KAJUR – CASE STUDY OF SWRO UTILIZING WORK EXCHANGER ENERGY RECOVERY ON A REMOTE ATOLL

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Abstract

Seawater desalination, from any perspective, is an expensive proposition. With numerous advancements in membrane technology, pump and motor efficiencies, and energy recovery devices, the operating expenses of Seawater Reverse Osmosis systems can be dramatically reduced. Although the capital cost of a state-of-the-art system may be higher, the price difference of a well-designed RO system will quickly pay for itself in energy savings.

On a remote island in the Pacific, with high salinity and expensive electricity, maximizing efficiency for the new Reverse Osmosis Desalination System was key. When Kwajalein Atoll Joint Utilities Resources (KAJUR) solicited bids for twin 75,000 gpd SWRO systems expandable to 100,000 gpd, Hydropro, Inc. presented two proposals. One was for a conventional SWRO systems and the other proposal was based on obtaining the highest level of efficiency. With lessons learned from experiences with their existing system, and a central concern for a reduction of operating cost and reliability, KAJUR selected the innovative Hydropro design.

The standard-technology Hydropro design for this type of system, incorporating centrifugal pumps and conventional energy recovery, produces product water at an approximate power consumption rate of 4.8 kWh/m^3. The state-of-the-art system Hydropro designed and built for KAJUR, employing high efficiency pumps and pressure exchangers, produces product water at a power consumption rate of approximately 2.5 kWh/m^3. In comparison, a system with a positive displacement pump and no energy recovery will consume approximately 6.9 kWh/m^3.

The new SWRO plant has been providing potable water for the 10,000 residents of Ebeye, Marshal Islands for nearly one year now. However, startup and operation were not completely straightforward. There were some issues with the feed water, and the initial performance of the installed system was less than what was projected.

This paper will discuss energy consumption and conservation for seawater Reverse Osmosis systems in general, and the prudence of using new technologies that allow for a more efficient system design. The project approach, system design, and major component selection will be discussed, as well as projected performance with respect to power consumption and feed and product water quality. Issues with system startup, testing, optimization, and reliability will be explored, as well as the actual system performance and the factors affecting it. Finally, this paper will conclude with an assessment of the successfulness of the project, and make recommendations for energy efficient designs and future work.

Introduction

As a pioneering Reverse Osmosis OEM with energy efficient installations worldwide, Hydropro was very interested upon learning of a RFP for a seawater system in the Marshal Islands. With a wealth of knowledge and a good understanding of energy recovery and energy efficient designs, Hydropro was able to respond to the RFP very quickly with the company's standard design based on a centrifugal pump and a Hydraulic Turbo Booster (HTB).

At the time of this proposal, Hydropro had been closely following the success of the Pressure Exchanger energy recovery device that was recently introduced by inventor Lief Hauge and his company Energy Recovery, Inc. (ERI). Intrigued by the exceptional hydraulic efficiencies and innovative design, Hydropro was considering incorporating the Pressure Exchanger into its standard SWRO designs.

This was an excellent opportunity for Hydropro to provide its customer with state of the art energy recovery and further develop its own capabilities and experience. Hydropro then presented a second, alternate proposal utilizing the Pressure Exchanger from ERI. Based on initial power calculations, Hydropro demonstrated in the proposal that the pumping power required of the pressure exchange system would be approximately half of the pumping power required by a similar system incorporating a HTB. The energy savings and simplistic, reliable design was well appreciated by KAJUR, and the job was awarded to Hydropro.

SWRO Design and Energy Recovery

Conventional Design

Previously, the standard Hydropro design for SWRO with energy recovery incorporated a single multistage centrifugal pump (or positive displacement) with a Hydraulic Turbo Booster. This design is fairly simple and generally does not require a significant increase in system controls or instrumentation and is for the most part a sound, and energy efficient SWRO design.

