BRACKISH WATER DESALINATION – ENERGY AND COST CONSIDERATIONS

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Abstract

Energy recovery devices are employed in nearly all seawater reverse osmosis (SWRO) desalination plants to recover pressure from the membrane reject stream and return it to the process. Because of the high pressures and low membrane permeate recovery rates common in these systems, the membrane reject stream contains a considerable amount of energy. The use of energy recovery devices in seawater RO is readily justified on the basis of operating cost savings. However, the application of energy recovery is much less common in brackish water RO systems, primarily because of the relatively low feed pressure and low flow rate of the membrane reject stream. The fear is that energy recovery devices can also potentially limit the flexibility of a brackish RO process because of efficiency losses or flow-rate constraints encountered during off-peak operation.

Recently, low-cost isobaric energy recovery devices and turbochargers have been evaluated for brackish RO applications. These devices are intended to provide greater energy-savings payback and greater operational flexibility than was previously achievable. They also have the potential to reduce the overall capital costs of an installation since they can be less expensive than the high-pressure pump capacity necessary in their absence.

The authors give an overview of available energy recovery technology for brackish RO systems. A number of different system design layouts for both new systems and retrofits are considered. Performance and capital costs are compared for brackish RO systems equipped with no energy recovery devices, with turbochargers and with isobaric devices. The goal of the analysis is to identify the process conditions for which each of the available technologies makes sense.

Introduction

Energy recovery devices (ERDs) are employed in nearly all seawater reverse osmosis plants. The high operating pressures and low recovery rates produce concentrate reject streams containing significant quantities of energy. Energy costs are one of the more significant costs in the life cycle cost of a plant, accounting for up to 45% of lifecycle costs. Therefore, it is economically infeasible to operate SWRO plants without energy recovery devices. Conversely, brackish water reverse osmosis (BWRO) systems have low operating pressures and high recovery rates. As a result, the concentrate streams from these systems contain significantly less energy available for recovery. Due to these factors, many BWRO plants do not employ energy recovery technologies.

Recently, methods to reduce energy consumption while improving operating performance in existing and new BWRO plants have gotten renewed focus. Additionally, advanced energy recovery devices have been developed specifically for brackish applications. For these reasons, the authors embarked on a survey of municipal brackish plants in the US in order to identify the process conditions for which the application of energy recovery technologies make sense.

Challenges Associated with Brackish Energy Recovery

It is illustrative to look at the ratio of hydraulic energy leaving the membranes to the energy entering them. This ratio can be calculated as follows:

$$\text{Energy Ratio} = (\text{Feed Pressure} - \text{Membrane dP})\times(1 - \text{Recovery}) / \text{Feed Pressure}$$

A typical seawater RO system might be comprised of a single-stage configuration with a feed pressure of 900 psi, membrane differential pressure of 30 psi and a recovery of 40%. In such a system, the hydraulic energy ratio is 58%. By contrast, there is much greater variation in brackish system configurations and process parameters. Systems typically have two or more stages and can employ inter-stage boost pumps. An example system might comprise a two-stage configuration with 175 psi of feed pressure, 60 psi of membrane differential and a recovery of 80%. The ratio of hydraulic energy in the concentrate to that of the membrane feed ends up being only 13%. Thus, the available energy to be recovered from the concentrate reject of a brackish system is a small fraction of the energy put into the system.

Another challenge with implementing energy recovery in brackish systems is the large variations in concentrate pressure and flow associated with variations in parameters such as membrane condition, feed water temperature and salinity, among others. Most BWRO feed pumps operate with variable frequency drives to compensate for this variation. Therefore, energy recovery devices for these applications must be able to operate efficiently over a broad range of flow and pressures.

Because of the high recovery employed in BWRO, systems typically comprised of two stages of membranes are arranged in a 2 into 1 configuration. This configuration keeps the velocity of the brine within the final elements of the membranes sufficiently high when up to 85% of the water has been extracted as permeate. Placing a pump, referred to as an interstage boost pump, between the first and second stages is often employed to keep the recovery roughly equal between the first and second stages. This “flux balance” can be changed by the action of an energy recovery device as described below, and therefore, must be considered when implementing a system.

Centrifugal ERDs

Centrifugal ERDs such as a hydraulic turbocharger can be employed in BWRO plants. The turbocharger uses a turbine to extract energy from the concentrate stream, converting it to rotational energy which in turn spins an impeller in order to pump another fluid stream. The fluid stream to be pumped could either be the first or second stage membrane feeds. If the turbocharger is positioned between the first and second stages, it can reduce the need for or even replace an interstage boost pump.

