

Treatment of Cooling Tower Blowdown Water with Membranes in a Zero Liquid Discharge (ZLD) Power Plant

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ABSTRACT

The Indiantown Cogeneration plant has recently modified their Zero Liquid Discharge (ZLD) scheme to incorporate membranes to treat the blowdown from their cooling tower. This was originally sent to two brine concentrators. The plant required the flexibility to use any combination of make up water. It was also desirable to replace the brine concentrators due to corrosion and resulting savings in power. The Integrated Membrane System (MF/RO) was commissioned in 2011. It allowed the brine concentrators to be replaced and generated high-quality permeate for boiler feed while maintaining zero liquid discharge.

INTRODUCTION

The recent need for water footprint improvement and continuous cost reductions has made the reuse of process and waste water in power plants increasingly important. This recycling of water will continue to be a significant topic for the future.

Cooling towers are the biggest users of water in a power plant, consuming about 90% of the water needs. A significant quantity of blowdown water is continuously generated in order to run the cooling towers at different cycles of concentration, usually exceeding 4. In the past few years, the normal treatment scheme involves the blowdown water being treated by softening and Reverse Osmosis (RO) membranes to remove suspended and dissolved contaminants. The treated blowdown water (permeate or filtrate) is reused as boiler feed or as process water. A portion of the blowdown (the RO reject stream) is sent to brine concentrators (evaporators). This is critical to enable the concept of zero liquid discharge. The treatment of blowdown water from the cooling towers is an enormous technical challenge and new technologies, such as Microfiltration (MF) as protection to RO treatment are now increasingly being employed to meet the stringent specifications.

INDIANTOWN POWER PLANT DETAILS

The Indiantown, Florida Cogeneration plant is a 360 MW coal fired power plant. It has a 2600 psi boiler supplying steam continuously to a "steam host" (customer). Cooling tower make up water is obtained from three different sources. The cooling tower is run at 4-7 cycles of concentration. The plant is designated as a ZLD facility. Blowdown volumes treated from the cooling tower were designed to be 650 gpm. A Spray Drier Absorber (SDA) is used to reduce SO_x emissions and to evaporate the reject stream. Two Brine Concentrators (Evaporators) were originally used to process cooling tower blowdown water and provide high-purity boiler feed water.

THE ORIGINAL TREATMENT SCHEME

Filtered make up water is sent as feed to the cooling tower. Blowdown from the cooling tower was originally sent to the two brine concentrators (**without membrane treatment**) and the clean distillate from the brine concentrators was utilized as boiler feed water after mixed bed demineralizer treatment. The reject from the brine concentrators was utilized as feed water to the SDA and was evaporated by the heat from the fuel gas. Hence, zero liquid discharge was achieved. **However, the brine concentrators suffered from extensive corrosion problems, requiring costly replacement.**

The make up water to the cooling tower is from three different sources.

Combinations of these three water sources are filtered before feeding the cooling tower. These are:

1. Surface water from Taylor Creek, high in organics, but cannot be used during droughts. Primary water supply for the plant.
2. Highly saline ground water from wells, used only during droughts and creates the most difficult processing case for the blowdown.
3. Treated municipal waste water. Used in combination with surface water during normal operation or well water during droughts.

Table 1 shows the varying properties of the three different water sources.

MAIN PROBLEMS ENCOUNTERED

- Brine Concentrators suffer from stainless steel skin corrosion issues. Elimination of these problems would require significant downtime and replacement costs in the millions of dollars.
- The two brine concentrators consumed 0.7 MWH each to operate and reduction of this parasitic load was desirable. The best outcome would be a complete bypass of these units.
- The plant required flexibility to use any combination of make up water to the cooling tower. A membrane system had to be designed to accommodate different water quality in the blowdown and provide low TDS permeate to the mixed bed demineralizer.

