Integrated Approach to Water/Wastewater Treatment at Zero Liquid Discharge, Combined Cycle Power Plants

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Abstract

This paper discusses the design process and experiences of selected integrated zero liquid discharge, water/wastewater treatment systems at power plants. Typically, the cooling tower treatment, demineralizer, and zero liquid discharge (ZLD) equipment are specified and designed independently for new plants. Two case studies with integrated treatment systems will be presented and reviewed.

Introduction

Environmental regulations and lengthy permitting processes pushed many of the recently installed (1999-2002) wave of natural gas-fired combined-cycle, power plants to use zero liquid discharge (ZLD). In some cases this significantly eased and speeded along the permit cycle. In other cases, no other viable discharge options existed. ZLD is more “politically correct” in today’s world and helps win local community acceptance of new facilities. ZLD also conserves water resources by reducing consumption by up to 10% to 20%, which can be significant in water-short areas around the world.

ZLD has been used at coal-fired power plants since the mid-1970’s for the treatment of cooling tower blowdown and other power plant wastewaters (demineralizer regeneration wastes, ash pile run-off, scrubber blowdown, plant drain, and site containment). Most of the early installations were at existing operating power plants. Substantial engineering studies were performed in many cases at these plants in an attempt to minimize overall water usage and maximize overall water recycling. These efforts helped to minimize the size of the required ZLD system, but little or nothing was done to integrate the water and wastewater treatment system involving the cooling tower, demineralizer and the ZLD equipment.

The recent combined-cycle plants have been predominantly greenfield sites. With the proper planning, this allowed for engineering evaluations to be performed up-front on the overall plant water balances. These efforts led to better optimization of the water/wastewater treatment systems resulting in an integrated approach. The approach links together the cooling tower, demineralizer system, and the ZLD equipment. Two case studies involving ZLD combined-cycle power plants from different regions of the United States have been evaluated. The design considerations, process parameters, unit capacity requirement, and overall performance of the treatment systems were reviewed along with the expected plant make-up water sources and composition. Most importantly, the advantages and benefits of integrated water/waste-water treatment systems to the power plants are summarized.
Case One: Southwest Power Plant

The Texas Independent Energy (TIE) Guadalupe Power Plant in Marion, Texas is a 1000 MW combined-cycle plant with two power blocks (2 x 1 configuration, 500 MW each) using General Electric 7F gas turbines. The plant was designed with supplemental duct firing during peak power demand periods. The plant started up in 2000 and went commercial in 2001.

The nearby Guadalupe River supplies the make-up water to the plant. The design make-up water chemistry is given in Table 1. The design range specified is a function of seasonal variations. A raw water clarifier was required to accommodate increased suspended solids (TSS) loads during the rainy season.

Table 1: Make-up Water Composition (ppm [mg/L] as ion) TIE Guadaloupe Power Plant

<table>
<thead>
<tr>
<th>Design Data Range</th>
<th>Design Basis</th>
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<tbody>
<tr>
<td>Sodium</td>
<td>12-18</td>
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<tr>
<td>Calcium</td>
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<tr>
<td>Magnesium</td>
<td>16-17</td>
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<td>Sulfate</td>
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<tr>
<td>SiO₂</td>
<td>9-12</td>
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<tr>
<td>TSS</td>
<td>5-15</td>
</tr>
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<td>TDS</td>
<td>279-297</td>
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The initial ZLD water treatment design included a raw water clarifier, a cooling tower sidestream softener/clarifier unit (SCU), a wastewater reverse osmosis (RO) unit, a brine concentrator, and a crystallizer. This type of system demanded a high chemical consumption, plus it created a large waste sludge stream requiring off-site disposal.

The plant engineering, procurement, and construction (EPC) company wanted single-source responsibility and a turnkey supply for the water and wastewater treatment. The system specifications allowed for alternate design approaches to allow for optimization of the overall water treatment scheme. Multiple suppliers proposed varying alternate schemes, allowing the initial treatment approach to be eliminated from further consideration after a preliminary evaluation. EPC and plant representatives visited operating ZLD plants to assess the overall reliability and operating histories, then selected a system which included a raw water softener/clarifier unit (SCU), brine concentrator (BC), calandria crystallizer, and an electrodeionization (EDI) unit with a mixed bed ion exchange (MB IX) polisher. The overall plant water balance and treatment subsystems are depicted in Figure 1.

The raw water softener/clarifier (SCU) reduces the calcium and silica in the make-up water to allow up to 12 cycles of concentration in the cooling tower. Hydrated lime is added to accomplish the required reduction. The clarifier also removes the silty suspended solids during the river water upset periods. The softener sludge is thickened, dewatered in a filter press, and disposed of off-site.

The cooling tower blowdown is sent directly to a mechanical vapor recompression (MVR) evaporator (commonly referred to as a Brine Concentrator (BC) - Figure 2) where 99% of the wastewater is recovered as high-quality distillate (5 to 10 ppm [mg/L] TDS).

The blowdown from the BC goes to the steam-driven calandria crystallizer (Figure 3), which coupled with a dewatering pressure filter, reduces the waste stream to solids suitable for off-site disposal.
A portion of the distillate from the BC is directed to the EDI (Figure 4), which provides the plant’s demineralized water and the remaining distillate is recycled back to the cooling tower. The off-site regenerated mixed-bed IX is provided as a back up to the EDI.

In addition to reducing the treatment chemical usage and waste disposal requirements, another advantage of this integrated approach is a streamlined project schedule. The entire ZLD water treatment plant was supplied and installed 13 months after the contract was awarded. Typically, similar systems require 18 to 24 months from award to mechanical completion.

