High Purity Boiler Water Production Using Municipal Wastewater at a Combined Cycle Gas-Fired Generating Station

Michael Sheedy and George Di Falco

ABSTRACT

The recovery of wastewater for industrial uses presents many challenges for the design and operation of water treatment equipment. Since the term wastewater can be applied to a wide range of water sources from municipal sewage to storm runoff to industrial discharge water, the water characteristics may have great variability. As such, the equipment to treat wastewater must be robust and forgiving. When these wastewaters are used to produce ultra high purity boiler feedwater, the challenges become magnified.

This paper describes a water treatment system, fed with municipal wastewaters, for the production of high purity boiler feed makeup water at a combined cycle gas-fired power plant, and the experiences of the plant operator after five years of continuous operation. This fully automatic water treatment system consists of micro-media filtration, reverse osmosis and a short bed ion exchange demineralizer/polisher, and requires minimal operator attention and maintenance.

INTRODUCTION

Typically, wastewater has higher levels and a wider variety of dissolved solids and metals, and potentially high levels of organic material, both natural and man-made, especially where municipal wastewater is concerned. With increasing environmental concerns and restrictions, it can be challenging to treat these wastewaters for mere discharge, let alone for reuse in industrial or municipal applications. Greater restrictions on the use of fresh water for industrial purposes and the diminishing supply from existing fresh water sources have necessitated some innovative ways to reuse these wastewaters. But until recently, their use for the production of high purity boiler feedwater had not been considered. In the power generation industry, particularly in areas where fresh water is scarce, this is now being considered as an alternative.

At a 600 MW combined cycle gas-fired power plant in northern Mexico, they have been using wastewater from the nearby municipality as their sole source of service and boiler feedwater since the plant began operations in 2002.

The original boiler feed makeup water treatment system consisted of two-stage sand filters, three-stage reverse osmosis (RO) and electro-deionization (EDI) polishers. During the first three years of operation, the water treatment system struggled to meet both the quality and capacity requirements of the power plant. The RO units fouled rapidly and required frequent cleanings, sometimes more than once per month, and this led to inconsistency in the output from the EDI system both in terms of quality and quantity.

Additional capacity was required and the operational difficulties and boiler makeup water quality issues needed to be resolved.

In 2005, the plant hired an independent engineering firm to evaluate improvement of the pre-filtration, increasing the capacity of the RO and improving the overall product water quality. After an extensive evaluation of the available water treatment technologies, micro-media filtration and compressed short bed ion exchange polishing were selected, along with some modifications to the existing RO units.

PRIMARY AND SECONDARY TREATMENT

Raw water from the nearby municipal primary treatment lagoons/settling ponds is delivered directly to the power plant. Municipal sewage makes up the main part of the water entering the lagoons, with minor sources which include industrial discharge, both process and sewage, and storm water run off.
The characteristics of the raw water being fed to the power plant are shown in Table 1.

The power plant provides the secondary treatment of the water to produce both cooling water and boiler feed makeup. This secondary treatment consists of an aerobic step to oxidize organic matter and NH₃, using a biological treatment process, followed by bacterial action, to remove nitrates, under anaerobic conditions. This eliminates biological contaminants and reduces other contaminants.

From the digesters, the water is treated with lime in a clarifier. This raises the pH, causing dissolved minerals such as calcium and magnesium to precipitate out, and reduces the overall dissolved solids content. Precipitates are removed from the clarifier and the sludge is thickened and dehydrated on a belt press. The resulting non-hazardous solids are then sent to a landfill.

Following the clarifier, the pH of the water is neutralized using sulphuric acid, and chlorine is added for disinfection.

The treated and clarified water is now suitable for use as makeup water to the cooling towers. A portion of this service water is further treated to produce high purity water for boiler feed makeup and other plant water uses.

The clarified water feed to the high purity water treatment system was found to have the characteristics depicted in Table 2.

### Pre-Treatment

Secondary water sources like this contain relatively high levels of suspended solids, organics, colloids and biological matter, even after clarification, and cannot be used to feed an RO system directly. An additional pre-treatment is required to prevent fouling of the RO membranes. Amongst the most commonly recommended techniques for pre-treatment are: conventional depth media filtration, microfiltration (MF), and ultrafiltration (UF) [2,3].

The long service life and relatively low cost of media are a major advantage of conventional depth media filtration. It is also generally quite robust and not prone to fouling.

The original pre-treatment system (Figure 1) consisted of two trains of two-stage media filtration utilizing effective media sizes of 0.85 mm and 0.65 mm in the primary and secondary filters, respectively. A coagulant (cationic polymer) was added to the feed stream before the primary filter to aid with solids removal, and sodium hypochlorite provided additional disinfection. The four filter vessels had a diameter of 1.402 mm (4.6 ft) and were generally operated at a service flow rate of ~ 13.7 m³·h⁻¹·m⁻² (~ 6 gpm/ft²). Parallel trains were required to ensure a sufficient supply of RO feed since backwashing took ~ 2 h to complete for each train.