The hydraulic turbo booster converts the hydraulic energy of the concentrate stream to mechanical energy and then applies this mechanical energy to the full flow of the feed stream in the form of a considerable pressure boost. In a single stage SWRO system, the energy benefit associated with this type of energy recovery device is realized solely in the form of lower pressure (and thus lower horsepower) requirements for the high pressure feed pump. Because the equations used to predict the pressure boost produced by a HTB are usually specific to the manufacturer and dependent upon the system parameters, they will not be explicitly discussed here. In this case, a reasonable assumption would be a 300 psi (693 feet H_2O) pressure boost from the HTB operating in a system as described in Example 1 below. The following example is used to demonstrate the reduction in high pressure feed pump horsepower requirements:

Example 1: Assume the membrane feed is 100 gpm, recovery is 35% and the membrane feed pressure is 2000 feet of H_2O, and all pump efficiencies are 75%. The first calculation will be the BHP required with no energy recovery, and the second calculation will represent the BHP required with a HTB energy recovery device.

BHP with no energy recovery:

$$BHP = \frac{GPM \times pressure \times SG}{3960 \times Eff} = \frac{100 \times 2000 \times 1.03}{3960 \times 0.75} \cong 70 BHP$$

BHP with HTB energy recovery:

$$BHP = \frac{GPM \times pressure \times SG}{3960 \times Eff} = \frac{100 \times 1307 \times 1.03}{3960 \times 0.75} \cong 45 BHP$$

Where: BHP = Brake Horsepower required
GPM = US Gallons per minute
Pressure = Head in feet
SG = Specific Gravity of the feed water
Eff = Efficiency of the pump

This HTB energy recovery device provides a substantial reduction in specific energy consumption, which, depending on the duty cycle and cost of power could pay for itself in a relatively short amount of time.

New Technology

The concept of a work exchanger energy recovery device was certainly not new, and several variations of these devices have come and gone. However, at the time of this proposal, there seemed to be a new approach to the design of these positive displacement devices that eliminated many of the problems associated with previous versions. The PE from Energy Recovery, Inc. (ERI) is an example of a novel work exchanger device that was in a position to profoundly affect the design of SWRO and the energy recovery industry.

The main idea of the Pressure Exchanger is its ability to *directly* transfer most of the hydraulic energy in the concentrate stream to an equal amount of feed water. The result is a side feed stream equal in flow to the concentrate stream (minus bearing leakage) that is boosted to near membrane feed pressure by the Pressure Exchanger. A small high pressure booster pump is then required to boost the high pressure feed exiting the PE so that it equals the discharge pressure of the high pressure feed pump and the two feed streams can be combined. This pressure boost accounts for pressure losses associated with inefficiencies of the pressure exchanger, losses across the membranes, and piping and fitting losses throughout the system. By significantly reducing the size of the high pressure feed pump to approximate the flow of permeate, the horsepower of the high pressure pump can be reduced by approximately two thirds of the total pumping power required. This substantial reduction in horsepower is, for the most part, specific to the high pressure, low recovery nature of the SWRO system. To illustrate the effect of this reduction in pumping power required, the following example is used:

Example 2: Assume the same conditions as in Example 1. The first calculation will be the BHP required with no energy recovery and the following calculations will be the BHP required with a pressure exchanger. With a PE energy recovery device, the flow of the high pressure feed pump is approximately equal to the permeate flow (35 gpm). A booster pump is added, which is sized for the flow of concentrate (65 gpm) and a pressure boost of approximately 30 psi (70 feet H_2O).

BHP with no energy recovery:

$$BHP = \frac{GPM \times pressure \times SG}{3960 \times Eff} = \frac{100 \times 2000 \times 1.03}{3960 \times 0.75} \cong 70 BHP$$

BHP with PE energy recovery:

$$BHP_{HPPump} = \frac{GPM \times pressure \times SG}{3960 \times Eff} = \frac{35 \times 2000 \times 1.03}{3960 \times 0.75} \cong 25 BHP$$

$$BHP_{BoosterPump} = \frac{GPM \times pressure \times SG}{3960 \times Eff} = \frac{65 \times 70 \times 1.03}{3960 \times 0.75} \cong 1.6 BHP$$

$$BHP_{Total} \cong 25 + 1.6 \cong 26.6 BHP$$

Although there are other energy considerations besides just pumping power when comparing a system with no energy recovery and a system with a PE, this simple analysis shows a significant reduction in energy consumption when using a Pressure Exchanger.

