The importance of energy recovery devices in reverse osmosis desalination

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Abstract

This paper addresses the purpose and priorities that should be taken into account during the design of a 25 million gallons per day (mgd) seawater reverse osmosis desalination plant in order to obtain reliable and low cost water supply. This focus of this presentation is on the energy recovery aspect of plant design.

This discussion relies on a sample energy tariff for Large Industry Service (LIS) from a Texas power supplier. This rate category is applicable to power demands in excess of 10,000 kW. The seawater reverse-osmosis (RO) desalination plant has to be at least of a 25 mgd capacity to be a power consumer above 10,000 kW and benefit from the LIS rate in the sample tariff. This LIS tariff can contribute to low water cost production only if the power demand will be kept even during all year. The water consumption and seawater temperature changes throughout the year, which makes it difficult to maintain an even power demand. This consideration has to be foreseen by the water purchaser during tender preparation for the desalination plant. And even if the water production is well balanced with the natural changes in the seawater temperature, the desalination process itself involves peak loads such as start and stop of power demanding equipment for backwashing, cleaning, flushing and maintenance. A well designed plant has to be able to change its operation parameters in such way that overall power demand will be kept even with no peaks.

The role of the energy recovery system is important to fulfill these requirements. Some technological schemes are able to precisely follow the maximum demand limits, some will operate at peaks. The type of energy recovery devise will depended on power cost, interest rate, and loan period. Energetically effective but expensive DWEER or ERI systems are not favored in conditions where the energy cost is low, the interest is rate high, and the loan period is short. The type of energy recovery devise will also depend on brine discharge condition. The DWEER or ERI systems are able to keep enough back pressure for brine discharge over long distances, whereas Pelton turbines create a foamy stream that has to be evacuated by gravity or re-pumped.

The relation between energy cost, interest rate, labor cost, and civil engineering cost will determinate the plant recovery, membrane flux, and even water velocity in pipelines. Low power cost, will challenging plant designers to push the desalination technology to borderline. The tender requirements have to put limits on several technological parameters such as: maximum recovery, flux, and velocity to have a reliable water supply.

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Desalination Plant Power Demand in Conjunction with Regional Power Demand Infrastructure

This discussion relies on a sample energy tariff from a Texas power supplier. The tariff includes a Large Industry Service (LIS) rate category applicable for power demands in excess of 10,000 kW. The seawater reverse-osmosis (RO) desalination plant has to be at least of a 25 mgd capacity to be a power consumer above 10,000 kW and benefit from the LIS rate in the sample tariff. This large power consumer has to be well integrated into the region's energy system. The desalination plant is able to maintain an even power demand during the year or, on the contrary, be designed to change its demand and, for example, take advantage of the low load in the region's energy system during night hours. This can be achieved by designing the desalination plant to produce more water during the night hours with specifically higher power consumption and decreasing water production and specific power consumption during power demand peak hours.

A further alternative for maintaining an even power demand from the power supplier's point of view is the association of the desalination plant with another large power consumer that is not able to maintain an even power demand due to its technological process. By designing the desalination plant to "fill in" the other large consumer's low power requirement times with its peak times, the two enterprises together can maintain an even power demand over time and benefit from lower power costs.

Low water costs can be achieved by synchronization of the seasonal water supply with the natural changes in the seawater temperature. The specific power consumption is higher during the low temperature season; it is thus mutually beneficial to both producers and consumers of water to produce more water in the summer and less in the winter. Although this is a well-known fact, in practice the right relationship between the seawater temperature and the amount of water to be supplied is rarely reflected in the tender book. The right relationship will enable maintain of an even power demand during the entire year.

The desalination process itself involves peak loads such as the starting and stopping of power-demanding equipment for backwashing, cleaning, flushing and maintenance. A well designed system balances these peaks against lower load requirements and maintains an even power demand.