Table 1. Typical Feed Water Analyses

Parameter	Units	Blend Of Well Waters	Waste Water	Taylor Creek Surface Water
Turbidity	NTU	3-10		3-30
Conductivity	microS/cm	6200	960	590
Iron	mg/l	0.13	0.05	0.56
Total Organic Carbon	mg/l			31
Ca Hardness	mg/l	440	260	98
Mg Hardness	mg/l	540	14	48
Sodium	mg/l	850	76	55
Aluminum	mg/l	<0.1		21
Barium	mg/l	0.4	2.0	0.03
Silica	mg/l	15.0	21	9.7
Sulfates	mg/l	300	31	58
Chlorides	mg/l	2000	97	110

PILOT TESTING OF MEMBRANE SYSTEMS

In mid 2009, an automated Pall single MF module was used in the pilot to treat the blowdown water. An automated pilot scale RO with four 4-inch diameter RO elements was also used to treat the MF filtrate. The main objective was to demonstrate stable operation of both MF and RO.

The main conclusions from the pilot study were that the MF/RO system was demonstrated to be a viable technology for treatment of cooling tower blowdown water. The pilot MF system was successfully operated at 35 GFD flux with recoveries >91%. The recorded inlet turbidities on the blowdown water ranged from 1-25 NTU. Filtrate Turbidity was <0.02 NTU with the Silt Density Index (SDI) <2 on the feed to RO. Iron in the cooling tower blowdown was identified as a major concern. Organic/biological fouling was observed in the RO units after extended shutdown and required high pH cleaning.

MEMBRANE TECHNOLOGY

The conventional clarifier/multimedia filters for the treatment of incoming fresh water into plants suffer from several shortcomings. The primary one is the inability of these systems to cope with sudden upset conditions that could result in increases in total suspended solids in the feed water. This is also reflected in an increase in SDI, conductivity or in turbidity (NTU values) in the product water. Technological

improvements since the 1990's have resulted in processes such as Microfiltration (MF) and Ultrafiltration (UF) becoming economical and popular. In a typical application, the incoming water passes through several thousand spaghetti-like hollow fiber polymeric membranes, which remove suspended solids and bacteria. The effluent performance for turbidity of MF and UF is similar.

For removal of dissolved solids, the treated water from the MF unit passes through the spiral-wound RO membranes. This technology is employed before the demineralizers. The pores in the RO membrane are only a few angstroms in size and can remove a majority of the dissolved salts.

MODES OF OPERATION

The MF filtration systems can be operated in the dead-end mode or in crossflow mode. The RO units operate in the crossflow mode. The MF unit described in this paper uses a hollow fiber membrane operated in the conventional dead-end filtration mode wherein the feed water flows in from the outside to inside of the hollow fiber and the suspended particles and bacteria are captured within the filter and the permeate is sent to the RO unit. These filters have a unique air scrub/reverse flush cleaning method every 10-20 minutes and are also regularly cleaned with chemicals (described in the next section). The RO unit operates in the crossflow mode, in which the feed water flows parallel to the membrane surface.

The water that is filtered through the fine pores (permeate) is mostly devoid of dissolved salts.

THE MICROFILTRATION SYSTEM AND CLEANING REGIMEN

The Pall Aria™ MF system installed in the Indiantown plant is shown in Figure 1. It's a unique system and it is fully-automated. It features 6350 hollow fibers made of PVDF in a single module. It has superb membrane integrity and it operates in the dead-end mode. Feed water enters the bottom of the module and is distributed uniformly to the outside of the hollow fibers. It operates under low pressure, typically 45 psig. The water, under pressure, flows through to the membrane core and the permeate flows to the top of the module, from where it is conveyed by a filtrate header to the next unit - in this case, the RO membrane. An increase in Trans Membrane Pressure (TMP) occurs with passage of time as fouling materials obstruct flow across the membrane.



Figure 1. Low Pressure Pall Aria Microfiltration System at Indiantown

CLEANING AND MAINTENANCE OF THE FILTER ELEMENT

Flux Maintenance is done constantly to lower the TMP values. Air scrub involves the injection of air at low pressure into the feed side of the module. Clean filtrate is also pumped in a reverse direction through the hollow fibers to dislodge the foulants and deposits. Enhanced Flux Maintenance (EFM) uses hot water with mild chemical solutions and is done periodically to lower TMP. As the TMP approaches 1.7-2.0 bar (25-30 psi), chemical Clean-in-Place (CIP) is performed. This is a two-step protocol, first using a caustic and then an oxidant solution, to return the modules to “nearly new” condition. This is done hundreds of times over the lifetime of the element.