Figure 4: Electrodeionization Process (EDI)

Most of the difficulties during the start-up were associated with the softener/clarifier, which was hard to operate with the frequent cycles and downtime associated with the plant commissioning period. The calandria crystallizer foaming was problematic until the optimal anti-foam program was developed. This was the first successful power plant installation coupling brine concentrator distillate with an EDI. After some initial problems with feed temperature excursions and membrane fouling (due to the improper feed pump seal water), the EDI system has worked very well, consistently averaging product quality of 15 to 16 megohm-cm.

The excellent performance of the EDI has rendered the mixed-bed ion exchange redundant, but it does provide an inexpensive back-up system.

Conclusions

The integrated approach at TIE Guadalupe yielded the customer the following benefits:

- Significant reduction in the sludge produced compared with the original design concept, reducing landfill disposal costs up to 25%.
- A simplified process design with more operating flexibility for feed chemistry fluctuations and flow rates.
- A single-source supplier dramatically reducing the overall schedule and providing single-point accountability and more efficient supplier management.
- Common integrated control system for monitoring the entire water and wastewater treatment plant, which allowed for reduced operator requirements.
Case Two: Northeast Power Plant

The AES Ironwood facility in Lebanon, Pennsylvania is a 700 MW combined cycle plant with a 2 x 1 configuration using Siemens Westinghouse 501G gas turbines. The plant is primarily designed to operate on natural gas, but originally had provisions to accommodate oil firing, if required. The plant started up in 2001 and went commercial in 2002.

The Ironwood plant has two sources of make-up water; secondary treated effluent from the nearby publicly owned treatment works (POTW) and quarry water from the adjacent quarry. The design make-up feed to the power plant is a 60% quarry - 40% POTW blend. See Table 2 for compositions.

<table>
<thead>
<tr>
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<th>Quarry</th>
<th>POTW</th>
<th>Design Blend</th>
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<tr>
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<td>9</td>
</tr>
<tr>
<td>TDS</td>
<td>511</td>
<td>504</td>
<td>508</td>
</tr>
</tbody>
</table>

Table 2: Make-up Water Composition (mg/l as ion) AES Ironwood Power Plant

The original design concept for the plant was for the cooling tower to operate at low cycles of concentration (about 8x). The tower blowdown was to be sent to a lime softener/clarifier and wastewater reverse osmosis (RO) system for preconcentration, then to a brine concentrator (BC), and finally to a crystallizer. With this approach, the preferred chemical supplier had determined the optimum cooling tower cycles, the wastewater treatment was designed by the ZLD system supplier, and the demineralizer system had not yet been fully developed. The plant EPC hired an independent consultant to take a look at the overall water balance. The consultant came up with the innovative idea of requesting one supplier to develop the optimum overall water/wastewater treatment system and supply all the required equipment and a one-year supply of the specialized cooling tower chemicals on a turnkey basis.

This total water management idea resulted in a fully integrated system for the plant. Refer to Figure 5 for the overall plant water balance and selected subsystems.

This integrated system utilized a more aggressive cooling tower chemical program to increase the cycles (about 15x at peak design conditions) with the blowdown going directly to a BC. The selected cooling tower chemical program required a scale inhibitor, corrosion inhibitor, dispersant, and biocide. This eliminated the need for a lime softener/clarifier and wastewater RO, thereby minimizing the number of unit operations required. The MVR BC operating at 97% recovery, blows down to a small steam driven crystallizer (Figure 6). The solids produced in the crystallizer are dewatered in a pressure filter and are sent to a landfill for disposal.

Figure 5: Overall Ironwood Plant Water Balance (Normal Mode)
The distillate is fed to the electrodeionization (EDI) units to produce the required 10 megaohm-cm boiler feedwater. During the normal, gas-fired mode, the distillate flow is sufficient to meet the EDI/demineralizer feedwater demand. The original design allowed for operation in an oil-fired mode, during which time the demineralized water demand for the plant was designed to be nearly ten times higher due to the NOx reduction requirements in the combustion turbines. Because there was not sufficient BC distillate to satisfy the EDI/demineralizer demand under all conditions, another source of EDI feed was required. A two-stage, two-pass RO unit (Figure 7) was included to supplement the BC distillate. The RO is only required during periods of high demineralized water demand.

The integrated system installed at the Ironwood power plant provided the following benefits:

- Optimized recirculating cooling tower treatment program.
- Elimination of the lime softener/clarifier minimized addition of bulk chemicals and reduced off-site sludge disposal requirements by up to 40%.
- Simplified treatment system with fewer unit operations, yet flexible enough to accommodate chemistry variations in the make-up water.
- Shorter contract schedule and more efficient supplier management by utilization of a single-source supplier for the entire plant water/wastewater treatment system.
- Common, integrated control system interface for all the plant water and wastewater treatment functions allowing for streamlined operation and fewer operators.

An integrated approach to water and wastewater treatment can yield a number of advantages to ZLD power plants when compared to conventional, segregated methods. The unit operations for the cooling tower, ZLD system, and demineralizer are based on fundamentally similar principles and combining the responsibility for the design makes good engineering and contracting sense. The performance of each operation is often dependent on the other, so having one supplier responsible for all the water treatment functions allows for streamlined operation and fewer operators.
treatment is the preferred solution to eliminate conflicts. When designed properly, the plant benefits with streamlined processes and simpler, easier-to-operate treatment systems.

Other recently commissioned power plants such as La Paloma Generating near Bakersfield, California and Hays Energy near San Marcos, Texas have used the same integrated approach. Both installations included reverse osmosis pre-concentration stages in the ZLD train to reduce the system’s overall power consumption.

References