Hydropro Design

Design Requirements

Traditionally Hydropro has always put the needs of the customer into the forefront of its company philosophy. By doing this, Hydropro has always stayed abreast of the latest advancements in technology in the water treatment field. In this case, mostly because of the remote location (nearly everything, including fuel for the diesel generators, is delivered by ship), the most important customer needs were associated with conserving energy and maintaining reliability. Availability of replacement parts was also a major concern due to the remote location and the lead-time required to ship items to the island. Another concern Hydropro had to address was ease of operation and ease of maintenance, as the remote island of Ebye did not have any skilled RO plant operators. The end result would incorporate all these requirements to produce a reliable supply of potable water from a seawater source for the citizens of Ebye.

In the original RFP, KAJUR requested twin 75,000 gpd SWRO units (expandable to 100,000 gpd) designed for a seawater feed of 45,000 mg/l TDS. The proposal presented by Hydropro was for two Seawater Reverse Osmosis Water Treatment units each designed to produce 75,000 gallons per day. Permeate water was projected to be of less than 300 mg/l TDS based on feed water from seawater wells with a maximum TDS of 50,000 mg/l and an SDI of less than 3. Each unit was designed to be easily expandable to a daily capacity of 100,000 gallons by the addition of one pressure vessel containing seven seawater membranes. All instrumentation, piping, valves, headers and pumps were pre-sized to accommodate the expansion.

Each proposed SWRO system consisted of four pressure vessels containing seven membrane elements each arranged in a single, one-pass array. With the expansion, the system would consist of five pressure vessels in a single staged array. Each system was designed to operate at a 30-40% recovery rate, with a maximum trans-membrane (feed to product) pressure of 1100 psi at a feed water TDS of 50,000 mg/l. With a feed water TDS of 46,000 mg/l, the trans-membrane pressure was projected to be approximately 900 psi at startup and 950 psi after three years of operation.

System Design

The final, installed 100,000 gpd Hydropro design consisted of the following major components and unit operations for each SWRO unit:

- Sand and Particulate Filters: Two HYDROPRO Tubular filter units Model STF5M2-400-PVC/150 each consisting of one PVC housing with a 150-micron wedge wire PVC screen for the removal of sand and particles, with automatic purge valves

- Micron Filters: Three heavy-duty filter housings constructed of FRP/PVC and built to ASME Code X, the housings are Eden Model 24EFC each accommodating six (6) 40" long five micron polypropylene cartridges

- RO High Pressure Booster Pumps: Two high pressure feed booster pumps Grundfos Model BM 17-27R (installed in series) - horizontal centrifugal, multi-stage construction of 904L Super Austenitic Stainless Steel, each driven by a 35 HP submersible type motor rated at 460V/60Hz/3∅ utilizing a Soft start motor starter and VFD

- RO Low Pressure Booster Pump: One booster pump Grundfos Model BM 30-4R - horizontal centrifugal, multi-stage type of 904L Super Austenitic Stainless Steel, driven by a 7.5 HP submersible type motor rated at 460V/60Hz/3∅ controlled by a variable frequency drive

- Membrane Modules: One FRP construction structural frame, five pressure vessels of FRP construction rated at 1200 psi operating pressure, 35 Thin Film Composite membrane elements – 8" x 40", 2205 DUPLEX SS headers for feed and concentrate and Sch. 80 PVC for the permeate headers and low pressure feed, suction and concentrate piping, Allen-Bradley PLC SLC 5/04 based control system - installed in a NEMA 4X enclosure with system switches lights etc. installed on the panel door

- Chemical Feed Systems: One anti-scalant dosing system and one chlorine dosing system

- Freshwater Flush/Membrane Cleaning System

The system skid was designed and fabricated for a compact footprint due to limited installation space and to allow for shipping both units in a single container. The entire system was pre-assembled as much as possible to minimize field services.

