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INTERSTAGE ENERGY RECOVERY TURBINE APPLICATION MARCO ISLAND, FLORIDA

JULIA NEMETH, PE Harn R/O Systems, Incorporated
Venice, Florida
STEVEN DURANCEAU, PHD, PE Boyle Engineering Corporation
Orlando, Florida

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Abstract: The City of Marco Island, Florida is a resort community located off the southwest coast of Florida. The private water supplier, Florida Water Services has pursued innovative technologies to provide their growing service area with high quality water at a competitive rate. The majority of the water is provided from a 6 million gallon per day (MGD) reverse osmosis (R/O) plant. The plant treats a brackish water that is one of the highest total dissolved solids (TDS) municipal water supplies in the country. The raw water TDS can vary from 7000, to over 11,000 mg/l TDS.

One of the innovative technologies the utility pursued was incorporating interstage energy recovery boosters in two new R/O skids added during an expansion. This was the first system with an interstage application of energy recovery boosters in the country. The systems were so successful, the utility decided to modify the existing skids to include boosters. The boosters receive concentrate and use the excess pressure to boost the pressure to the second stage. The interstage turbines have not only provided significant energy cost savings, they have enhanced the performance of the skids by improving hydraulic balance and permeate quality. Also, they enable the skids to operate in a stable manner with the highly variable feedwater. The R/O plant has been operating for two years with the energy recovery turbines. Herein, data will be presented on capital costs versus energy savings. Also, data on improved performance and projected increased membrane life will be provided.

INTRODUCTION

Florida Water Services (Florida Water) owns and operates a 6 MGD reverse osmosis plant in Marco Island, Florida. Marco Island is a tourist resort area on the Gulf Coast, south of Naples. The population can increase tenfold in the winter tourist season. To meet rapidly increasing water demand the utility built a 4 MGD reverse osmosis plant in 1992. The raw water TDS varies from 7000 to 11,000 mg/l depending on which wells are operating. The original plant was planned to allow expansion to 6 MGD. The first 1 MGD expansion was completed in 1996. The expansion was completed within a 7 month period, including design, using a negotiated fast-track procurement method.

The original four trains were configured as a 24:12 array with Filmtec membranes. The design of the new train considered a hybrid array of brackish membranes from all suitable manufacturers and also considered the feasibility of incorporating an interstage booster. Based on the analysis that will be summarized in this paper, Florida Water decided to incorporate an interstage energy-recovery turbine booster in the new train. As a result of the successful outcome of the expansion, the Owner decided to retrofit the four existing trains with interstage turbines. Also, when the final 1 MGD train was installed in 1998, an interstage turbine was included.

MEMBRANE PROCESS DESCRIPTION

The original process arrays in Train Nos. 1 - 4 were designed as a 24:12 (first stage : second stage) system, with each pressure vessel containing six 8-inch diameter, 40-inch long membrane elements. Each of the original trains initially provided about 1.0 MGD permeate capacity for a total of 4 MGD. The first stage of each train contains 48 sea water membrane elements and 96 brackish water membrane elements in 24 pressure vessels. The first two elements in each vessel are sea water membranes and the remaining four elements are brackish membranes. The second stage of each train contains 72 brackish water membrane elements in 12 pressure vessels. The original trains provided a total of 72,000 ft^2 of membrane surface area. This surface area provided an average system flux of 13.9 gallons per square foot day (gfd).

The membrane process array in the first expansion, Train No.5, was designed as a 22:12 (first stage : second stage) system, with each pressure vessel containing six 8-inch diameter, 40-inch long membrane elements. The 1.0 MGD permeate capacity membrane skid contained 132 Fluid Systems thin-film composite (TFC) 8822XR high-rejection brackish membrane elements in 22 pressure vessels in the first stage, and 72 Fluid Systems TFC 8822HR brackish membrane elements in 12 pressure vessels in the second stage. The membranes were selected because their projections indicated they would produce the highest quality permeate at the lowest feed pressure.

The design projections indicated a third year permeate water quality of 125 mg/l TDS at 25 degrees Celsius, based on a design feed water quality of 10,500 mg/l TDS. Train No. 5 was designed to provide 67,320 ft^2 of membrane surface area and to operate at an average flux of 14.8 gfd. Train No. 6 was designed for the same array as Train No. 5. Table 1 provides an overview of the different membrane types and numbers for each process train at the Marco Island reverse osmosis plant.