Leveling the Power Demand

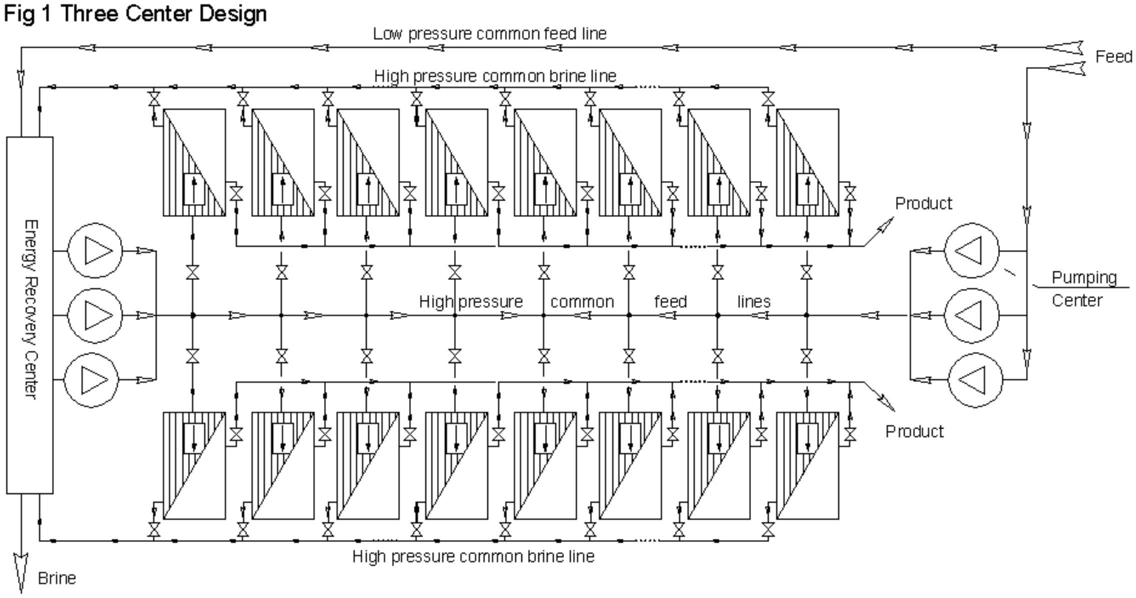
Not every desalination plant design is flexible in maintaining an even level of power demand, nor is all equipment suitable for maintaining a constant level of power demand. The key to low cost water production is the optimal combination of design and suitable equipment.

The conventional design of standard plants, with each RO train comprised of the RO membrane bank with its opposite pump and turbine, also does not lend itself to keeping an even level of power demand. The starting and stopping of individual RO trains causes power demand peaks and is not an effective way of leveling the power demand.

The traditionally designed RO train, where the high pressure pump is located on the same shaft as the Pelton turbine, does not allow this broad range of changes between the pump flow and the brine flow. For small and medium size desalination plants, this scheme is compact, simple and effective. For large desalination plants the benefits of power savings and plant availability outweigh those of compaction and simplicity, making the three center design, with its separation of the pump from the energy recovery system (ERS) and its ability to independently change the pump and brine flow across a broad range, a more attractive solution.

The Three Center Design (TCD) is a centralized pump and energy recovery system. It – comprises a pump center, a membrane center and an energy recovery center. The TCD has the flexibility required to change water production and power demand in a smooth and effective way, without harming the desalination equipment. This centralized pump and energy recovery system, together with small membrane banks, is an effective solution for large desalination plants.

Fig 1 Three Center Design



The system's ability to level the power demand is related to the ability of the Energy Recovery System (ERS) to change the brine flow smoothly, across a broad range of flows, without changing the high pressure pump flow and losing pumping efficiency. The best way to achieve this is to mechanically separate the energy recovery system from the pump system. This allows the change in flow without having to stop and start equipment, which, as previously mentioned, causes peaks in power demand.

