Potential for thermal desalination in Texas

John Tonner[1]

Abstract

Thermal desalination covers a wide range of processes which have a history dating from the 19th century. Thermal desalination is most widely used in the Arabian Gulf which has led some to presume that only oil rich nations can afford a process which appears thermodynamically inefficient. The reality is that an integrated power plant and distillation process (as in the Middle East) has higher energy efficiency than achieved when generating electricity and desalting seawater separately. In some cases the energy improvement can be 10-20% better. Seawater reverse-osmosis (SWRO) is often the lowest cost method of desalting seawater in a stand-alone process, especially for low salinity waters. When thermal processes are integrated with heat from power generation (or elsewhere) the total water cost can be very low, even lower than SWRO.

This paper will outline the techniques used to achieve successful thermal desalination and give examples of cogeneration integrated into power generation and waste heat sources.

Approximately one-half of the world's installed desalination capacity is produced by distillation. From a practical point of view, distillation is usually employed only on seawater sources, although smaller, specialized distillation units are used to concentrate wastewaters and in zero liquid discharge systems.

Thermal desalination covers a wide range of processes that have a history dating from the 19th century. The oldest designs utilized simple stills that were both inefficient and troublesome to operate for sustained periods. While there are many different thermal processes the most widely used is multi-stage flash (MSF), which was developed in the 1950s.

[1] Water Consultants International

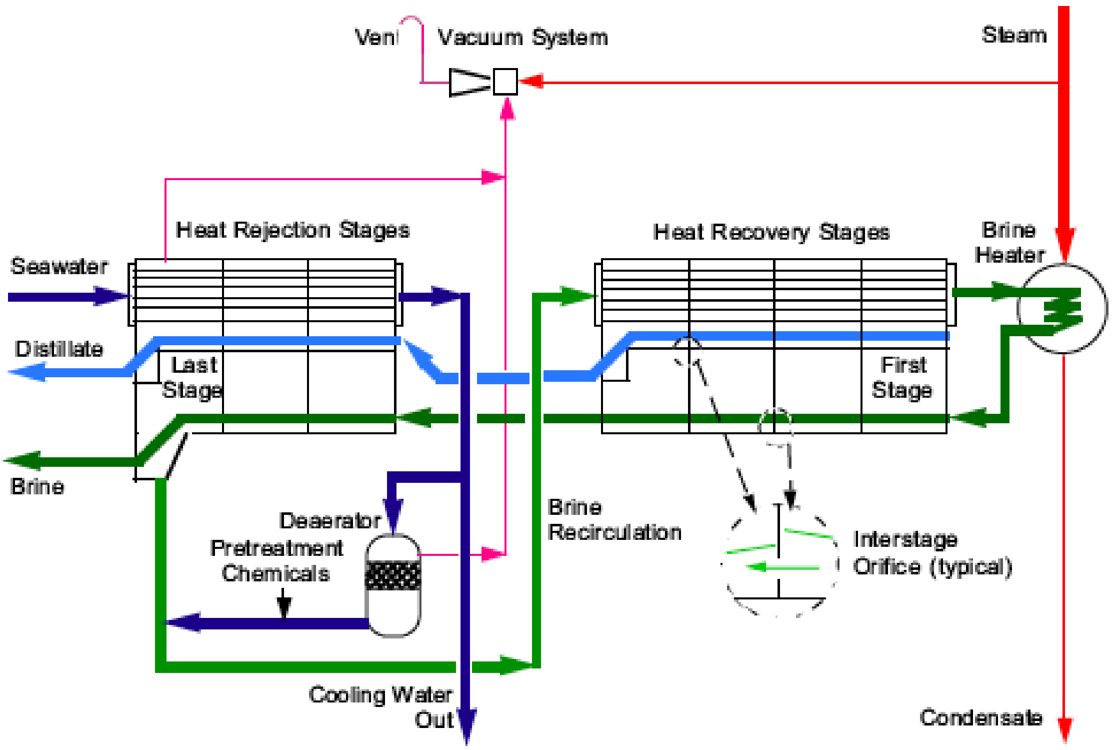

Figure 1 Multistage flash with brine recirculation

The MSF process quickly established itself as a reliable process that can provide sustained water production in multi-million gallon capacities. Furthermore the MSF process lent itself to integration with low-grade heat from power generation and operated with energy efficiency an order of magnitude better than simple stills. Today's MSF plants produce up to 15 million gallons per day (per unit) with thermodynamic efficiencies higher than achieved in other processing industries.

