going into the G/T, for NOx control, and plant maintenance.

But what of the question of final brine disposal? By using a hybrid system, the brine volume has been reduced from 0.5 ML/day to 0.05 ML/day, This brine could be solidified in smaller evaporation ponds or be re-injected into the gas bearing strata for residual CSM recovery enhancement. As previously mentioned, if the brine was rich in bicarbonate, a bicarbonate by-product may be possible.

Other Options: Would a Third Stage RO do the same job? Answer: Not completely and there would be serious risk of significant fouling from the deposition of sulphates etc, and membrane life could be seriously reduced.

Queensland (Australian) Specific Applications for Desalination in Power Generation – The Conclusion.

The list may include:

• Water for new thermal power plants for use in hybrid and parallel wet/dry cooling,
• Water for heat recovery from hot rock geothermal resources,
• The recovery and use coal seam methane associated water in local power generation, and
• Water for the conversion of open cycle gas turbine plants to combined cycle plants.

Each of the above applications will require a knowledge of the water requirements of the generation technology, the size, reliability and composition of the water resource and the Capex and Opex of the desalination system as part of the whole power generation operation.

Water availability will determine the viability of many proposed power projects. Schemes to desalinate seawater and brackish water, recycle sewage water, run power generation on reduced water loads (by dry cooling and dry ash management) all have a place in water strategies as applied to water management in the power industry.

The options will however come at a cost, a cost that will be passed on to power consumers. There will be operational (including energy conversion efficiencies and risk management) as well as environmental and economic considerations that will need to be considered.

Good Water Management in Power Generation is a necessity of the modern power generation industry.

Desalination will have a part to play in many new and rehabilitated power generation projects.

Glossary of Terms

BWRO	Brackish Water Reverse Osmosis
CSM	Coal Seam Methane
CSMAW	Coal Seam Methane Associated Water
ED & EDR	Electro dialysis and electro dialysis reverse
G/T	Gas Turbine
kL/day	Kilolitres per Day
MED	Multi-effect distillation
µg/L	Micrograms per Litre
mg/L	Milligrams per Litre (=ppm)
ML/day	Megalitres per Day
MSF	Multi-stage flash
MVC – MVR	Mechanical vapour (re) compression
NF	Nano-filtration
NOx	Nitric Oxides
PJ	Peta Joules
RO	Reverse Osmosis
SS	Suspended Solids
SWRO	Seawater Reverse Osmosis
TDS	Total Dissolved Solids

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