In large desalination plants, the energy recovery centers can be based on several Pelton turbines connected to an electro-generator, or the DWEER and ERI systems which can operate independently of the high pressure (HP) pumps.

Large Pumps mean High Efficiency, Low Cost, Flexible Operation

A large scale desalination plant allows the implementation of large size pumping equipment. There are a number of benefits to a few large pumps pumping high pressure seawater for a number of relatively small RO membrane banks.

Let us consider the desalination plant in Ashkelon, Israel, as an example. The total capacity of the plant is 88 mgd, divided into two plants each producing 44 mgd. Instead of sixteen high pressure pumps per plant, there are only three pumps in operation and one stand-by pump in each plant. The efficiency of the large pumps is five percent higher than that of the small pumps, with significantly lower specific cost. A further advantage is related to the stand-by pump. With one stand-by pump installed for all the RO trains this also avoids the need for the extremely expensive piping and valves system that is required when having a stand-by pump and turbine connected to sixteen trains. This increases the high availability – low cost aspect of the plant.

The relationship between pressure and flow is an important factor in pump efficiency and mechanical simplicity. The pressure is the same in all cases as it depends on the salinity of the water, but the flow of any one pump can be selected.

As well as higher efficiency at lower specific cost, larger pumps have a simpler mechanical design. If we consider the traditional design, each of the sixteen pumps has four impellers, whereas each large pump has only two impellers. In order to be efficient and simple, the centrifugal high pressure pumps have to be high flow pumps. If the pump flow is big enough, the pump can be manufactured with one large diameter impeller and efficiency theoretically can reach 95 percent. This scenario indicates the direction in which desalination will progress in the future: large pumps not joined together on the same shaft as the ERS, and a number of small RO banks.

Large Reverse Osmosis banks - Low Plant Availability

According to the traditional design in the desalination industry, each HP pump works with its own RO membrane bank and ERS. This unit comprised of the pump, membrane bank and ERS is called the RO train. As desalination plants have increased in size, it has become necessary to increase the size of the RO trains. However, where the enlargement is beneficial for the pumps, it is detrimental to the membrane bank, resulting in a conflict in the relationship between the pump flow and the membrane bank feed flow.

Large size membrane banks have low availability and long down-time.

Let us assume that a 25 mgd plant will include 1080 pressure vessels, with seven membranes per vessel. This makes a total of 7560 membranes, an equal number of plastic interconnections and twice the number of O-rings operating in the desalination plant. More than thirty thousand plastic and rubber elements will operate under high pressure. For the period of their operation, all these components move and twist during start and stop of the membrane bank, temperature changes and maintenance activity. Although each of these thirty thousand components is well-designed and well-made and can operate non-stop, without failing, for twenty five years; statistically, every day, the membrane bank will have 3.3 stoppages for replacement of one failed O-ring, membrane or interconnector. Usually three hours are required for this type of repair. Depending on the number of pressure vessels in the train, the plant availability will be significantly affected due to the fact that one O-ring replacement will stop the entire RO bank. In a large RO bank 540 pressure vessels will be stopped for three hours whereas in a small RO bank, the same O-ring replacement will stop only 54 pressure vessels.

Number of pressure vessels per RO bank.	Number of RO membrane banks per Plant	Total stop cases per plant of 25 mgd per day	Down time of Pressure Vessels-hours per day	RO banks availability
54	20	3.3	538	98%
108	10	3.3	1076	96%
216	5	3.3	2151	92%
540	2	3.3	5378	79%

Simple division of a large RO bank into smaller blocks by means of disconnecting valves will not solve the problem, as every RO block has to have its surrounding system of piping and valves to perform the direct osmosis process during stoppage, membrane flushing, cleaning, filling, and draining.