Table 1
Marco Island RO Membrane Information

Train (#)	Stage	Element Type Model	Vessels (6/PV) (#)	Surface Area per Element (ft^2)	Surface Area per Stage (ft^2)
1-4		Filmtec			
	1st *	SW30-8040	24	345	48,240
	1st	BW30-8040	–	330	
	2nd	BW30-8040	12	330	23,760
5		Fluid Systems			
	1st	8822XR	22	330	43,560
	2nd	8822HR	12	330	23,760
6		Fluid Systems			
	1st	8822XR	22	330	43,560
	2nd	8822HR	12	330	23,760

* First two elements are seawater construction

INTERSTAGE BOOST AND ENERGY RECOVERY

The RO process, by its nature, produces a concentrate stream that is under relatively high residual pressure. Because of the characteristics of the Marco Island facility there is sufficient energy in the concentrate to make energy recovery worthwhile under certain scenarios. During the design of Train No. 5, utilization of an energy recovery device was evaluated.

Generally, the recoverable energy is proportional to the concentrate flow rate, the pressure of the concentrate stream, and the efficiency of the energy recovery device. This energy is normally recovered in the form of a reverse turbine attached to a booster pump in the membrane feed line. Energy recovery boosters are frequently used in seawater reverse osmosis systems. There are several different types, however, the type deemed most suitable for Marco Island was a reverse turbine-type. Unlike most seawater applications, evaluation of the high brackish conditions at Marco indicated a booster would be most effective on an interstage application, rather than on the feedwater. The analysis reviewed the benefits of using a booster that would recover the residual pressure from the total concentrate and use it to boost the pressure of the first stage concentrate before it was fed to the second stage.

The hydraulic TurboCharger, manufactured by Pump Engineering Incorporated (Monroe, MI), was specified for this application. The TurboCharger is an energy recovery device specifically designed for RO processes. This patented device can be used to transfer hydraulic energy from RO concentrate streams to any other stream in a RO process. The hydraulic pressure boost has been used to reduce feed pump energy requirements, increase permeate production, and reduce permeate TDS. For Train No. 5 at Marco, based on the membrane suppliers projections and the TurboCharger design information, the booster could be expected to provide from 30 psi to over 90 psi of boost to the second stage feed. Using information provided by Pump Engineering, Inc., a payback period of 2 to 3 years on the equipment was estimated.

TRAIN 5 -- MEMBRANE INTERSTAGE EVALUATION

Construction of Train 5 was completed in 1996. The train operated as projected, producing 1 MGD of permeate at 75% recovery. The production was hydraulically balanced, with the average first stage flux about 15 gfd and the average second stage flux at about 13 gfd. During the performance test, the energy recovery booster provided approximately 70 psi of boost to the second stage feed. The raw feedwater conductivity was 14,000 *u*mhos/cm, the total permeate conductivity was 350 *u*mhos/cm.

Florida Water continued to collect data on all five trains throughout 1996 and the first quarter of 1997 to compare the performance of the existing trains to the operation of Train 5 with the booster. Average recovery, normalized flux, and salt passage were calculated from the performance data. Train 5 consistently showed improved performance with an average recovery of 74.6%, a normalized flux of 13.3 gfd, and an average salt passage of 1.8. Trains 1-4 operated at an average recovery of 69.9%, a normalized flux of 13.3 gfd, and a salt passage of 2.7. Additionally, feed pump amperage data was collected on the five trains from February 1997 to March 1997. Energy savings for each train was determined by measuring the amperage of the high pressure feed pump used for each train and comparing the permeate flow produced per train. Train 5 required 14% less power and produced 6% more permeate over this period of time. Also, Train 5 showed less variation in power required to treat a widely ranging feedwater. This is due to the ability of the booster to provide more or less interstage boost depending on interstage salinity, thereby requiring less variation from the high pressure feed pump. The permeate quality was more consistent, as well. Converting the energy savings to cost savings, it was estimated the booster was saving the owner about $0.07 per 1000 gallons, a reduction in energy costs of 20%. A summary of the operating data is shown in Figures 1 and 2 below.