Figure 2 illustrates a single MSF unit that can produce approximately 12 million US gallons per day (MGD) of distilled water. The unit is one of six that was installed as a project for a facility which has over 212 MGD of MSF capacity (plus an additional 63 MGD of MED-TC (Multiple Effect Distillation with ThermoCompression) and planned expansion with other processes). The first phase of this massive project started operation in 1990. This type of project is not unusual or uncommon in many countries. These projects are both public owned and private sector.

Figure 2 Multistage flash distillation in Abu Dhabi Emirate

The 1980s saw the revitalization of multiple effect distillation (MED) in a new configuration that yielded lower capital and operating costs than MSF, while producing the same high quality distilled water. MED systems can now be provided with unit capacities up to 8 million gallons per day.

To date this type of MED, often called MED-TC or TVC (thermal vapor compression), has mostly been configured in a manner to replace aging MSF units. This leads to expensive additional equipment being required (namely a steam transformer) which otherwise would not be utilized; despite this the MED process generally has lower capital (CAPEX) and operating (OPEX) costs than MSF.

The following diagram (figure 3) and picture (figure 4) represent one of the world's largest MED units that can produce over 5 MGD of water. MED units of multi-MGD capacity have now been operational for over 15 years. Since most MED systems are designed to replace aging MSF systems (and fit into existing power plant heat and mass balances) the thermal performance of the systems is generally the same.

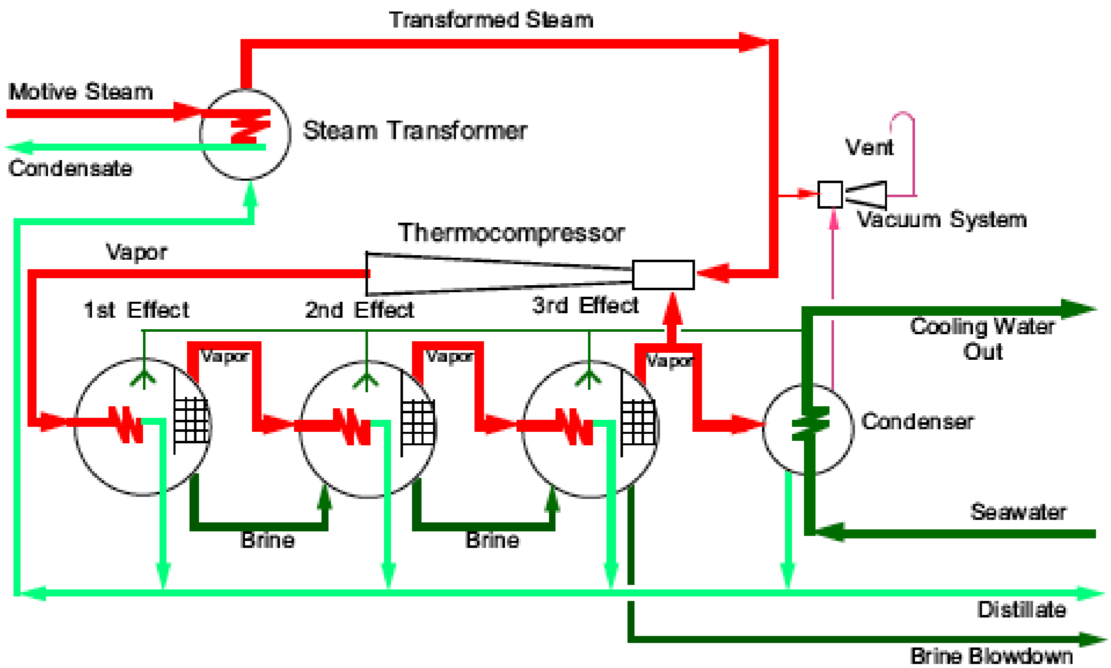

Figure 3 Diagram of multiple effect evaporation with thermal vapor compression

Thermal desalination is most widely used in the Arabian Gulf, leading some to presume that only oil rich nations can afford a process that appears thermodynamically inefficient (compared with seawater reverse osmosis, SWRO). The reality is that an integrated power plant and distillation process (as used in the Middle East) has higher energy efficiency than when generating electricity and desalting seawater separately. In some cases the energy improvement can be 10-20% better.

SWRO is often the lowest cost method of desalting seawater in a stand-alone process, especially for low salinity waters. However, when thermal processes are integrated with heat from power generation (or elsewhere) the total water cost can be very low, even lower than SWRO. Thermal processes can more readily accommodate highly saline feedwaters (than can membrane processes), which is another reason thermal desalination has a significant market share in the Middle East.