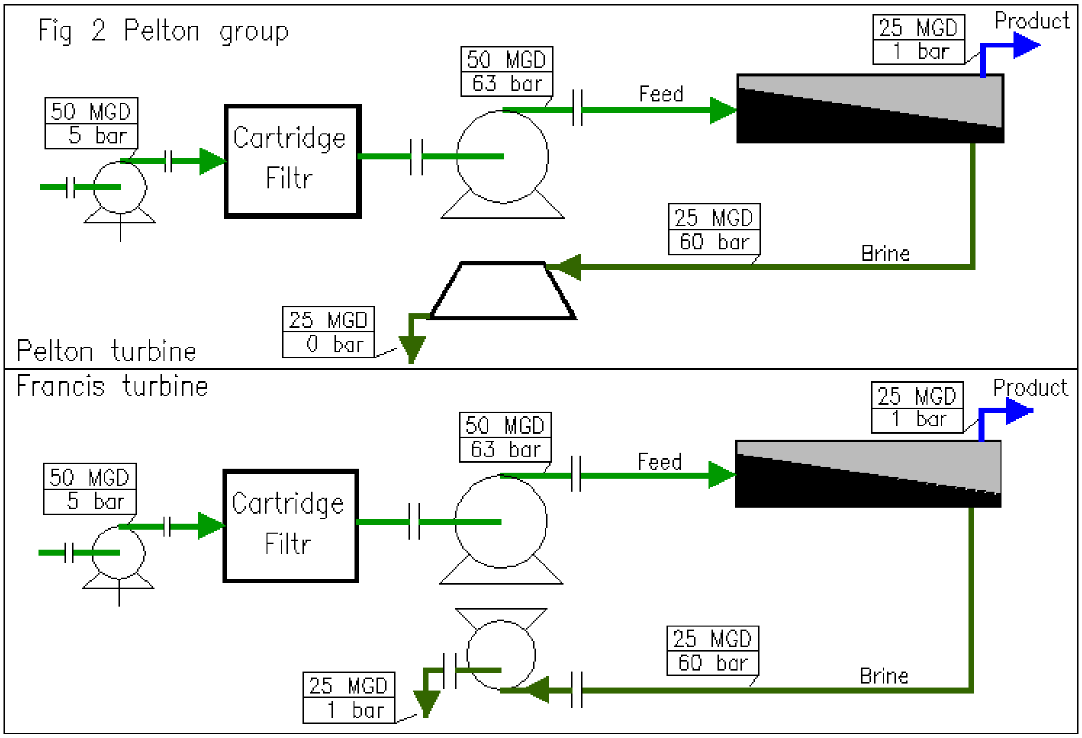
There is no doubt that small trains are more expensive, but pay for themselves well during the plant operation period.