Figures 1 and 2 show the two turbo application methods mentioned above. One of the key advantages of the turbocharger in this application is the simplicity by which it is utilized. A disadvantage of the turbocharger is the lower peak efficiency as well as bell-shaped efficiency curve. As process flows and pressures vary, the turbo efficiency can move off of the best efficiency point of the efficiency curve. Also, particularly in the application shown in figure 1, the relative flow rates on the concentrate and feed sides of the turbo significantly differ. This causes the turbine, impeller or both to operate off of their optimum speed for the given flow.

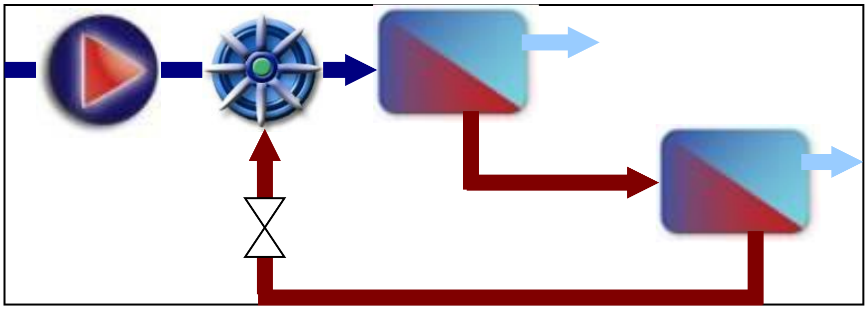

Figure 1. Typical Two-stage System with Turbocharger

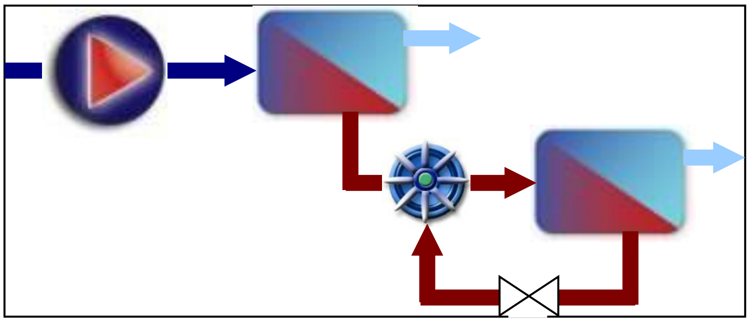

Figure 2. Typical Two-stage System with Turbocharger for Interstage Boost

The interstage boost application shown in Figure 2 is a particularly advantageous application of a turbocharger. In addition to saving energy, the turbocharger acts to balance flux between the stages. The closer match between the interstage and second stage concentrate flows as compared to that of the first stage feed and concentrate means that the turbine and impeller will operate at a higher overall efficiency. Additionally, the capital cost will be lower because the size of the pump stage is proportionally smaller.

Ideally, a turbocharger for BWRO applications will be custom designed for the specific application. This design will include machining the components to optimize hydraulic performance for the flow and pressure conditions of the application as well as integrating an auxiliary nozzle to maintain high efficiency during process variations.

Other centrifugal devices worthy of mention but not included in this study include turbine-based electrical generators [1, 2], and hybrid motor driven pumps with linked turbines [2]. These hybrid systems are applied in configurations similar to those in figures 1 and 2 and have the potential to operate over a broad range of process variations. Hybrid pump turbocharger products are typically operated with standard induction motors and variable frequency drives. The operating rpm range of the device is consequentially limited to approximately 1,000 to 3,600 rpm. This severely limits the peak efficiency obtainable by the device when compared to an optimized turbocharger which can spin at up to 12,000 rpm. Additionally, the slower device requires more materials and a larger footprint which potentially would increase capital costs.

Isobaric ERD Applications

Isobaric energy recovery devices function by directly hydraulically pressurizing the feed stream via exposure to the concentrate stream. In the case of a rotary isobaric device, ducts filled with low pressure feed water are pressurized by rotating them into direct contact with the pressurized concentrate stream. In a single-stage system, the process would work as shown in figure 3.