Figure 4 Single MED-TC unit in Sharjah Emirate

Refineries, similar petrochemical facilities, and factories often require water that exceeds potable standards and may also have large quantities of waste heat available. Many such facilities in the Caribbean, Middle East and Asia utilize thermal desalination driven by the waste heat to produce high quality distilled water to meet their internal demand.

Thermal processes are, in general, insensitive to changes in temperature, salinity, and organic activity which can be troublesome for membrane processes. While the capital cost for distillation is always higher than for membranes processes, the total cost of water produced by thermal process can be competitive when properly integrated with available energy sources and matched to demand for appropriate water quality.

The thermal performance or efficiency of distillers is most frequently referred to as Gained Output Ratio (GOR). The GOR is defined as the ratio (in terms of mass flow rate) of distilled water produced from steam consumed by the process. A variation of GOR is the Performance Ratio (PR), which measures the water production per unit of energy consumed. In US customary units, PR is expressed as pounds of water produced per 1000 BTU of heat consumed. In the metric system PR is kilograms of water per 2326 kilo-Joules of heat. Thankfully PR is both metric and US units is the same numeric value which is also, mercifully, essentially the same as GOR in mass terms. For simplicity and in consideration of the fact that heat is often provided in steam form GOR is used in the following discussion.

Typical values for GOR can range from as low as 1:1 to as high as 17:1. Generally CAPEX increases as desired GOR is increased. Since a higher GOR means a lower heat consumption and OPEX, an optimal solution exists for a given set of conditions. The cost of capital and prevailing value of energy should vary from project to project, especially when waste or recovered energy is used as a driving force for the process.

Each project will yield a different optimum GOR point. For projects with low value waste heat, the optimal GOR will shift toward the left tending towards a GOR of 1:1. Examples of such applications include desalination integrated with Methanol production and Liquid Natural Gas processing which typically have optimized GORs of between 3:1 and 4.5:1.