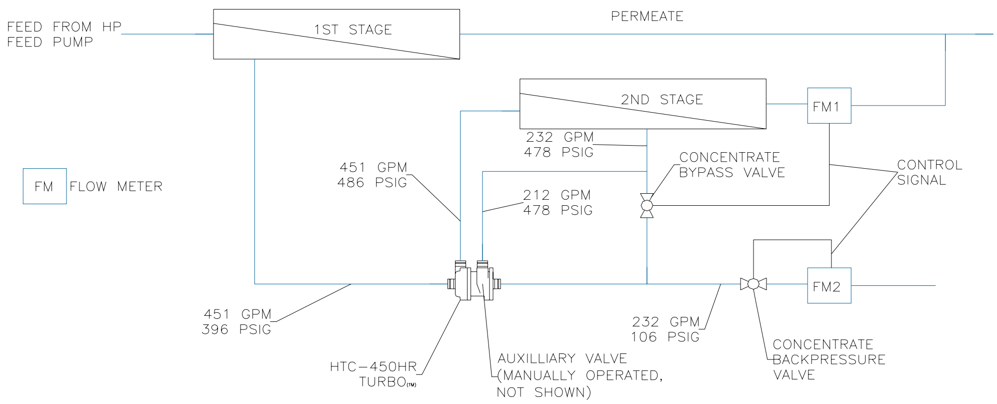

FIGURE 1. INTERSTAGE BOOST PUMP OPERATING CONDITIONS (YEAR 0, 75%)

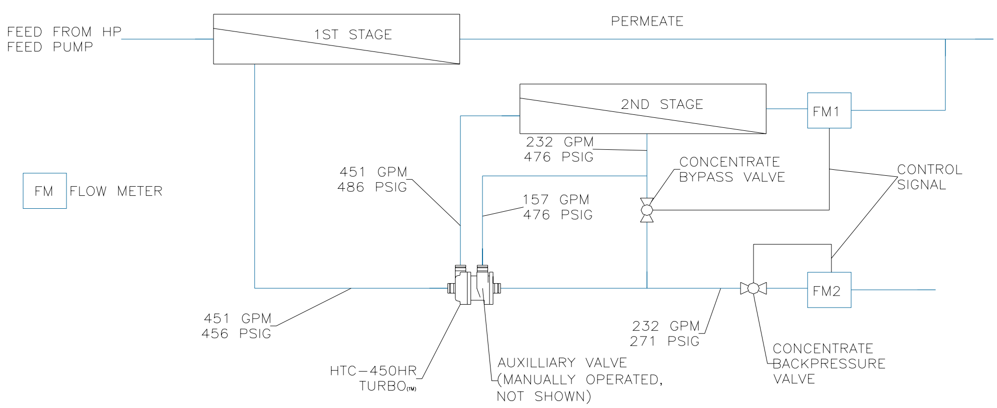

FIGURE 2. INTERSTAGE BOOST PUMP OPERATING CONDITIONS (YEAR 3, 75%)

RETROFIT OF REVERSE OSMOSIS TRAINS

From the results of the analysis Florida Water determined it would be cost-effective to retrofit the existing trains with interstage boosters. One of the driving factors, in addition to energy cost savings, was the benefit of possibly of increasing the life of the existing membranes. The existing membranes were about five years old in 1997. They had experienced some sand damage earlier. Installing the interstage turbines would allow more permeate – and better quality permeate – to be produced from the existing trains. This would enable the owner to postpone membrane replacement for possibly another year or two, which would be a substantial cost savings. The retrofit of Train 1 was completed in February 1997. The retrofit of Trains 2,3, and 4 were all completed by the end of 1997. The plant was operational the entire time, with shutdowns carefully scheduled and construction planned to minimize plant interruption.

It was determined that the average salt rejection had increased overall between 0.3 and 0.6 percent after the retrofit of an interstage turbine into the four existing trains. Also, the average water recovery stabilized at 75% after the retrofit for the four modified trains. The variable frequency drive (VFD) speed decreased from about 90 percent on average for the four membrane trains before the retrofit construction to about 80 percent after the retrofit was completed.