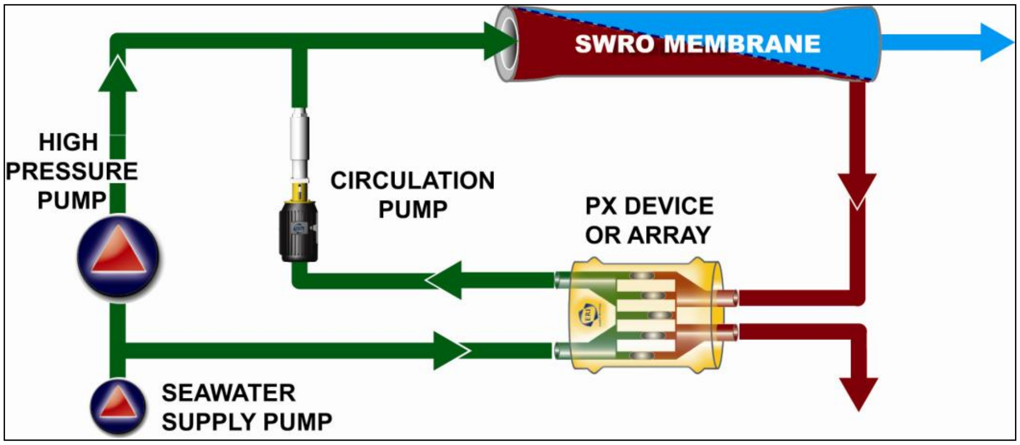

Figure 3. Typical Single-stage RO System with Isobaric ERD

The isobaric ERD, along with the circulation pump, supplies a volume of pressurized feed water essentially equal to the concentrate flow rate. The circulation pump makes up for the membrane differential pressure, piping losses and a small differential pressure in the isobaric ERD. The high pressure feed pump flow rate is reduced to that of the permeate flow. A result of the momentary direct contact between the concentrate and feed water streams is a small amount of mixing. This mixing causes a small salinity increase at the membrane feed (typically <3%) which results in slightly higher feed pressure.

The isobaric ERD is not a centrifugal device and thus cannot create or "boost" pressure. The pressure of the feed water leaving the device is equal to the pressure of the concentrate inlet pressure minus the ERD (typically about 10 psi). This pressure is completely independent of the feed water inlet pressure.

A new rotary isobaric ERD has been designed specifically for the brackish market. This device can handle flows up to 240 gallons per minute and pressures up to 400 psi. It was specifically designed for brackish applications where the low concentrate energy content requires low capital cost in addition to good efficiency and low mixing.

A multi-stage brackish system without interstage boost can be modeled just like the single-stage system shown in figure 3. In this case, the concentrate from the last stage is used to pressurize a stream of feed water for the first stage. The circulation pump makes up for the pressure losses in the membrane stages, associated piping and the ERD.

Applying an isobaric ERD to a two-stage system with interstage boost is somewhat different than the above example. In this case, the interstage boost pump is used to increase the recovery from the second stage as well as make up for the pressure losses associated with the system. The boost must be such that the pressure of the concentrate coming out of the second stage is higher than the feed pressure of the first stage plus the ERD dP of roughly 10 psi. A control valve after the ERD can be used to control the flow through the high pressure circuit. Figure 4 is an example of such a system.

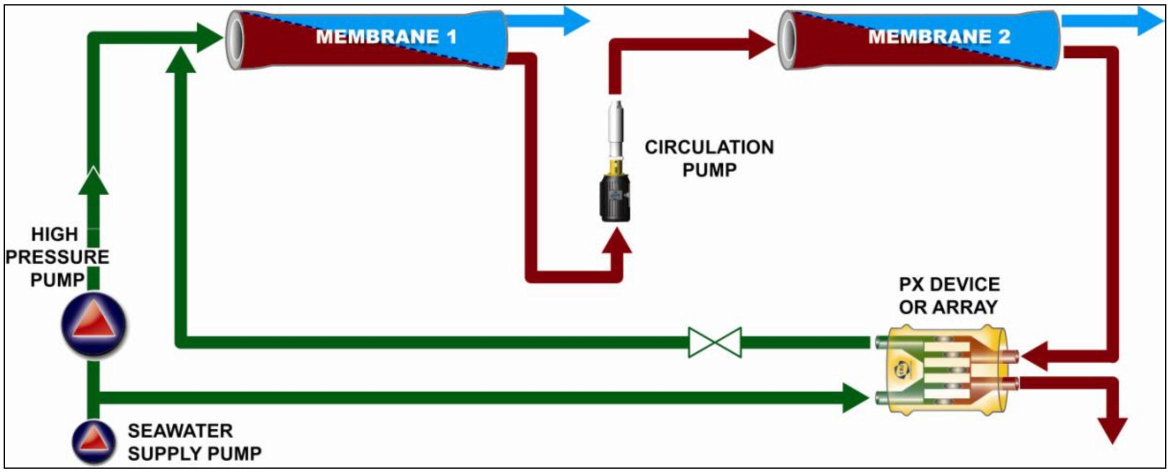

Figure 4. Typical Two-stage RO System with Interstage Boost and Isobaric ERD

Brackish Case Study

In 2009, the authors conducted a study of ERD opportunities for US municipal brackish applications. With the help of 8 experts from the fields of OEM plant design system consulting and academia, the authors gathered data on over 15 examples of existing plants for retrofit opportunities and new system designs without ERDs. Specific operating data and plant locations are being kept confidential due to the nature of the cooperation; however, the aggregate data is shown later in the paper (see Figure 5) and helps clarify when the application of ERD technology makes sense.