The spiral RO system installed at the Indiantown power plant is shown in Figure 2. There were two spiral RO systems installed (RO A and RO B). Each train of RO A and RO B had two stages apiece. The RO system was then fully integrated with the MF system, having a common control system and the same cleaning chemicals. The MF system was the pre-filter to the RO system.



Figure 2. The Pall Spiral Two Stage RO System at Indiantown

PROPOSED SOLUTION

A fully integrated MF/RO system was proposed and installed at Indiantown with the following design features.

<p>FULL-SCALE MF PARAMETERS Filtered Water Inlet Flow: 620 gpm Number of Modules: 56 Design Flux: 35 gfd Recovery: >90% Filtrate Turbidity: <0.2 NTU SDI <3 Maximum TMP: 43 psi EFM Interval: 1 per day CIP Interval: >30 days</p>	<p>FULL-SCALE RO PARAMETERS Number of Trains: 2 Array: 8:4 (RO A) 4:2 (RO B) Feed Flow: 415 GPM (RO A) 205 GPM (RO B) Average Flux: <14 GFD Recovery: 45-75% CIP Interval: 30-90 days Operating Temperature: 80°F</p>
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A schematic of the proposed integrated membrane system is shown in Figure 3. Here, the clean permeate from the two stage RO is sent to the boiler feed water demineralizer. The RO reject is processed in the Spray Drier Absorber or used in lime slaking. The brine concentrators have been completely replaced. Zero liquid discharge is thus achieved without the use of brine concentrators.

OPERATIONAL CHALLENGES

During the first month of operation (May 2011), high pressure drops were consistently recorded on the first stage RO (RO A). An autopsy indicated severe microbiological fouling on the leading RO elements. A biocide (DBNPA) was injected at 100 ppm into the blowdown (MF feed). This eliminated the biological fouling problem and the system ran smoothly.

The plant also experienced fouling due to aluminum in the second stage RO, especially when surface water was fed to the cooling tower. This problem was solved by decreasing the pH in the feed from 6.5 to 5.5. Also, an extremely efficient cleaner was used to clean the RO modules during this period until the pH reduction mitigated the problem.

PERFORMANCE DATA

Figure 4 illustrates the variation of Trans Membrane Pressure (TMP) of the Microfiltration Unit and the turbidity of the incoming water to the unit (i.e, the cooling tower blowdown). It is shown over a seven week period (September 1 - October 25, 2011). The TMP rose slowly from the initial value of about 5 psig to around 25 psig during this period. A CIP was performed shortly after this and showed that the membrane was cleaned effectively and worked well. The inlet turbidity varied from 7-20 NTU. The turbidity of the filtrate (not shown in the graph) was consistently below 0.2 NTU, thereby meeting design goals.