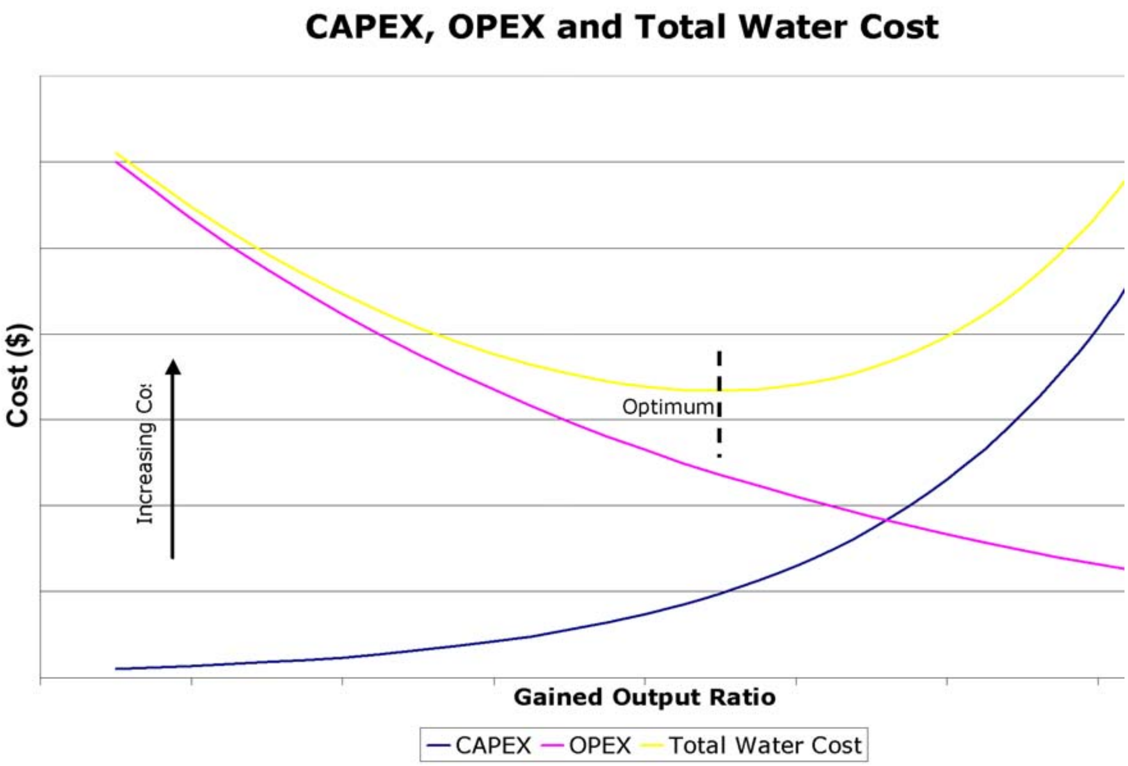

Figure 5 Capital, operational, and total water costs

Dual purpose power and water facilities in the Middle East generally have GOR values of between 7.5:1 and 8.5:1. This represents a relatively low fuel value, but also a high demand for water. In the Caribbean energy values are among the highest in the world and consequently so are GORs, with values as high as 10:1 - 15:1 being used for some designs in the region.

Seawater desalination to meet municipal water requirements is a current news subject in the USA today with active project development in California and Florida in addition to Texas. While co-locating the desalination plants with power generating facilities is a common topic, the processes discussed are exclusively SWRO. This is driven in part by the fact that a thermal desalination process cannot easily or effectively be retrofitted to an existing power plant; the integration really needs to be planned for a green field project. A second factor was alluded to earlier. Even though co-generation using thermal desalination is significantly more efficient (than power or water production alone) the number of kilowatt hours produced from each BTU[2] of fuel is lower. The measure of kWh per BTU is known as the "heat rate" and is a significant factor in the ability

[2] BTU = British Thermal Unit, a measurement of the calorific value of fuel. The term is only commonly used only in the USA. The International equivalent of BTU is Giga-Joule, (GJ).

of a generator to sell power into the grid. Existing policy, legislation, and practice have some impact on the competitiveness and utilization of distillation processes.

Industrial utilization of distillation is not subject to the regulation or practices of the power industry. There are many sources of heat that are co-located with a demand for high quality water that often must exceed drinking water requirements. Outside the continental USA there are many examples of this type of industrial waste heat utilization especially in the petro-chemical and mining industries. Most typically the demand for water and the heat available in these applications are less than the more widely known power based systems. The amount of water which can be produced from industrial heat sources can exceed multi-million gallons per day. The water production can exceed the captive water needs of the industrial facility. External consumption of this water requires integration with regional water plans: currently a missing link in most locations.

One example of this type of integration is a coke calcining facility for a Middle Eastern aluminum smelter. The calcining process produces large quantities of waste heat which is completely utilized in a multiple effect desalination system. The MED process produces water for the calcining plant and also for blending with other municipal supplies. In this region, use of distillation processes has allowed the utilization of raw sources which would otherwise be too brackish and also permits higher salinity permeate from RO plants to be economically produced and then blended with distillate..   The coke calcining desalination facility produces over 11 MGD and has operated since 2000.

Figure 6 Coke calcining facility for aluminum smelter

Figure 7 Solid waste incinerator, Netherlands

Another growing application is the utilization of heat from solid waste incineration. One of the first such installations is in the Netherlands. The facility pictured to the left produces 6 MGD using heat solely from garbage. It has been operating since 1999.   This concept has also been considered for dual purpose use focused on garbage disposal and fresh water production. Several such projects are in the development stage overseas.

Decentralized power generation is also an ideal candidate for waste heat driven desalination. Heat from marine diesel propulsion engines produces over 750 MGD of water in merchant, commercial marine and cruise vessels around the world. These same engines are now being used for decentralized power generation on land in capacities suitable for captive industrial generation or for small communities. As an example cruise ships typically produce around 1 MGD of distilled water using engine waste heat. The expansion of the decentralized power industry, including the adoption of microturbines and fuel cell technology yields more opportunity to co-generate water.

Thermal desalination units producing approximately 2 MGD have been integrated into US owned plastic fiber manufacturing plants in Asia. Waste heat from process columns is successfully directed to MSF desalination units to provide heat rejection from the chemical plant while simultaneously producing boiler feedwater quality distillate for in-house consumption.

Some processes simply produce heat as a by-product in what is known as an exothermic reaction. For example, in the production of sulphuric acid, when the acid is diluted (with fresh water) it releases dilution heat. This heat can be used to produce the water required for dilution. Several locations around the world are looking at this very option because the mining industry, which uses the acid, is often located in arid coastal plains. Other exothermic reactions can be identified in the petrochemical industry with either in-house demand for the produced fresh water or adjacent industrial or municipal clients.