Hydraulically, the retrofit improved water recovery between stages, from about 60 percent in the first stage and 35 percent in the second stage (prior to interstage boost) to about 55 percent first stage recovery and 45 percent second stage recovery. The turbine is providing approximately 70 to 90 psi of boost to the second stage feed stream, depending on the feedwater salt concentration. As the salinity rises, the available boost increases as a function of the osmotic pressure. The turbine has enabled the feed pressure to the first stage of each of the four original trains to be reduced approximately 40 to 50 psi, depending on the feedwater salinity.

The overall permeate water quality was found to be slightly improved after the retrofit construction was completed. The overall salt rejection for the four original process trains prior to the retrofit construction using an interstage turbine was approximately 96 percent. The second pass salt rejection averaged about 93 percent prior to the modification using turbines. The overall salt rejection improved to 98 percent across the four original trains after modification, and the second stage salt rejection increased to about 97 percent after construction was completed.

Tracking the energy savings attributed to retrofitting the four original process trains with interstage turbine booster pumps demonstrates that the trains after the retrofit have more control of varying water quality and flow conditions compared to the original trains without an interstage turbine. Using an assumed conservative electrical cost of $0.075/kW-hr, energy cost calculations were performed for before and after the interstage turbine retrofit conditions. The results of energy analyses due to the retrofit of the four original process trains with an interstage turbine indicated that approximately $0.05 per 1,000 gallons permeate was saved by using the interstage device.

SUMMARY

The function of the interstage turbine is to increase the pressure of the first stage concentrate stream prior to it being directed as the feed stream to the second stage. This is accomplished by routing the second stage concentrate through a reverse turbine and utilizing residual pressure from the second stage concentrate stream to increase the feed pressure to the second stage. This source of "free energy" allows the second stage to be operated at higher feed pressure than that of the first stage, which permits both stages to operate more efficiently and produce a higher quality finished water. Based upon an evaluation of the performance of the membrane process trains at the Marco Island ROWTP, it has been demonstrated that a membrane train that utilizes an interstage pressure boost via the use of a turbine between the first and second stage is more efficient than that same process train that does not have the interstage device. Results of data collected on the original process trains after the retrofit with interstage turbines indicates that the process trains are operating under enhanced conditions.

In 1998 the last 1 MGD expansion train, Train 6, was installed, with the interstage turbine. As the owner had hoped, several more years of life were obtained from the original membranes in Trains 1-4. As of mid-2000, Trains 2, 3, and 4 are operating on the original Filmtec membranes at nearly eight years of age. Train 1 membranes have been replaced and sequential replacement of Trains 2, 3, and 4 is expected to be completed by the end of 2001. Although the plant is currently built-out at a capacity of 6 MGD, Florida Water is investigating the possibility of increasing the plant capacity by between 1.5 and 2 MGD by increasing each train’s array and by using new higher square footage membranes in the future membrane replacements. The existing trains were designed to allow the addition of several pressure vessels. The ability to increase the production capacity hinges primarily on the capacity of the high pressure feed pumps. As noted above, the addition of the interstage boosters lowered the VFD speed about 10%, therefore, the pumps, motors, and VFD’s have more room to provide increased capacity to the reverse osmosis trains.

The use of membrane processes for water production has continued because of innovations relative to membrane manufacturing and ease of operation. More importantly, the historical operating experience has significantly improved the understanding of the technology related to construction activities, cost and performance. This innovative first use of an interstage turbine for energy recovery and enhanced water production in a brackish water ROWTP has been successful, and this work is significant to the water community in that it provides historical documentation that decision makers can use in evaluating energy recovery design and construction issues.

REFERENCES

S.J Duranceau et al. "Coping with a variable TDS brackish water during the retrofit expansion of a desalting facility" *Proceedings of the ADA 1996 Biennial Conference Membrane and Desalting Technologies*. Monterey, CA: ADA August 4-7, 1996.

S.J. Duranceau et al. "Innovative Application of Off-the-Shelf Technology Pays Dividends for a Florida Utility." *Proceedings of the IDA World Congress on Desalination and Water Reuse*. International Desalination Association: Madrid, Spain. October 6-9 (1997) 455-468 (Volume 1).

E. Oklejas. "The Hydraulic TurboCharger for Interstage Feed Pressure Boosting". *Proceedings of the National Water Supply Association Conference*. Newport Beach, CA: NWSIA, August (1992).