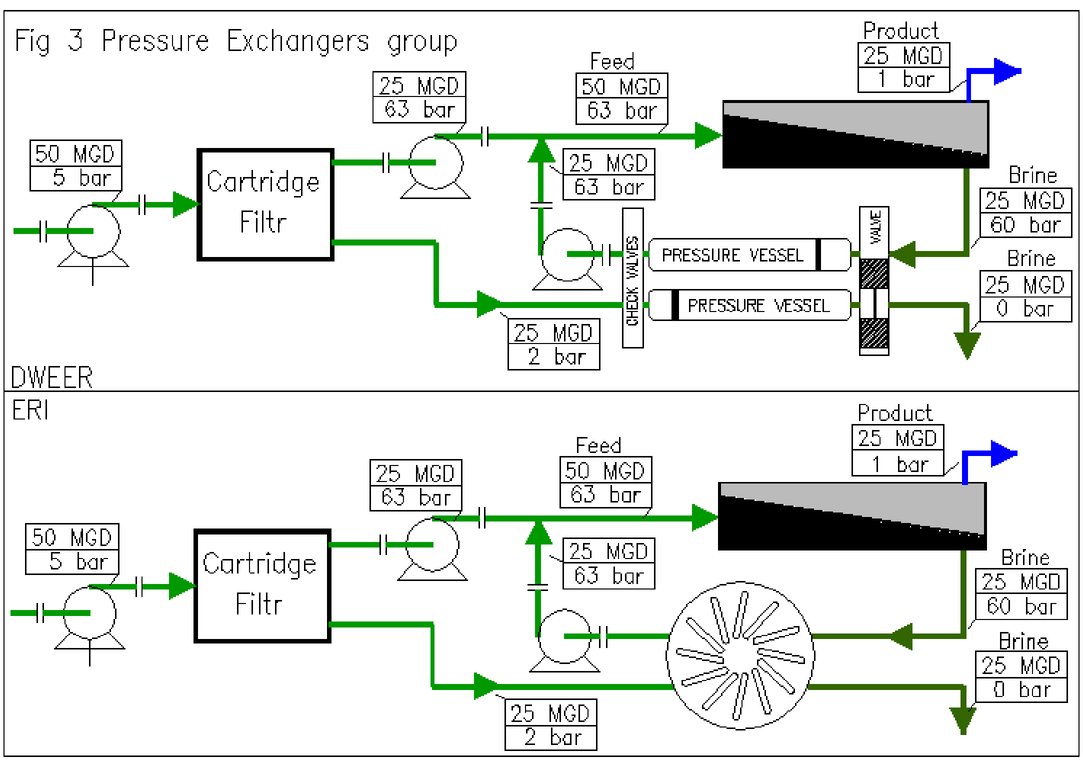
Main Groups of Energy Recovery Systems

Existing energy recovery systems can be divided in two groups: Pressure Exchangers [PE] that transfer the brine pressure directly to feed, such as DWEER, ERI, SalTec etc., and devices that transfer brine pressure to mechanical power, such as Pelton turbine, Francis turbine and back-running pumps.

Some qualifications are in order prior to the process explanation. Pressure Exchanger systems have mix and leak features (1.5%-2.5%) which is important for the detailed process design, but will not be mentioned in this paper which is intended for overview. There are differences between the special types of equipment in each group, which will be looked at in a later section addressing this issue. For the moment, the differences between the two main groups will be presented in Fig. 2 – Pelton Group and Fig. 3 – Pressure Exchangers Group.

Flow and Pressure Balance





The main difference between groups is the flow pumped by the HP pump. In the Pelton group the HP pump pumps the entire feed flow, whereas in the Pressure Exchangers group the HP pump pumps only part of the feed flow equal to the product flow. This means that the normal pump and motor losses will be applied only to a portion of the feed flow. This is the first element of power savings credited to the Pressure Exchangers group.

The particularity of the RO desalination process lies in the fact that the brine coming from the membranes loses very little from the feed pressure, and this brine stream contains almost 50% of the energy required for desalination. This is why the efficiency with which the energy contained in the brine pressure is transferred for pumping of the feed water is critical.

The form of energy transfer in the Pressure Exchangers group is direct from brine to feed water, as in the steam-engine, making the Pressure Exchangers, at the same time, a high pressure pump for flow almost equal to brine flow. This is the reason that the HP pump in this scheme has to pump only part of the feed flow equal to permeate. The transfer losses are few, and the compensation of pressure difference between brine and feed (3-4 bar) is delivered by the circulation pump.

The efficiency of energy recovery in the Pressure Exchangers group is around 96 percent.

The energy transfer in the Pelton group is indirect, with the brine jet hitting the turbine buckets. The efficiency of Pelton turbine itself is around 87 percent. The energy is transferred to the shaft and from the shaft to the pump.

Good pump efficiency is 85 percent, and at the end of the retransmission chain, of the 100 kWh energy in the brine, only 74kWh can be transferred to the feed stream again.