Major Component Selection

The sand screens and micron filters were selected because of the durable and corrosion resistant fiberglass and PVC construction. The specific model of Eden micron filters was chosen to maintain the filter element flux at approximately 3.3 gpm/per 10" equivalent.

Due to the relative remoteness of the installation site, multistage-centrifugal, high-pressure pumps have been selected for their reliability, availability of parts, economics of operation and easy maintenance. Centrifugal pumps in general are smoother, quieter, and require less ancillary equipment (i.e. pulsation dampeners) than positive displacement pumps. Hydropro has found that positive displacement pumps are much more prone to failure and lengthily downtimes than high-quality centrifugal pumps.

The Grundfos Booster Modules were chosen for several reasons. The inline style helped conserve space and provided ease of installation, allowing everything to be mounted on the same skid (with the exception of cleaning/flush tanks, raw water booster pumps, and chemical feeds). These submersible, multi-stage centrifugal pumps were also chosen because they are very efficient and quiet, and are constructed of corrosion resistant, 904L super austenitic stainless steel.

The high pressure feed and concentrate headers were made of 2205 duplex stainless steel for superior corrosion resistance, and the structural skid was constructed of FRP for low weight and zero maintenance. ERI's Pressure Exchanger was chosen because of its high energy efficiency, dependability, and corrosion resistant materials.

Performance

Values for the projected power consumption rates that were presented in the proposal were based on a 27ºC feed stream of 45,000 mg/l TDS and a permeate flow rate of 100,000 gpd. The membrane manufactures projection software was used to determine the system parameters at a recovery of 35%, and these parameters were subsequently used to determine the projected power consumption. The result was an anticipated feed pressure of 900 psi and a specific power consumption rate of 3.02 kWh/m^3.

Once the system was installed and operating, the specific power consumption was calculated based on actual system parameters and the result was a much lower value of 2.65 kWh/m^3. There were several reasons the actual value was lower, the main reason however, was the conservative design.

Because of some uncertainty in the feed water quality, the SWRO system was designed with a relatively low flux (approximately 8 gpm/ft^2), and a somewhat large hydraulic envelope. As it turned out, the feed water TDS was closer to 36,000 ppm and fairly stable. The lower feed TDS enabled the system to operate at a lower membrane feed pressure of 790 psi and a higher permeate flow rate of 120,000 gpd, consequently using less energy than originally projected and making higher quality permeate.

Conclusion

With most of the system assembled, the installation was fairly straightforward and went smoothly. The two units were installed, started up, tested and operator training was completed in less than three weeks. There was, however, a problem with the feed water quality and the pretreatment system, which was discovered after only 24 hours of operation. It immediately became apparent that the raw water was loaded with particulate that was quickly fouling the sand screens and the micron filters. Fortunately, the feed system could be modified to flow into an existing 250,000 gallon seawater tank from the wells, and the SWRO feed was then drawn out of this tank. This settling tank solution worked quite well and provided a feed water with a pre-filter SDI of 1.25.

There was also one other performance issue that needed to be resolved. Initially, the permeate quality was less than what was projected, and it was not clear why. The system was extensively checked ant tested for leaks, and the possibility that seawater was somehow mixing with the permeate was eventually eliminated. It was finally determined that the membranes did not meet the design rejection required to produce the projected permeate TDS. Once the membranes were replaced, the system was making plenty of high quality permeate that was well below the maximum acceptable permeate TDS.

KAJUR and the residents of Ebye have since been enjoying low-cost, high-quality water for over a year now without any noteworthy system failures. They are so pleased, in fact, that KAJUR has recently awarded Hydropro another SWRO job utilizing work exchanger energy recovery.

References

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