Filtration performance was generally poor with frequent spikes in the solids content of the filtrate. This overloaded
the cartridge filters between the media filters and the RO and resulted in solids leakage to the RO. This had an adverse effect on RO performance and increased the frequency of membrane cleaning.

**High Efficiency Micro-media Filter:** The original two-train, two-stage media filters were replaced with a single “micro-media” filter (Figure 2) which differs from conventional depth media and dual media filters in a few key characteristics.

The micro-media filter uses a top layer of coarse anthracite, with an effective size of ~0.7 mm, and a lower “micro-media” layer, with an effective size of less than 0.10 mm. This is significantly finer than conventional fine media filters and not only provides greater filtration, but also allows the micro-media filter to operate at much higher service flow rates. The single micro-media filter vessel used to replace the original two-train, two-stage system is 1,676 mm (5.5 ft) in diameter with a design service flow rate of 36.7 m³·h⁻¹·m⁻² (15 gpm/ft²).

The micro-media filter, like all other media filters, exhibits the classic ripening effect at the beginning of each service cycle, where the initial filtrate quality is poor and gradually improves as the cycle proceeds.

To ensure that only high quality filtrate is fed downstream to the RO system, the original filter system had to bleed ~10 vessel volumes to waste during the first 2 h of its service cycle. The micro-media filter has a much shorter ripening period, and RO feed quality filtrate is achieved after only 2 vessel volumes (<10 min) of the service cycle.

The micro-media filter operates with a simultaneous air scour/backwash cleaning cycle to maximize the cleaning efficiency. During the backwash cycle, water is first drained to the top of the media. Air and water are then simultaneously passed up through the media. The water flow expands the media and the air agitates the media much more violently and uniformly than water alone. Once the vessel has been refilled, the air is turned off and a water only backwash flushes the dirt from the filter. The entire cleaning cycle of the single micro-media filter is ~15 min.

Operating data for the micro-media filter (Figure 3) indicates that the typical service cycle is ~8 h long. With the addition of coagulant, filtrate turbidity of ~0.1 NTU¹ and SDI-15² values of <3 are achieved.

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¹ Nephelometric turbidity unit (ASTM D6855-12 – Standard Test Method for Determination of Turbidity below 5 NTU in Static Mode)

² Silt density index (ASTM D4189-07 – Standard Test Method for Silt Density Index (SDI) of Water)
Reverse Osmosis System

The original RO system consisted of two trains configured in three stages (3-2-1) of five element vessels.

Prior to the upgrade, each train produced 14.2 m³·h⁻¹ of permeate with an indicated conductivity of 392 µS·cm⁻¹. Because of this, the second train was being used as a second pass RO to improve permeate quality. At the time of the analysis, the RO membranes were three years old. Leaky seals between membranes and membrane fouling degradation were partly to blame.

Since the RO vessels were sound, it was determined that an upgrade consisting of new membranes with higher surface area and flux rate, along with valves and instruments, was all that was needed to provide the required capacity and quality for the plant. After the upgrade, the RO system capacity was increased to 28.4 m³·h⁻¹ for each train with a permeate quality of 30–70 µS·cm⁻¹.

Approximately half of the RO permeate is fed to the ion exchange process and the remainder is used elsewhere in the plant.

Compressed Short Bed Ion Exchange (IX) Polisher

The original polishing system used electro-deionization (EDI) stacks. This is a well-established technology and is typically used to treat double pass RO permeate. A detailed description of EDI with a comparison to ion exchange can be found in [4]. The only concern expressed about the installed EDI equipment, beyond the requirement for additional capacity, was the slow and inconsistent restart after shutdown [1]. However, other concerns related to this technology include leaks, hardness scaling, lack of warning when a stack becomes inoperable and the inability to field service the stack assemblies.

The plant decided to replace the EDI system and expand the overall capacity using the compressed short bed IX system recommended by the evaluating engineer. Aside from the more favourable economics, there were a number of technical considerations in arriving at this decision, including the rapid startup after a shutdown provided by the compressed short bed system, short cycle times which allow a single polisher to meet the capacity requirements, operating and maintaining a single type of polishing system, and the elimination of the second pass RO requirement.

The principles of the compressed short bed IX system date back to the late 1960s at the University of Toronto's Chemical Engineering Department. A detailed explanation of the principles of the short bed IX system and its use in the power generation industry can be found in [5,6]. Some of the major design features incorporated into the system are:

1. fine mesh resin for greater surface area and IX kinetics
2. compressed short resin bed heights of 152 or 76 mm (6 or 3 in) for lower resin volumes
3. counter-current regeneration with internally re-circulated rinse for reduced regenerant consumption and waste volumes
4. low resin loading and short cycle times for higher quality and less redundancy
5. feed forward conductivity control for flexibility in operation

The one drawback of the short bed IX system is the need for highly efficient pre-treatment. One of the main concerns with packed bed IX systems is resin fouling. Since the resin cannot be backwashed during regeneration of the short bed system, any dirt that accumulates will not be removed. RO permeate polishing by a short bed system therefore becomes an ideal application.