Membrane optimization and flux balancing in the example systems with added ERDs was beyond the scope of this study. Therefore, for each example, the ERDs were applied to the system while changing as little as possible. In the case of systems without interstage boost, this meant configuring the turbocharger to boost the feed of the first membrane and applying an isobaric ERD with a circulation pump. Likewise, in the case of systems with interstage boost pumps, the turbo was used to replace some or all of the boost from the interstage boost pump and the isobaric ERD was used in conjunction with the interstage boost pump and a control valve. In one example with interstage boost, the turbo would have supplied too much boost and therefore the interstage boost pump was retained and the turbo was used to boost the first stage feed pressure. The introduction of an ERD to a system design should be considered an opportunity to further optimize the utilization of the membranes.

Process Optimization and Life Cycle Cost

Clearly, the benefit of including energy recovery devices in a plant design is reduced overall energy consumption; however, other potential benefits should be considered as well. One such benefit is the reduction in the capital cost of the high pressure feed pump. In the case of an isobaric ERD, the flow through the feed pump is reduced from the total membrane feed flow to that of the permeate. This flow reduction of 20-25% for typical brackish systems (75-80% recovery) can equate to an appreciable reduction in the pump cost. For some configurations, the reduction in feed pump cost more than paid for the cost of the requisite isobaric ERD and circulation pump [3]. In the case of the turbocharger, depending on configuration, the capital cost of the unit may be less than the cost of the interstage boost pump it replaces. Figure 5 shows the results of the study graphed according to membrane feed pressure and overall recovery. Each data point indicates if the life cycle cost favors an isobaric ERD, a turbocharger or no ERD.

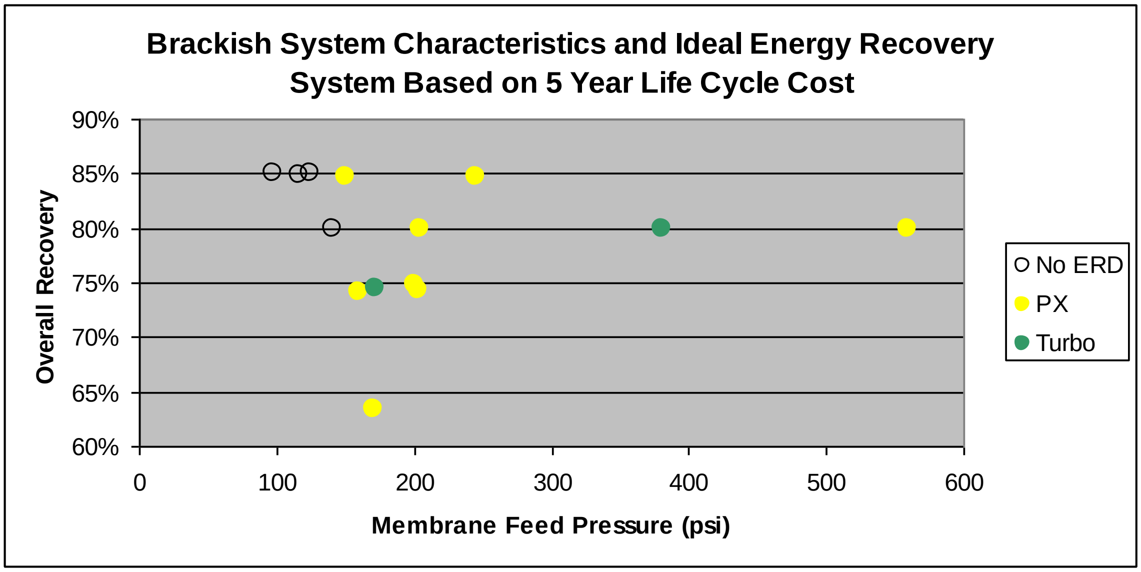

Figure 5. Energy Recovery Device Applicability for the Application Examples in Study

Conclusions

The results of the study indicate that energy recovery devices would be economically beneficial in most brackish systems. As indicated in the study results, a feed pressure of greater than 150 psi is approximately the point where energy recovery devices start to have a payback of less than 5 years. In addition to retrofit applications, isobaric ERDs can enable a plant to be expanded by the reject ratio without replacing the high pressure feed pump or significantly increasing energy consumption.

In contrast to seawater RO applications, the successful application of ERDs to brackish applications requires detailed analysis of the entire RO system. The study indicated clear advantages for the application of ERD technologies without optimizing membrane projections to take advantage of the ERD. The energy cost savings and operating improvements will be even greater if all parts of the BWRO system, including membrane and pump designs, are considered in conjunction with ERD selection. In most cases, such effort is rewarded with a return on investment (ROI) of less than 5 years as well as an overall carbon footprint reduction.

References

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