MF TMP and Inlet Turbidity

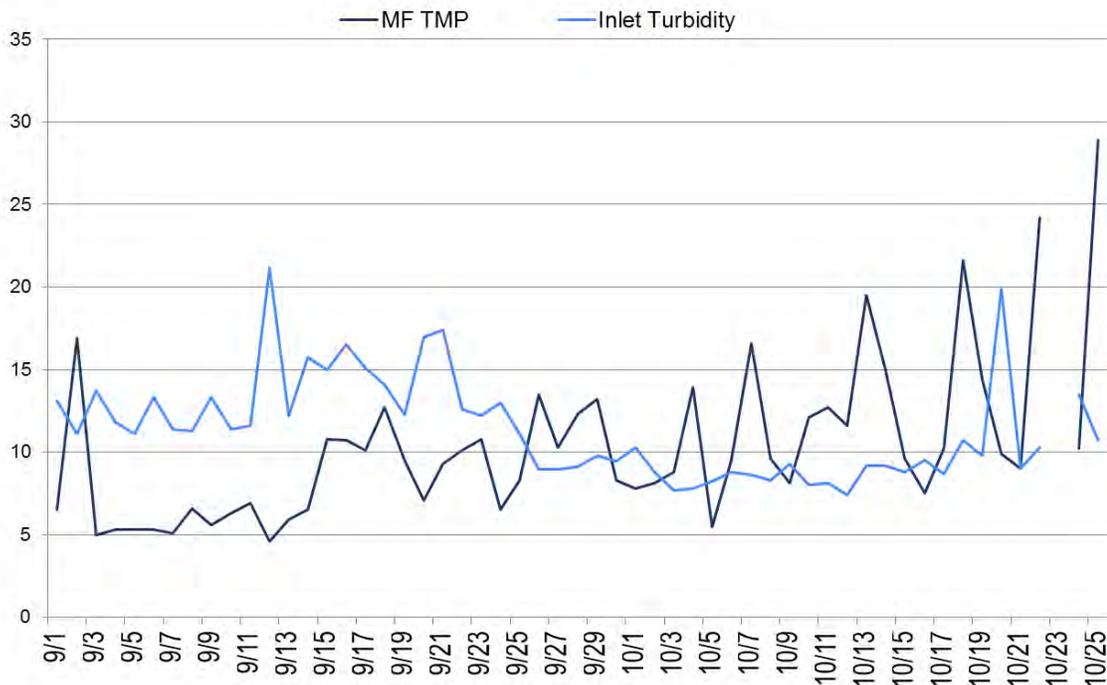


Figure 4. Plot of Trans Membrane Pressure and Inlet Turbidity with Time

Figure 5 illustrates the variation of SDI over a seven month period from August 2011 - March 2012. The measurements were made on the filtrate from the MF system being sent as feed to the RO system. Measurements were made periodically and not on a daily basis. The SDI value remained well below 2.0, which reflects the excellent protection provided by the MF to the RO system. Generally acceptable industry standards are $SDI < 3.0$.

In Figure 6, we plotted the variation of pressure drop in the first RO train (RO A) as a function of time from September 1 - October 25, 2011. The pressure drops on both stages of RO A are shown over this seven week period and the cumulative pressure drop is also shown. The pressure drop remained relatively flat over this period, indicating consistently good performance without the need for a cleaning of the RO modules. Similar results were obtained on the second train (RO B).