System Design Basis and Description

The specification identified the characteristics of the RO permeate being fed to the demineralizer/polisher as follows (Table 3).

The limiting factor with regards to product water quality, when using separate beds of cation and anion resins, is generally sodium leakage from the cation bed or from residual caustic left on the anion resin after regeneration. When trying to produce very high quality water (< 0.1 µS·cm⁻¹) and with higher feed TDS (> 25 mg·L⁻¹), this becomes more problematic.

In this application, the average feed TDS of 30 mg·L⁻¹ or more and the desired product water quality of
<0.1 µS · cm⁻¹, a cation/anion combination was not sufficient, even with the advantages of the short bed IX system. A third polishing bed of cation resin was added to remove the low levels of sodium.

Since this final cation bed is only removing low levels, it can be operated at higher flux rates and requires less frequent regenerations than the primary resin beds.

A single train, skid mounted compressed short bed IX system was supplied and is shown in Figures 4 and 5. The primary cation and anion beds are 762 mm (30 in) in diameter and 152 mm (6 in) deep, while the final polishing cation bed is 610 mm (24 in) in diameter and 76 mm (3 in) deep.

**System Performance**

In August of 2006, the system was commissioned and all performance objectives (Table 4) were achieved. After almost six years of continuous operation, the water treat-

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
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<tr>
<td>Calcium (as CaCO₃)</td>
<td>mg · L⁻¹</td>
<td>4</td>
</tr>
<tr>
<td>Chloride (Cl⁻)</td>
<td></td>
<td>32</td>
</tr>
<tr>
<td>Silica (as SiO₂)</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>pH</td>
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<td>7.15</td>
</tr>
<tr>
<td>Temperature °C</td>
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<tr>
<td>Bicarbonate (as CaCO₃)</td>
<td>mg · L⁻¹</td>
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<tr>
<td>Nitrate (NO₃⁻)</td>
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</tr>
<tr>
<td>Sodium (Na)</td>
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<td>35.91</td>
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<tr>
<td>Sulfate (as SO₄²⁻)</td>
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Table 3: Demineralizer/polisher feed composition.

Figure 4: Short bed Recoflo IX system.
The plant maintains a full charge of resins for the demineralizer unit in inventory, along with approximately half of a charge of filter media, but to date they have not had to replace either of the ion exchange resins, or any filter media.

Table 4:
System performance.

<table>
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<th>Proposed Performance</th>
<th>Actual Performance</th>
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<tr>
<td>Conductivity</td>
<td>µS · cm⁻¹</td>
<td>&lt; 0.10</td>
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<tr>
<td>Silica</td>
<td>µg · L⁻¹</td>
<td>&lt; 10</td>
<td>&lt; 5</td>
<td>&lt; 3</td>
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<tr>
<td>Net Flow Rate</td>
<td>m³ · h⁻¹</td>
<td>40</td>
<td>40</td>
<td>41</td>
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</tbody>
</table>

Figure 5:
Installation of short bed Recoflo IX system.
The plant’s operations and maintenance manager reports that they are very pleased with the water treatment system since it is fully automatic and requires very minimal operator attention. He explained that since there is never a need to service the equipment, it tends to get neglected. “In fact, we sometimes forget that the system is there.”

SUMMARY
At a 600 MW combined cycle power plant, municipal waste water is the only source of service and cooling water for the plant. During the initial three years of operation, the original water treatment system could not consistently meet the quality and capacity requirements, creating operational difficulties for the plant. An upgraded and expanded water treatment system was supplied to produce high purity boiler feed makeup water.

After nearly six years of operation, the new water treatment system continues to exceed the quality and capacity requirements of the plant. This system utilizes a single micro-media filter to provide pre-treatment to the RO system and a single compressed short bed IX demineralizer/polisher.

As a result of the reliable operation and consistent quality provided by the water treatment system in Mexico, a similar system was selected for a 900 MW, super-critical coal-fired generating station in Texas. This power plant also uses treated effluent from a nearby municipality.

REFERENCES


THE AUTHORS
Michael Sheedy (M.A.Sc., Chemical Engineering, University of Toronto, Toronto, Ontario, Canada) joined Eco-Tec Inc. in 1990. He is currently the vice-president of technology. His work has included the development of chemical recovery processes and systems for the production of demineralized water using short bed ion exchange technology. Michael Sheedy has authored 19 technical papers in various journals and conference proceedings.

George Di Falco is the marketing communications coordinator for Eco-Tec Inc. He is a former editor of industrial trade publications and has had a wide range of works published covering topics such as alternative energy solutions, new manufacturing methods, and advances in environmental legislation.

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