Thermal processes can provide additional benefits as part of a complete water plan. The high quality distilled water can have a tremendous impact on the ability to blend and improve other sources of water. This can extend to improving other desalination processes such as SWRO; the RO plant can be economically designed to produce permeate with higher dissolved solids which can be blended with the distilled water (figure 8). Integrating thermal and membrane processes in a hybrid design also yields operational efficiency improvements.

It is not always possible to consider and design for constant base load water demand or production. In situations with varying power and water demand curves the most common operating load is often far from optimal. Hybrid systems are now being adopted to compensate for changes in the demand curve, which are particularly difficult to accommodate for electricity that cannot readily be stored. In a hybrid desalination facility, RO production can be increased at times of low grid power demand with the linked benefit of increasing heat flow to the distillers and increasing overall operational efficiency and economics. At times of peak grid demand RO production can be slightly produced. This hybridization improves the efficiency and costs of the average operating condition.

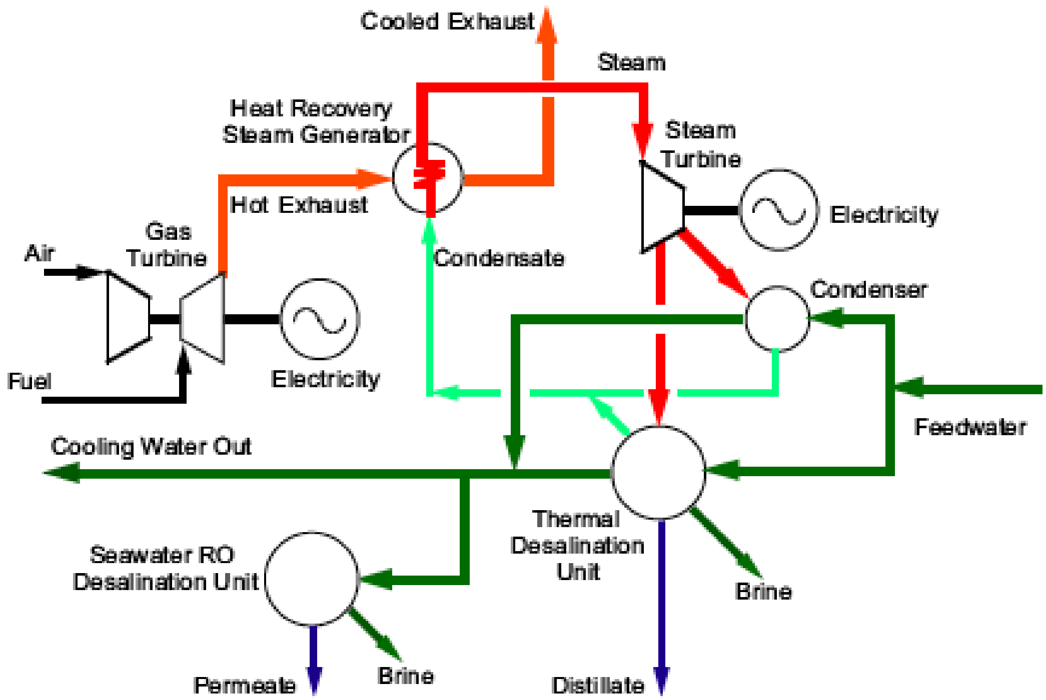

Figure 8 Cogeneration of power and water using combined power cycles and hybrid desalination.

Figure 9 - World's largest hybrid - 78 mgd multi-stage flow and 45 mgd seawater reverse-osmosis [Photo courtesy of Doosan]

Large scale thermal desalination facilities with capacities in excess of 50 million gallons per day have successful operating records now measured in decades. These and smaller thermal facilities differ from RO desalination facilities because they are integrated into a heat source from some other process. This integration does add a level of complexity but leads to rewards associated with robust technology proven capable of producing massive quantities of distilled water under utility load conditions for many years.

There are obviously many locations along the Texas coast where these techniques could be applied to existing industrial facilities. With appropriate planning and regulatory oversight it is also possible to utilize large scale dual-purpose hybrid configurations for new power plants. Thermal desalination processes are robust pieces of process equipment that operate effectively and economically using technology that is macroscopic in nature; the components of the process can be inspected with the naked eye. This is an advantage over processes that work at a microscopic level, but to recognize and achieve the advantage of that simplicity requires more complex integration of separate industrial processes be considered.

All photos and diagrams are courtesy of desalination.com unless otherwise noted.