SILT DENSITY INDEX - MF FILTRATE

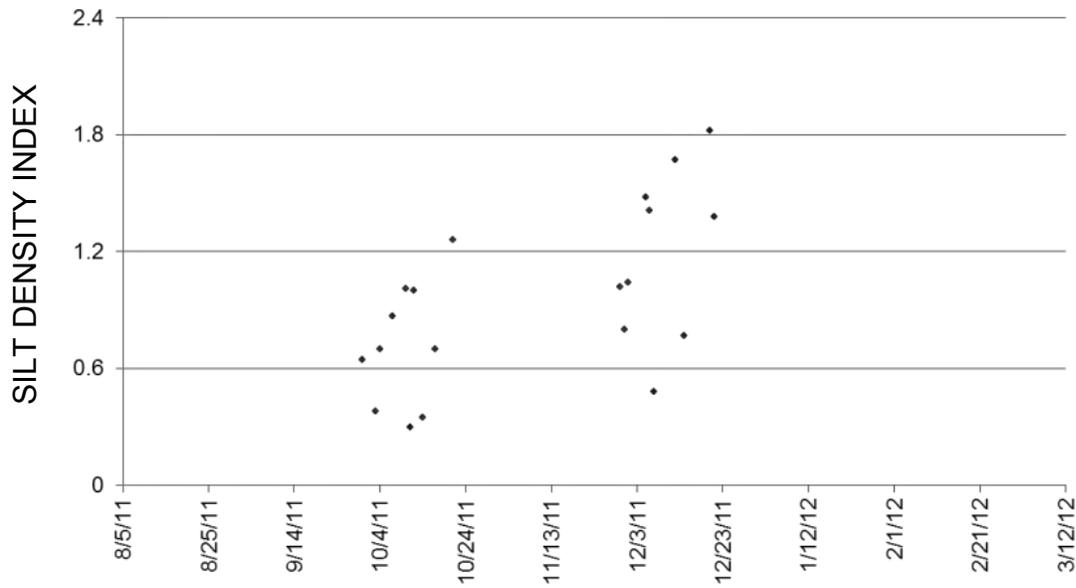


Figure 5. Variation of Silt Density Index on MF Filtrate with Time

RO A Membrane Pressure Drop

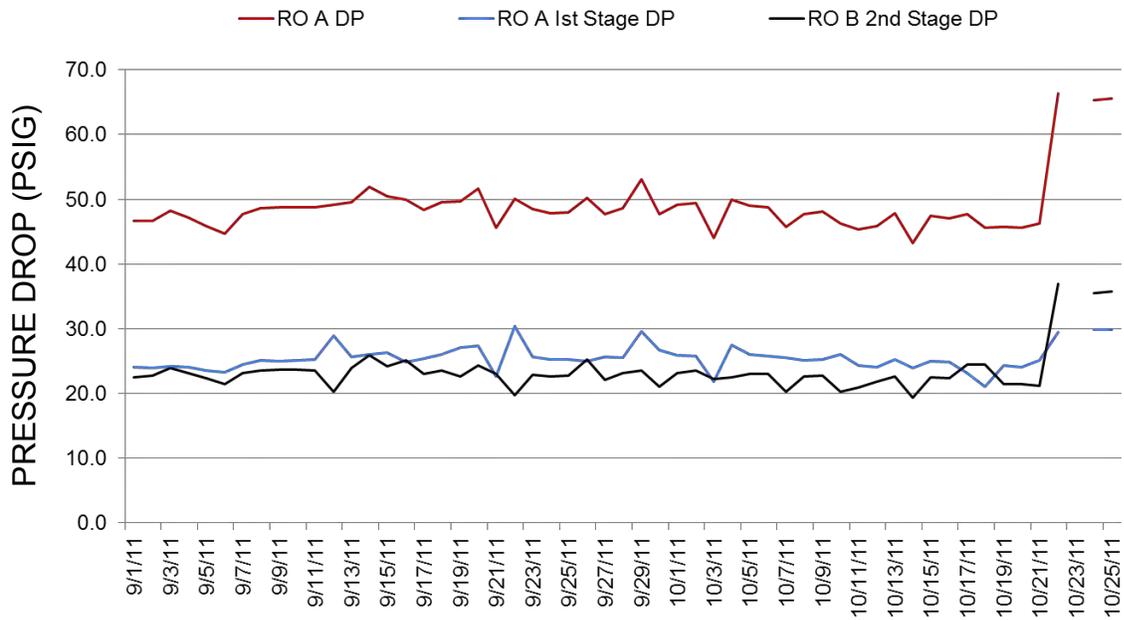


Figure 6. Variation of Pressure Drop Across Two Stage RO A with Time

RETURN ON INVESTMENT (ROI) CALCULATIONS

SAVINGS TO PLANT

- Brine Concentrator power annual savings = \$397,000/year
- Savings by elimination of maintenance/refurbishing/retubing and chemical cost on evaporators = \$782,000/year
- Total savings = \$397,000 + \$782,000 = **\$1,179,000/year**.

COSTS TO PLANT

- Cost of MF/RO System = \$1,549,993
- Cost of Installation = \$705,000 (estimated)
- Annual Power, Chemical and Consumables cost to operate the MF/RO Plant @ average 420 GPM blow down = \$203,000
- Total cost over three years = **\$2,863,993**

Years for Return on Investment = $2,863,993/1,179,000 = 2.4$ years

MAJOR CONCLUSIONS

- The highly automated Integrated Membrane System has functioned smoothly for over a year while treating challenging cooling tower blowdown water and has met performance goals
- **The Integrated Membrane System allowed for complete replacement of the brine concentrators. This resulted in a reduction of parasitic load and substantial savings.**
- A return on investment will be achieved within three years
- Initial operational challenges were successfully overcome
- The reject of the RO system could be processed in the existing Spray Drier Absorber system, thereby implementing Zero Liquid Discharge
- The results demonstrated that the Membrane System generated very high quality permeate that could be used as boiler feed
- The plant now has the flexibility to treat different quality feed waters with the membrane system

The Microfiltration System provided successful protection and smooth operation of the RO system. Overall, this case study illustrates how membranes can be used to achieve Zero Liquid Discharge, while effecting significant savings in power plant operating costs.