Power Savings - Numerical Example

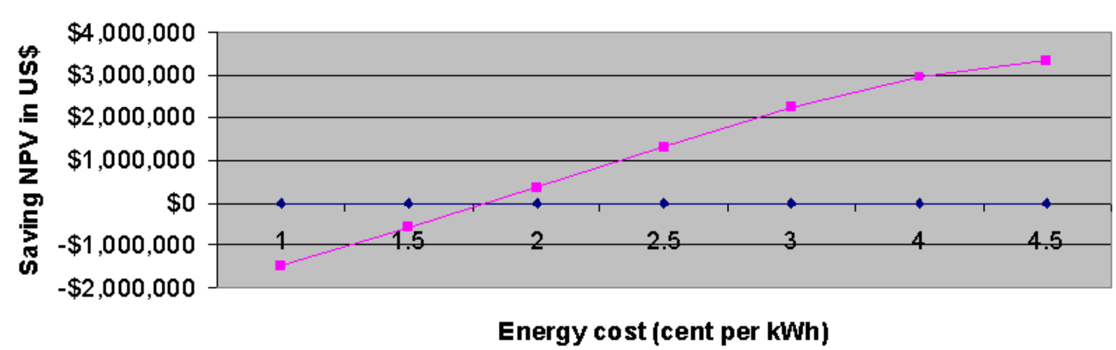
Let us assume that a 25mgd desalination plant can be built with one of two technological approaches - Pelton turbine or pressure exchanger –see table below.

The equipment and maintenance costs in the Pressure Exchanger group are higher than in the Pelton group.

The merit of implementation of one or other group depends on several factors such as energy cost, project lifetime, and interest rates. Fig 4 shows the cost effectiveness of the Pressure Exchanger group as opposed to the Pelton group, versus energy cost. The graph represents the case of a 25 mgd desalination plant, 10 year loan, 7.5 percent interest rate. As can be seen, if the energy cost for large industrial service is above 1.75 cent per kWh, the Pressure Exchanger group can be more economical than equipment from the Pelton group.

Common data of design parameters used in both technological groups.							
Water Plant production	Pressure to membrane	Brine Pressure from membrane	Plant recovery	HP pump efficiency	Pelton efficiency	Circulation pump efficiency	Motor efficiency
25 mgd	63 bar	50%	85%	87 %	89%	95 %	
Pelton Group							
Energy consumption of HP pump	Energy recovered by Pelton	Total energy consumption for one hour of operation	Specific energy consumption per 1000 gal				
16232 kW	5716 kW	11069 kWh	10.63 kWh				
Pressure Exchangers Group							
Power of HP pump	Power of Circulation pump.	Total energy consumption for one hour of operation	Specific energy consumption per 1000 gal			The difference in energy consumption between Pressure Exchangers group and Pelton group is 2.04 kWh per 1000 gal	
8543 kW	405 kW	8948 kWh	8.59 kWh				

Fig 4, Cost effectiveness of Pressure Exchanger group opposed to Pelton group versus energy cost



The Difference between Types of Equipment in Each Group

There is a major difference in efficiency between Pelton and Francis turbines. The Pelton turbine is more efficient and used in the majority of seawater reverse-osmosis (SWRO) desalination plants. The weak point of Pelton technology is the formation of a foamy stream that can only be evacuated by gravity, or re-pumped after it has settled.

The differences between DWEER and ERI systems are minor, with both types of equipment having good reference records as reliable energy recovery systems.

Energetically effective but expensive DWEER and ERI systems cannot be used in conditions where the energy cost is low, the interest rate high and the mortgage period short. The type of energy recovery device also depends on the condition of the brine discharge. The DWEER and ERI systems are able to maintain sufficient back pressure for long distance brine discharge.

Unique Properties of a Region

The relationship between energy cost, interest rates, and labor and civil engineering costs will determine the plant recovery, membrane flux, and even water velocity in the pipelines. Low power cost and high labor cost, as found in the USA, is unusual for traditional seawater desalination areas. This combination of economical parameters will challenge plant designers to push desalination technology to its limits. In the effort to reach low overall water cost, the SWRO designers will implement high membrane fluxes and high recovery in order to reduce the physical dimension of the plant and increase the energy components of the water cost.

The tender requirements should define the limits on several technological parameters to ensure a reliable water supply.